



# Teaching Organic Farming and Gardening



Resources for  
Instructors



UCSC Farm & Garden Apprenticeship  
Center for Agroecology &  
Sustainable Food Systems  
University of California  
Santa Cruz



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Center for Agroecology &  
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University of California  
Santa Cruz

Edited by Albie Miles and Martha Brown

The Center for Agroecology & Sustainable Food Systems is a research, education, and public service group dedicated to increasing ecological sustainability and social justice in the food and agriculture system. Our mission is to advance sustainable food and agricultural systems that are environmentally sound, economically viable, socially responsible, nonexploitative, and that serve as a foundation for future generations. The Center is located at the University of California, Santa Cruz.

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# Foreword

It is a great pleasure to reflect upon the publication of *Teaching Organic Farming and Gardening: Resources for Instructors*. I first became acquainted with the Apprenticeship in Ecological Horticulture more than seventeen years ago when I arrived in the U.S. to take a faculty position at the University of California, Davis. I remember being very impressed with what the program was doing, and the people involved in making it work. I had never seen a program like it anywhere else, and jumped at the opportunity to come and work with the apprentices a couple of times as a guest speaker. Twelve years later I accepted the position of Director of the Center for Agroecology and Sustainable Food Systems, providing me the opportunity to work closely with the Apprenticeship as it continued to evolve into the dynamic program that has led to this manual being produced. The past five years working with the staff have been immensely rewarding. I have seen them spend many hours and weeks working to improve the course every year and to further refine the vision of what the program could become.

Now with the publication of this resource manual, the thought and experience that have culminated from years of running the program are available in a form that others can use. One of the strengths of the manual is that it effectively combines years of practical experience and staff knowledge with insights from farmers, extension personnel, graduate students, and faculty. When I read the manual myself, I realized how useful it would be to me as a professor. Not only does it encapsulate a solid foundation in multiple aspects of sustainable agriculture, as well as organic farming and gardening, it also provides practical teaching tools and resource links that can be used in numerous educational settings. I commend the efforts of everyone involved in putting this manual together, and am proud to have been involved in the process. I hope that others will find the manual as useful and informative as I did.

– Dr. Carol Shennan  
Director, Center for Agroecology &  
Sustainable Food Systems



# The Center for Agroecology & Sustainable Food Systems, and the Farm & Garden Apprenticeship

The Center for Agroecology and Sustainable Food Systems (the Center) is a research, education, and public service unit of the Division of Social Sciences at the University of California, Santa Cruz, dedicated to increasing ecological sustainability and social justice in the food and agriculture system. Center research and education efforts seek to increase understanding of the social, economic, political and ethical foundations of agricultural sustainability; to establish the ecological and agronomic basis for sustainable production systems; and to demonstrate and facilitate the use of information critical to the adoption of sustainable food and agriculture systems.

The Center's work covers a spectrum that includes academic education and practical training, theoretical and applied research, and public service for audiences ranging from international grower groups to local school children. The Center's Alan Chadwick Garden and the 25-acre UCSC Farm are unique organic demonstration, education, and research sites on the UCSC campus.

The Farm & Garden Apprenticeship is a six-month training program held annually at the Center's farm and garden sites. Initiated by Alan Chadwick in 1967, this full-time course now brings participants of all ages from around the world to learn the basic skills of organic gardening and farming, while also studying the complex social and environmental issues surrounding sustainable agriculture and food systems. The program combines classroom instruction, small group demonstrations, and readings with hands-on learning in the fields, gardens, greenhouses, and orchards. The main instructors in the Apprenticeship course are the Farm Manager, the two Garden Managers, and the Community Supported Agriculture (CSA) Manager who work daily alongside the apprentices, present classes, and lead training sessions. UCSC faculty, researchers, and members of the agricultural community add a wide range of expertise to the course.

To date more than a thousand apprentices have completed the Apprenticeship training program. Graduates have established their own commercial farms and market gardens, run community gardens for inner city and prison populations, and developed

"There are very few programs that provide an academic component to the very real world of organic agriculture. This [Apprenticeship] program ranks among the very best in the nation thanks to the skill of the instructors, the diversity of the students, and the certified organic gardens and fields themselves."

—Bob Scowcroft, Executive Director  
Organic Farming Research Foundation

school garden programs. Many graduates take part in international development and food security project. Others have raised the standards of the organic food industry through work with certification programs and retailers. One of the most important outcomes of the Apprenticeship is the ripple effect our graduates have working locally, nationally, and internationally to promote, practice, and teach sustainable, organic farming and gardening.

Our 25-acre farm and 3-acre garden are vibrant demonstration and education sites open to the public year-round on the UCSC campus. Thousands of visitors come annually to see the hundreds of varieties of annual vegetable and flower crops, fruit trees, and perennial plantings and to learn about sustainable growing methods. The Center and the Life Lab Science Program work together to put on school group tours and a children's summer camp using the Life Lab Garden Classroom at the farm. In conjunction with our community support group, the Friends of the UCSC Farm & Garden, the Center offers a year-long series of organic gardening classes, workshops, and seasonal celebrations.

For more information on the Center and its activities, contact us at:

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For questions about the Apprenticeship program, see the Center's web site or contact us at 831.459-2321, [apprenticeship@ucsc.edu](mailto:apprenticeship@ucsc.edu).



# Preface to the Second Edition

In his 2003 review of *Teaching Organic Farming and Gardening: Resources for Instructors*, Raymond Poincelot, editor of the *Journal of Sustainable Agriculture*, wrote that “Both the Center for Agroecology and Sustainable Food Systems and the UCSC Farm and Garden Apprenticeship have been in the forefront of organic farming and gardening for many years. Their track record has been excellent and this resource guide is no exception. This resource guide is likely to become the benchmark for such materials and promises to be very useful to educational, extension, research and other professional institutions and programs interested in training organic farmers and gardeners.”

*Teaching Organic Farming and Gardening* appears to be living up to that promise, based on feedback from educators, extension personnel, community gardening coordinators, farmer-mentors, international workers and others. We’ve received letters and emails from around the world noting the useful role it has played in their own training programs, and in many cases thanking us for making the resources available to download for free from our web site ([www.ucsc.edu/casfs](http://www.ucsc.edu/casfs)).

We also received a number of questions about another critical aspect of farming and gardening education: learning to sell what you grow. Making the farm or

market garden an economic success requires a suite of skills, including locating land, planning appropriate marketing strategies for selected crops, and managing income and expenses. In response we produced a second training manual in 2005, *Teaching Direct Marketing and Small Farm Viability: Resources for Instructors*, that addresses business planning, marketing options, budgeting and cash flow management, and land tenure (also available to order or download from the web site noted above).

Another outgrowth of *Teaching Organic Farming and Gardening* also debuted in 2005. *Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource* offers instructors a complete course outline, catalogue description, and set of annotated resource lists to use in developing classes in sustainable agriculture (click on the *Instructional Resources* link at [www.ucsc.edu/casfs](http://www.ucsc.edu/casfs)). This online tool grew out of an effort spearheaded by Albie Miles, curriculum coordinator at the Center for Agroecology and Sustainable Food Systems, in collaboration with college and university educators around the country.

This second edition of *Teaching Organic Farming and Gardening* includes new and updated material, and incorporates feedback we received on the first edition. Along with our other new resources, we hope you’ll find it useful in your work.

# Preface to the First Edition

This training manual, based on the core classes of the Center for Agroecology and Sustainable Food System’s Apprenticeship Program, provides instructional materials for teaching organic farming and gardening, along with related sustainable agriculture topics, in a wide variety of educational settings. Our staff instructors are often asked to share their expertise and lesson plans with other groups that want to develop similar training programs. Drawing on the Apprenticeship’s 35-year history, the staff and seven invited authors have written and produced this 600+-page resource for teaching many of the basic skills and concepts covered in the six-month course.

The training manual is designed for—

- colleges and universities with programs in sustainable agriculture, student farms or gardens, and on-farm education programs
- urban agriculture, community garden, and farm training programs
- farms with internship or apprenticeships
- agriculture extension stations
- school gardening programs
- organizations such as the Peace Corps, US AID, and other groups that provide international training in food growing and ecological growing methods
- master gardener programs

One strength of the Apprenticeship is its combination of classroom instruction, small group field classes, hands-on training, and student-directed reading or projects. It was our intention to capture that combination of practical skills training and more academic instruction in this resource. Although much of the material is designed for field or garden demonstrations and skill building, most of the units can also be tailored to a classroom setting.

The instructional materials included in this manual are also available on our web site, [www.ucsc.edu/casfs](http://www.ucsc.edu/casfs), in PDF format. Individual units or the entire text can be downloaded from the web site at no cost. It is our intention that the instructional materials be updated and added to on the web site in the future, and we encourage educators to visit the site to offer evaluations and to send us instructional materials that may be of use in future revisions. We hope that this resource will be used as widely as possible for education and training.

# Acknowledgments

This resource represents the work of many different people and many years of instruction and hands-on training in the fields, gardens, greenhouses, and classrooms at UC Santa Cruz. For years, decades even, the Center for Agroecology and Sustainable Food Systems' (the Center's) staff had wanted to develop a formal document that encompassed the core classes and practical training sessions of the Apprenticeship course. It took the diligent work of Albie Miles to bring this project to fruition. He shepherded the project for over two years, coaxing drafts and rewrites out of busy instructors and farm/garden managers, overseeing the pilot testing and evaluation of classes and demonstration sessions, and writing or contributing to many of the units.

Special thanks goes to Martha Brown for overseeing the production of the manual, working extra hours with the designer and printer on how to best present this unusual resource, and editing and proofreading every one of its more than 600 pages. Designer Nancy Enge of Ajax Designs provided the invaluable service of creating an attractive and user-friendly document, and donated a good portion of her time to finish the project. Science illustrator Cathy Reinhard produced wonderful line drawings for several units.

The Apprenticeship staff instructors, Jim Leap, Orin Martin, Christof Bernau, and Nancy Vail, took time from their busy production and instruction schedules

to write and pilot new versions of classes. Center Director Carol Shennan wrote and pilot tested classes as well as reviewing all of the units. The other contributing authors, listed on the next page, deserve many thanks for writing and, in many cases, teaching (and then revising and teaching again) the materials now presented in this resource. The reviewers performed the important service of checking units for facts, relevance, and usability based on their expertise as growers, scientists, and instructors.

Ann Lindsey brought in the grant funding for the training manual and helped initiate and guide the project. We want to acknowledge again and thank those who funded the project: The Richard and Rhoda Goldman Fund, The Arkay Foundation, The Organic Farming Research Foundation, The Mary A. Crocker Trust, The Foxwhelp Group of the Tides Foundation, and John Kinder. Without their generous support, this project would not have been possible.

We want to acknowledge the many apprentices in the 2000–2002 Apprenticeship courses who helped shape this document by offering their evaluations of classes and training sessions. We also want to recognize that the foundation for this manual has been laid over 35 years of training, with many hands and minds of apprentices and instructors building the garden and farm on the campus, as well as building a pool of knowledge and skills that we continue to draw upon.

# Contributors and Reviewers

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# Introduction: How to Use This Resource

*Teaching Organic Farming and Gardening: Resources for Instructors* is a tool intended to increase and improve education in practical organic agriculture and horticulture skills and concepts. While the majority of the manual is devoted to practical training, the instructional materials also cover the science behind the practices, and provide a detailed introduction to social and environmental issues in agriculture. Although much of the material is designed for field or garden demonstrations and skill building, most of the units can also be tailored to a classroom setting. The manual is designed so that units or even individual lectures or demonstrations can be pulled out to be used on their own or in any sequence.

This manual is divided into three sections:

## **PART 1: ORGANIC FARMING AND GARDENING SKILLS AND PRACTICES**

The eleven units in this section emphasize the “how-to” aspects of organic gardening and farming, including propagation, irrigation, tillage, transplanting, and compost production. This section also introduces students to critical skills and considerations in the management of soil fertility and agricultural pests (arthropods, diseases, and weeds) in organic systems. The information included in the manual is based on certified organic production practices that meet or exceed the USDA’s National Organic Program (NOP) standards. Included throughout is an overview of principles and practices used in NOP-certified production.

## **PART 2: APPLIED SOIL SCIENCE**

This three-unit section covers basic information on soil physical properties, soil chemistry, and soil biology and ecology, providing a more detailed overview of the underlying scientific principles that inform many of the organic farming practices covered in Part 1.

## **PART 3: SOCIAL AND ENVIRONMENTAL ISSUES IN AGRICULTURE**

This four-unit section first outlines the history and development of agriculture in the U.S. and then introduces students to social and environmental issues associated with conventional agriculture practices and the current organization of the food system. This section also introduces students to sustainable agriculture

and to some of the current obstacles to more sustainable food and agriculture systems.

## **UNIT COMPONENTS**

Each unit in this manual contains multiple components, with some components being designed for the instructor, some for students, and some for both. Not all units contain all of the components outlined below, as some units are largely lecture-based (requiring no field demonstrations or hands-on exercises, for example) and others are exclusively field-based, thereby requiring no lecture.

The units are designed with some or all of the following components:

**Introduction**—A one- or two-page overview for use by instructor and students

In the Introduction, the *Unit Overview* provides a summary of the unit, including a description of the information and skills to be conveyed. The *Modes of Instruction* list the suggested lectures, demonstrations, exercises, and assessment questions included in the unit (with an estimated time required for both preparation and implementation). The *Learning Objectives* list the fundamental skills and concepts in each unit that students are expected to learn. The learning objectives serve as the foundation for overall unit content and provide the basis for the evaluation of student comprehension.

**Lecture Outlines**—Instructor outlines to guide presentations and/or discussions

The lecture outlines include pre-assessment questions that may be used to gauge student knowledge at the beginning of the unit. The outlines are intended to provide a broad but comprehensive overview of a subject, identifying many of the key concepts within a given discipline. Instructors are encouraged to adapt the overall content of the lecture to specific audiences or settings. Some units have one lecture outline and some have several.

**Detailed Lecture Outlines**—Student outlines that parallel the instructor outline in greater detail

These include the essential qualitative and quantitative information addressed in lectures/discussions. Copies



(or electronic versions) of the lecture notes can be given to the student before the lecture. All technical terminology is either defined in the text or included in the glossary of terms at the end of each unit.

### **Demonstration Outlines**

These instructor outlines provide an overview of the preparations and suggested content for field demonstrations of specific agricultural and horticultural practices. They include time requirements for preparation, materials lists, site preparation instructions, the demonstration sequence, and demonstration lecture outline.

### **Step-By-Step Sheets**—For student use following Demonstration Outline

These detailed “how-to” instructions walk students through tasks such as building a compost pile and preparing a planting bed. The sheets include the preparation, sequence, and techniques used in executing a task (parallels the instructor’s Demonstration Outline). The step-by-step sheets contain sufficient information for students to use them as a reference tool when working independently. Intended to be provided with the Hands-on Exercises, below.

### **Hands-On Exercises**

These activities or exercises serve to reinforce student comprehension of the subject matter or skill through active participation and practice immediately following a technique-based demonstration.

### **Assessments Questions (and Answer Key)**

Five to ten short essay questions based on the lecture content and demonstration(s) are used to gauge student comprehension of the subject matter presented. Questions are intended to be a balance of theoretical and applied knowledge and require some synthesis of information. Assessments are based on learning objectives.

### **Suggested Readings**

Certain units list specific preparatory readings for the student (see the Unit Overview or the beginning of the Resources section).

### **Resources Section**

This section includes an annotated listing of books, periodicals, web sites, video productions, organizations, and equipment or material suppliers on the subject matter addressed in each unit.

### **Appendix Section**

The appendices provide tables, graphs, charts and/or graphics used as visual aids in lectures, demonstrations, or as student reference materials associated with the Hands-on Exercises.

### **Glossary**

Several units include an alphabetical listing of technical terms used in either the lecture or demonstration.

# Part 1 Organic Farming and Gardening Skills

- Unit 1.1 Managing Soil Fertility
- Unit 1.2 Garden and Field Tillage and Cultivation
- Unit 1.3 Propagating Crops from Seed  
and Greenhouse Management
- Unit 1.4 Transplanting and Direct Seeding
- Unit 1.5 Irrigation: Principles and Practices
- Unit 1.6 Selecting and Using Cover Crops
- Unit 1.7 Making and Using Compost
- Unit 1.8 Managing Arthropod Pests
- Unit 1.9 Managing Plant Pathogens
- Unit 1.10 Managing Weeds
- Unit 1.11 Reading and Interpreting Soil Test Reports



# 1.1 Managing Soil Fertility

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# Introduction: Managing Soil Fertility

## UNIT OVERVIEW

*“Feed the soil to feed the plant” is a basic principle of organic farming and gardening. This unit introduces students to the ways that farmers and gardeners develop and maintain soil fertility in certified organic farming systems. Lectures describe the objectives and components of soil fertility management and the various practices used to develop and maintain fertile soil. It should be emphasized throughout the lectures that the overall goal of a fertility management program is to balance nutrient inputs and outputs and ensure a good balance of nutrients for the crop. This balance requires a complex mix of soil management activities including proper tillage, irrigation, crop residue management, weed management, and crop rotation planning. Neglecting any of these components can compromise soil quality, affect crop performance, and create potential pollution problems due to nutrient runoff or leaching.*

## MODES OF INSTRUCTION

- > LECTURE (2 LECTURES, 3 HOURS TOTAL)  
Lecture 1 presents the concepts, objectives, and components of sound soil fertility management programs for certified organic production systems. Lecture 2 describes the sustainable agriculture practices (e.g., tillage, cover crops, composts, soil amendments) that go into organic fertility management.
- > ASSESSMENT QUESTIONS (0.5 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- Certified organic agriculture as defined by the U.S. federal government’s National Organic Program
- Sustainable agriculture
- Soil fertility in organic and sustainable farming systems
- Soil quality
- The relationship amongst soil fertility, plant health, and the resistance and resilience of crop plants to pests and pathogens
- Goals of a sustainable fertility/soil management program
- Components of a soil fertility management program
- The role and impacts of tillage
- The role of cover crops in the organic management of soil fertility
- The use of composts, manures, and other organic amendments
- Management and the concept of nutrient budgets
- Considerations in the design of crop rotations





# Lecture Outline 1: Soil Fertility Management— Concepts, Goals, and Components

## *for the instructor*

### A. Pre-Assessment Questions

1. What are some of the environmental concerns associated with the use of agricultural chemicals?
2. What are some of the human health concerns associated with exposure to agricultural chemicals?
3. What is organic farming?
4. What would be the goals of an organic and sustainable soil fertility management program?
5. What would be the major components of a soil fertility management program?
6. How would you define soil quality?
7. How would you define soil fertility for an organic farming system?

### B. Organic Agriculture

1. “Certified Organic” agriculture as defined by The National Organic Program (NOP; [www.ams.usda.gov/nop/](http://www.ams.usda.gov/nop/))
2. Requirements for organic certification under the NOP
  - a) Organic System Plan
  - b) Necessary components of an Organic System Plan
    - i. Practices and procedures used
    - ii. Characterize each substance used as a production input
    - iii. Identify the monitoring techniques that will be used to verify that the organic plan is being implemented
    - iv. The record-keeping system used to preserve the identity of organic products
    - v. Management practices and physical barriers established to prevent commingling of organic and non-organic products
    - vi. Information deemed necessary by the certifying agent to evaluate site-specific conditions relevant to compliance with program regulations
3. “Sustainable agriculture” defined: A broader, more inclusive definition (see [www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu))

### C. Soil Fertility and Soil Quality in Sustainable Farming Systems

1. Soil fertility and soil quality defined
  - a) Soil quality (see [soils.usda.gov/sqi/](http://soils.usda.gov/sqi/))
  - b) Soil quality indicators
    - i. Accepts, holds, releases, and mineralizes nutrients and other chemical constituents
    - ii. Accepts, holds, and releases water to plants, streams, and groundwater
    - iii. Promotes good root growth and maintains good habitat for soil organisms
    - iv. Resists degradation
    - v. Maintains good soil structure to provide adequate aeration and tilth
    - vi. Good soil structure allows for rapid water infiltration
    - vii. Moderate pH (6.0–7.5)
    - viii. Low salinity levels
    - ix. Low levels of potentially toxic elements
    - x. Balanced fertility

- c) Soil fertility: The capacity of a soil to provide nutrients required by plants for growth; one component of soil quality
- 2. Soil fertility, plant health, and the resistance and resilience of crop plants to pest and pathogens

#### **D. Goals of a Sustainable Soil Fertility Management Program**

- 1. To sustain high crop productivity and crop quality in food and fiber production
  - a) Crop productivity, crop quality, and the success of a given operation
- 2. To minimize risks to environmental quality and human health associated with agricultural production
  - a) Important steps in minimizing human health risks, and on and off-farm impacts
    - i. Avoid the use of all synthetically compounded materials; balance inputs of organic matter and mineral inputs to avoid exceeding crop needs
    - ii. Avoid creating nonpoint source pollution through surface runoff and leaching
    - iii. Prevent soil erosion and sedimentation of waterways
    - iv. Close nutrient cycles as much as possible within the field and farm
    - v. Close nutrient cycles at multiple scales: watershed, regional and national scales

#### **E. Components of a Sustainable Soil Fertility Management Program: The Means to Achieving the Above Goals**

- 1. Improve and maintain physical and biological properties of soil
  - a) Sustainable agricultural practices used to improve and sustain soil physical and biological properties
    - i. Maintaining or building soil organic matter (SOM) levels through inputs of compost and cover cropping
    - ii. Properly timed tillage
    - iii. Irrigation
    - iv. Sound crop rotations, soil amending, and fertilizing techniques all serve to improve the quality of agricultural soils, which in turn affects soil quality and crop performance
- 2. Improve and maintain chemical properties of soil
  - a) Benchmarks of optimal soil chemistry
    - i. Balanced levels of available plant nutrients (see Unit 1.11, Reading and Interpreting Soil Test Reports)
    - ii. Soil pH ~6.0–7.0
    - iii. Low salinity levels
  - b) Sustainable agricultural practices used to develop and maintain optimal soil chemical properties
    - i. Provide a balanced nutrient supply for the crop
    - ii. Conduct soil sampling and periodic monitoring
    - iii. Conduct plant tissue testing
    - iv. Time seasonal nutrient release from organic amendments to correspond with crop requirements
      - The quality of the organic matter input
      - Environmental factors such as soil temperature and moisture
    - v. Avoid leaving fields bare to avoid wind and water erosion and nutrient leaching
    - vi. Manage irrigation carefully to avoid runoff, erosion, and leaching of soluble nutrients
    - vii. Supply major nutrients primarily through organic matter and mineral soil amendments
    - viii. Allow sufficient time for fresh residue to break down before planting crops
    - ix. Use in-season supplemental fertilizers when necessary

### 3. Minimize disease/pest susceptibility

- a) Sustainable agriculture practices used to minimize disease/pest susceptibility in organic farming systems
  - i. Maintain soil nutrient levels and soil pH within optimal range
  - ii. Build and maintain soil organic matter to promote desirable soil physical properties and supply essential plant nutrients
  - iii. Maintain soil moisture within optimal ranges for plant growth and the avoidance of compaction and erosion
  - iv. Design appropriate rotations to break pest cycles
  - v. Plant polycultures
  - vi. Use appropriate preventative and active biocontrol practices

### 4. Summary

The sustainable farming practices described above, including crop rotations, soil amending and fertilizing, tillage, and irrigation techniques, must be used in concert to improve and maintain the quality of agricultural soils. Soil quality in turn affects crop performance (yield) and the resistance and resilience of crop plants to pest and pathogens.



# Detailed Lecture Outline 1: Soil Fertility Management— Concepts, Goals, and Components

*for students*

## **A. Pre-Assessment Questions**

1. What are some of the environmental concerns associated with the use of agricultural chemicals?
2. What are some of the human health concerns associated with exposure to agricultural chemicals?
3. What is organic farming?
4. What would be the goals of an organic and sustainable soil fertility management program?
5. What would be the major components of a soil fertility management program?
6. How would you define soil quality?
7. How would you define soil fertility for an organic farming system?

## **B. Organic Agriculture**

1. “Certified Organic” agriculture as defined by The National Organic Program (NOP; [www.ams.usda.gov/nop/](http://www.ams.usda.gov/nop/))

Organic production: “A production system that is managed in accordance with the Act (The Organic Foods Production Act [OFPA] of 1990, as amended in the NOP) to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity.”

Further, it is a system of agriculture that encourages healthy soil and crops through such practices as nutrient and organic matter recycling, crop rotations, proper tillage, and the strict avoidance of synthetic fertilizers and pesticides for at least three years prior to certification.

2. Requirements for organic certification under the National Organic Program
  - a) Organic System Plan: The NOP requires that all crop, wild crop, livestock, and handling operations requiring certification submit an organic system plan to their certifying agent and, where applicable, the State organic program (SOP). The organic system plan is a detailed description of how an operation will achieve, document, and sustain compliance with all applicable provisions in the OFPA/NOP. The certifying agent must concur that the proposed organic system plan fulfills the requirements. The organic system plan is the forum through which the producer or handler and certifying agent collaborate to define, on a site-specific basis, how to achieve and document compliance with the requirements of organic certification.
  - b) Necessary components of an Organic System Plan
    - i. The organic system plan must describe the practices and procedures used, including the frequency, in the certified operation
    - ii. Second, it must list and characterize each substance used as a production input
    - iii. Third, it must identify the monitoring techniques that will be used to verify that the organic plan is being implemented
    - iv. Fourth, it must explain the record keeping system used to preserve the identity of organic products
    - v. Fifth, the organic system plan must describe the management practices and physical barriers established to prevent commingling of organic and non-organic products

- vi. Finally, the organic system plan must contain the additional information deemed necessary by the certifying agent to evaluate site-specific conditions relevant to compliance with these or applicable State program regulations.
3. “Sustainable agriculture” defined (see [www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu))
- Sustainable agriculture can be defined as an approach to agriculture where the aim is to create environmentally sound, economically viable, and socially just food and agricultural systems. Maximum reliance is placed on locally or farm-derived renewable resources and the management of self-regulating ecological and biological processes and interactions in order to provide acceptable levels of crop, livestock, and human nutrition, protection from pests and diseases, and an appropriate return to the human and other resources employed. Reliance on external inputs, whether chemical or organic, is reduced as far as possible. The objective of long-term sustainability lies at the heart of organic farming and is one of the major factors determining the acceptability of specific production practices.
- Sustainable agriculture is not just the conservation of non-renewable resources (soil, energy, minerals) used to produce food and fiber. Sustainable agriculture also encompasses maintenance or restoration of the environmental quality of surrounding landscapes; the economic viability for all involved in agricultural production; and more equitable distribution of agricultural products to assure that basic human needs are met (see Unit 3.4, Sustainable Agriculture and Food Systems).

### C. Soil Fertility and Soil Quality in Sustainable Farming Systems

1. Soil fertility and soil quality defined (see [soils.usda.gov/sqi/](http://soils.usda.gov/sqi/))
  - a) Soil quality: The capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health
  - b) Soil quality indicators
    - i. Soil accepts, holds, releases, and mineralizes nutrients and other chemical constituents
    - ii. Soil accepts, holds, and releases water to plants, streams, and groundwater
    - iii. Soil promotes good root growth and maintains good biotic habitat for soil organisms
    - iv. Soil resists degradation (e.g., erosion, compaction)
    - v. Soil maintains good soil structure to provide adequate aeration
    - vi. Good soil structure allows for rapid water infiltration
    - vii. Soil has a moderate pH (~6.0–7.0) at which most essential soil nutrients are available
    - viii. Soil has low salinity levels
    - ix. Soil has low levels of potentially toxic elements (e.g., boron, manganese, and aluminum)
    - x. Balanced fertility that provides adequate levels of macro- and micronutrients that plants and soil microbes require
  - c) Soil fertility: The capacity of a soil to provide nutrients required by plants for growth. This capacity to provide nutrients to crop plants is in part influenced by the physical properties of soils and is one component of soil fertility. Desirable soil physical properties and the capacity of the soil to provide nutrients for growing crops are both soil quality indicators.
2. Soil fertility, plant health, and the resistance and resilience of crop plants to pest and pathogens  
Soil fertility requires a balance of critical plant nutrients and either deficiency or excess of nutrients can adversely affect plant growth, susceptibility to pests, and post-harvest quality

### D. Goals of a Sustainable Soil Fertility Management Program

1. To sustain high crop productivity and crop quality in food and fiber production (not maximum yields, which typically require excessive nutrient inputs to achieve)
  - a) Crop productivity, crop quality, and the economic viability of a given farming operation

2. To minimize environmental quality and human health risks associated with agricultural production
  - a) Important steps in minimizing human health risks and on- and off-farm impacts
    - i. Avoid the use of all synthetically compounded materials (e.g., fertilizers and pest control agents, etc.) known to have an associated environmental quality or human health risk
    - ii. Avoid creating non-point source pollution through surface runoff and leaching. Agricultural nutrients can degrade the quality of groundwater or the water in rivers, lakes, wetlands, and estuaries through eutrophication.
    - iii. Prevent soil erosion and sedimentation of waterways. Soil loss reduces production capacity and soil entering waterways may degrade aquatic habitat.
    - iv. Close nutrient cycles as much as possible within the field and farm to reduce energy used and environmental impact of food and fiber production
    - v. Close nutrient cycles at multiple scales (e.g., watershed, regional, and national scales)

### **E. Components of a Sustainable Soil Fertility Management Program: The Means to Achieving the Above Goals**

1. Improve and maintain physical and biological properties of soil
  - a) Sustainable agricultural practices used to improve and sustain soil physical and biological properties
    - i. Maintaining or building soil organic matter (SOM) levels through inputs of compost and cover cropping: SOM has a large capacity to hold and release inorganic (crop-available) nitrogen and other essential nutrients. Organic matter inputs enhance the stability of soil aggregates, increase the porosity and permeability to water and air, and improve the water-holding capacity of soils. Building or maintaining the level of soil carbon provides the energy and nutrients necessary to stimulate the soil biological activity responsible for decomposition, the formation of soil aggregates, and more desirable soil structure.
    - ii. Properly timed tillage: Stimulates the decomposition of SOM by increasing aeration (O<sub>2</sub> supply to aerobic microbes), breaking up compacted areas and large soil clods, and exposing a greater surface area of SOM for microbial breakdown. Appropriate tillage also increases water infiltration and good drainage (see Unit 1.2, Garden and Field Tillage and Cultivation).
    - iii. Irrigation: For irrigation-dependent crops, manage soil moisture between 50% and 100% of field capacity through soil moisture monitoring and moisture retention techniques such as mulching
    - iv. Use of sound crop rotations, soil amending, and fertilizing techniques all serve to improve the quality of agricultural soils, which in turn affects soil quality and crop performance
2. Improve and maintain chemical properties of soil
  - a) Benchmarks of optimal soil chemistry
    - i. Balanced levels of available plant nutrients (see Unit 1.11, Reading and Interpreting Soil Test Reports, for more on this subject)
    - ii. Soil pH ~6.0–7.0: At this soil pH the greatest amount of soil nutrients are available to crops
    - iii. Low salinity levels: The accumulation of salts in the soil may result in plant water and salt stress
  - b) Sustainable agricultural practices used to develop and maintain optimal soil chemical properties
    - i. Provide a balanced nutrient supply for the crop. As plant growth is related to the availability of the most limiting nutrient, it is essential that we consider the balance (ratios) of soil nutrients available. Yield and quality may be limited if levels of some nutrients are too high while others are too low.



- ii. Conduct soil analysis with periodic monitoring. Soil analysis provides current quantitative information on the nutrient profile of a given soil. Soil analysis report data should be compared to established optimal benchmarks of soil fertility when developing soil amendment plans to assure adequate but not excessive nutrient applications. Comparing results from multiple years of sampling will show whether you are depleting or accumulating soil nutrients over time, and indicate whether changes in fertility management are needed.
  - iii. Conduct plant tissue testing. In-season plant tissue testing provides current quantitative data on the nutrient profile of growing plants. Such data may be compared with recommended nutrient levels and may be used to determine the need for mid-season supplemental fertilizing (see Resources section). However, be aware that most tissue testing information has been developed for systems using synthetic chemical fertilizers, and sufficiency levels may well differ for organic systems.
  - iv. Time seasonal nutrient release from organic amendments to correspond with crop requirements. Example: Along the central coast of California, crops are planted approximately 2–3 weeks after the incorporation of cover crops in late March–early April in order to synchronize the nitrogen demand of cash crops with the nitrogen liberated from cover crop decomposition. Important factors influencing the mineralization rate include:
    - The quality of the organic matter input: E.g., carbon:nitrogen ratio, lignins, tannins, polyphenols, etc.
    - Environmental factors such as soil temperature and moisture
    - Note: When nitrogen from cover crops is mineralized in excess of crop demand, nitrate will be vulnerable to leaching
  - v. Avoid leaving fields bare to avoid wind and water erosion and nutrient leaching
  - vi. Manage irrigation carefully to avoid runoff, erosion, and leaching of soluble nutrients
  - vii. Supply major nutrients primarily through organic matter and mineral soil amendments (e.g., cover crops, composts, limestone, rock phosphate, etc.)
  - viii. Allow sufficient time for fresh residue to break down before planting crops
  - ix. Use in-season supplemental fertilizers (when suggested as necessary by soil test results, plant growth observations, or plant tissue testing) to prevent or address plant nutrient deficiencies
3. Minimize disease/pest susceptibility
- a) Sustainable agriculture practices used to minimize disease/pest susceptibility in organic farming systems
    - i. Maintain soil nutrient levels and soil pH within optimal range to reduce possibility of plant nutrient deficiencies or excesses. Plant nutrient deficiencies or excesses often lead to increased susceptibility to pests and pathogens.
    - ii. Build and maintain soil organic matter to promote desirable soil physical properties and supply essential plant nutrients. Soil physical properties are an essential component of soil fertility, influencing aeration (gas exchange and mineralization), drainage, root penetration and development, and habitat for beneficial soil microbes that may impart disease-suppressive qualities to agricultural soils.
    - iii. Maintain soil moisture within optimal ranges for plant growth and the avoidance of compaction and erosion.
    - iv. Design appropriate rotations to break pest cycles, and include disease-suppressive crops or cover crops. Annually changing the place in the garden or field where crops are grown interrupts the host/pest cycle and thereby reduces or limits the development of populations of pest and pathogens.
    - v. Plant polycultures. Planting a diversity of crops in a garden or farm reduces the carrying capacity of the land for a given pest population.
    - vi. Use appropriate preventive (e.g., farmscaping) and active biocontrol practices to suppress the growth of pest populations (see Unit 1.8, Managing Arthropod Pests)

#### 4. Summary

The sustainable farming practices described above, including crop rotations, soil amending and fertilizing, tillage, and irrigation techniques, must be used in concert to improve and maintain the quality of agricultural soils. Soil quality in turn affects crop performance (yield) and the resistance and resilience of crop plants to pests and pathogens.



# Lecture 2 Outline: Soil Fertility Management— Sustainable Agriculture Practices

## *for the instructor*

### **A. Soil Tillage in Sustainable Agriculture**

1. Services provided by tillage
  - a) Prepares the ground for seedlings and transplants
  - b) Provides a range of residue incorporation options
  - c) Enables the incorporation of amendments
  - d) Improves soil aeration, and breaks up soil clods to form good seed and root beds
  - e) Improves water infiltration
  - f) Increases microbial activity and mineralization rates
  - g) Deep tillage can break through compacted layers
2. Disadvantages of tillage
  - a) May accelerate the rate and extent of long-term declines in soil organic matter, and loss of soil quality
  - b) May increase sub-soil compaction
  - c) High energy and labor costs
  - d) Loss of soil organic matter (SOM) from excessive tillage can lead to crusting of bare soils
3. Advantages of reduced and no-tillage systems
  - a) Residue cover protects the soil from wind and water erosion
  - b) Allows for greater moisture retention in rain-fed systems
  - c) These systems build SOM over a period of years, and reach a higher “steady state” level than tilled systems in the same environment
  - d) Reduced tillage in agricultural soils creates a greater carbon sink
4. Limitations of reduced and no-till agriculture systems
  - a) Residue cover lowers soil temperature, which delays seed germination and slows seedling growth and may place growers at an economic disadvantage
  - b) Weed control is very difficult without use of herbicides
  - c) Requires specialized equipment to plant through thick layer of residue
  - d) Increased leaching of nutrients and herbicides into the groundwater has been shown in some conventional reduced and no-till systems after many years of these practices

### **B. Cover Crops in Sustainable Agriculture**

1. Services provided by cover crops
  - a) Cover crops increase nutrient availability
    - i. The role of legume cover crops in biological N fixation and nutrient budgeting
    - ii. Nutrients are released into the soil solution as the cover crop residues are broken down
    - iii. Cover crops can stimulate microbial activity and increase the breakdown of existing SOM
    - iv. Deep-rooted cover crops are able to recycle nutrients acquired from deeper in the soil profile (e.g. P)
    - v. Grass/cereal cover crops may reduce nutrient losses by capturing mobile nutrients (e.g., nitrate)

2. Influences on the nutrient release from cover crops
  - a) Soil temperature and moisture conditions
  - b) Placement of the residue
    - i. Residue on soil surface: Will decompose more slowly due to drying
    - ii. Incorporation into the top 6–8 inches of the soil: Will decompose most rapidly due to high oxygen levels and the presence of large populations of decomposing organisms
    - iii. Below 6–8 inches: Will decompose more slowly due to lower oxygen levels, fewer decomposers
  - c) Composition/“quality” of the cover crop residue
    - i. The C to N ratio of the cover crop residue and N mineralization
      - C:N ratios around 22:1 or less = net mineralization of N
      - C:N ratios above 22:1 = net immobilization of N
    - ii. Optimum stage of development to incorporate cover crops = 75%–100% of full bloom
    - iii. The presence of lignins and tannins in cover crop residue slows decomposition
3. The timing of nutrient release, crop demand, and the fate of essential plant nutrients
  - a) Managing the timing of nutrient release from cover crops to coincide with crop demand
  - b) Leaching: Nutrients (N) can become vulnerable to loss if timing is mismatched
  - c) Nutrient deficiencies: If timing is mismatched, nutrient deficiencies (N) may then result
4. Some effects of cover crops on agricultural soils
  - a) Improvements to soil physical properties: Carbon and nutrient cycling through the use of cover crops
  - b) The influence of cover crops on disease and pest severity
    - i. Rye, triticale, forage rapeseeds, mustards, and oil seed radish are known to suppress certain plant parasitic nematodes and soil borne diseases
    - ii. Many legumes can actually increase pest populations
  - c) Weed-suppressive effects of cover crops
    - i. Competition for light/smothering
    - ii. Allelopathy
5. Importance of gathering regional cover crop information

## C. Composts and Animal Manures in Sustainable Agriculture (see Unit 1.7, Making and Using Compost)

1. Composts
  - a) How much compost to apply annually
  - b) The nutrient contribution of a manure-based compost: ~1N-1P-1K, i.e., balanced contribution of N-P-K. As nutrient levels in compost vary, it is recommended that you check with supplier or have a compost nutrient assessment done to confirm nutrient levels and proportions.
  - c) Application timing: Nutrient release should ideally coincide with crop demand
    - i. Depending on compost quality, may be an inefficient source of N in short term
    - ii. Release of N may last 6 weeks–several months following incorporation, depending on compost quality and environmental conditions
    - iii. Need to incorporate into root zone if applying mid season as side dress
  - d) Compost quality indicators
    - i. C:N ratio
    - ii. CO<sub>2</sub> levels
    - iii. Ammonia levels
    - iv. Smell

- v. Color
- vi. Texture/feel
- vii. Temperature
- e) Ease and economics of use
- f) Labor and/or equipment requirements for on-farm production of compost (see Unit 1.7)
- g) National Organic Program standards for on-farm compost production
- h) Transportation issues
  - i. Local/regional availability and costs
  - ii. Variability in quality
- 2. Manure
  - a) The use of fresh and undecomposed manure in agricultural systems
  - b) Restrictions on the use of manure under National Organic Standards of 2002
  - c) Variations in the nutrient profiles of animal manures
  - d) Handling and storage of animal manures to conserve nutrients
  - e) Food safety issue

#### **D. Soil Amendments and Supplemental Fertilizers in Sustainable Agriculture** (see Unit 1.11, Reading and Interpreting Soil Test Reports, and Unit 2.2, Soil Chemistry and Fertility)

1. Soil fertility management and nutrient budgets: Balancing nutrient inputs with nutrient outputs each year
  - a) Inputs > outputs = accumulation. Potential risk of excess nutrients creating nonpoint source pollution through leaching and run off, and enhancing disease and pest incidence.
  - b) Inputs < outputs = soil depletion. Potential risk of plant nutrient deficiencies and stress, reduced yield, and increased susceptibility to pest and pathogens.
  - c) Goal: Balance inputs and outputs once you have achieved desired/optimal nutrient levels in the soil
 

Example of inputs factored into budget for nitrogen

    - i. Inputs = imported fertilizers and amendments + atmospheric deposition + N fixation through cover crops
    - ii. Outputs = N exported in crop harvest + N lost through leaching, erosion, and denitrification
    - iii. Calculating nutrient budgets: See Unit 1.11, Reading and Interpreting Soil Test Reports
2. Organic amendments
  - a) OMRI/NOP-certified materials in certified organic farming systems
  - b) Nutrient budgeting
3. Supplemental fertilizers
  - a) When used
4. Application of nutrient budgets in assessing the health of larger-scale units: Watersheds, regions.
 

Example of accumulation and depletion, e.g., the impact of high densities of confinement animal production facilities.

#### **E. Crop Rotation in Sustainable Agriculture**

1. Crop rotation
  - a) Crop rotation defined
  - b) Rationale behind crop rotation

## 2. Rotation considerations

- a) Try to avoid rotation of crop species that share similar pests and diseases.  
Intersperse with different crops to break pest and disease cycles.
  - i. Example: Solanaceae rotation
- b) Rotation of crops to maximize use of nutrient inputs and distribute nutrient demand placed on the soil
  - i. Examples of multi-year crop rotations (see Coleman 1995)
- c) Fallow periods and perennial cover crop rotations

# Detailed Lecture 2 Outline: Soil Fertility Management—Sustainable Agriculture Practices

## *for students*

### **A. Soil Tillage in Sustainable Agriculture**

1. Services provided by tillage
  - a) Prepares ground for seeds or transplants
  - b) Provides a range of residue incorporation options giving flexibility in residue placement and timing residue input
  - c) Enables the incorporation of amendments such as compost, lime, etc.
  - d) Improves soil aeration, and breaks up soil clods to form good seed and root beds
  - e) Improves water infiltration
  - f) Increases microbial activity and mineralization rate
  - g) Deep tillage can break through compacted layers that are a barrier to root growth and water movement
2. Disadvantages of tillage
  - a) May accelerate the rate and extent of long-term declines in soil organic matter
  - b) May increase sub-soil compaction problems and impede root growth, drainage
  - c) High energy and labor costs
  - d) Loss of soil organic matter (SOM) from excessive tillage can lead to crusting of bare soils that impedes seedling emergence and water infiltration
3. Advantages of reduced and no-tillage systems
  - a) Residue cover on the soil surface protects the soil from wind and water erosion
  - b) Reduced tillage systems show greater moisture retention in rainfed systems
  - c) These systems build SOM over a period of years, and reach a higher “steady state” level than tilled systems in the same environment
  - d) The capacity of reduced tillage in agricultural soils to create a greater carbon sink is attracting the interest of climate change researchers and policy makers
4. Limitations of reduced and no-till agriculture systems
  - a) Residue cover lowers soil temperature, which delays seed germination and slows seedling growth and may place grower at an economic disadvantage
  - b) Weed control is very difficult without use of herbicides
  - c) Requires specialized equipment such as no-till drills for seeding
  - d) Increased leaching of nutrients and herbicides into the groundwater has been shown in some systems after years of reduced or no-till agriculture

### **B. Cover Crops in Sustainable Agriculture**

1. Services provided by cover crops (also see Unit 1.6, Selecting and Using Cover Crops)
  - a) Cover crops increase nutrient availability
    - i. The role of legume cover crops in biological N fixation and nutrient budgeting: Legume cover crops, in association with Rhizobium bacteria, are able to convert atmospheric nitrogen ( $N_2$ ) to a plant usable form ( $NO_3^-$ )
    - ii. Nutrients are released into the soil solution as the cover crop residues are broken down by decomposer soil organisms



- iii. As a source of labile carbon, cover crops can stimulate microbial activity and increase the breakdown of existing SOM
  - iv. Deep-rooted cover crops are able to recycle nutrients acquired from deeper in the soil profile (e.g., phosphorus)
  - v. Grass/cereal cover crops, when used alone or with nitrogen-fixing legume cover crops, may reduce nutrient losses by capturing mobile nutrients (e.g., N) that would otherwise be vulnerable to leaching, or loss through soil erosion
2. Influences on nutrient release from cover crops
- a) Temperature and moisture conditions affect the level of microbial activity (lower bioactivity at cooler temperatures, and under dry or waterlogged conditions)
  - b) Placement of the residue
    - i. Placement of cover crop residue on soil surface: Will decompose more slowly due to drying
    - ii. Incorporation into the top 6–8 inches of the soil: Will decompose most rapidly when moisture is adequate due to high oxygen levels and the presence of large populations of decomposing organisms
    - iii. Below 6–8 inches: May decompose more slowly due to lower oxygen levels and fewer decomposers
  - c) Composition/“quality” of the cover crop residue
    - i. The C to N ratio of the cover crop residue and N mineralization
      - C:N ratios around 22:1 or less = net mineralization of N: Nitrate is liberated into soil solution. Available for plant uptake or leaching.
      - C:N ratios above 22:1 = net immobilization of N: Nitrogen is bound and unavailable for plant uptake. Nutrient deficiencies may result if this state of nitrogen depression is prolonged.
      - Because the C:N ratio of cover crops increases as they age, it is generally recommended that cover crops be harvested or incorporated into the soil when close to full bloom (but prior to seed set) to assure a C:N ratio of 22:1 or less so that net mineralization occurs
    - ii. The presence of lignins and tannins in cover crop residue slows the rate of decomposition
3. The timing of nutrient release, crop demand, and the fate of essential plant nutrients
- a) Managing the timing of nutrient release from cover crops to coincide with crop demand (see E. 2. in Lecture 1 Outline)
  - b) Leaching: Nutrients (N in the form of nitrate) can become vulnerable to loss if timing is mismatched
  - c) Nutrient deficiencies: If timing is mismatched, nutrient deficiencies (N) may then result during key stages in the growth cycle, leading to poor yields. This is especially true with longer-season crops, e.g., peppers, tomatoes.
4. Some effects of cover crops on agricultural soils
- a) Improvements to soil physical properties: Carbon and nutrient cycling through the use of cover crops result in short-term improvements to soil physical properties
  - b) Examples of the influence of cover crops on disease and pest severity
    - i. Rye, triticale, forage rapeseeds, mustards, and oil seed radish are known to suppress certain plant parasitic nematodes and soil borne diseases
    - ii. Many legumes are highly susceptible and can actually increase nematode pest populations
  - c) Weed suppressive effects of cover crops
    - i. Competition for light/smothering: Tall, fast-growing, and high-biomass cover crop species that form a dense canopy can suppress weeds in both winter and summer

- ii. Allelopathy: Many plants and certain cover crop species secrete allelopathic compounds from their root systems or other plant parts. Such compounds inhibit the germination and/or retard the vegetative development of weedy plants.
- d) Importance of gathering regional cover crop information: Which to use, which to avoid to address pests and diseases prevalent in your area. Always consult with local growers, agencies.

### C. Composts and Animal Manures in Sustainable Agriculture

1. Composts (see Unit 1.7, Making and Using Compost, for additional information)
  - a) Common annual application rates: ~4–5 tons/acre/year on field scale; 10–12 tons/acre/year on garden scale (cropping dependent)
  - b) The nutrient contribution of compost: ~1-1-1 (N-P-K on a dry-weight basis); varies with source. Check with supplier or have a compost nutrient assessment done to confirm nutrient levels and proportions.
  - c) Application timing: Nutrient release should ideally coincide with crop demand
    - i. Depending on compost quality, may be an inefficient source of N in short term
    - ii. Release of N may last 6 weeks–several months following incorporation, depending on compost quality and environmental conditions
    - iii. Need to incorporate into root zone if applying mid season as side dress
  - d) Compost quality indicators (see Unit 1.7, Making and Using Compost, for details)
    - i. C:N ratio
    - ii. CO<sub>2</sub> levels
    - iii. Ammonia levels
    - iv. Smell
    - v. Color
    - vi. Texture/feel
    - vii. Temperature
  - e) Ease and economics of use: E.g., costs associated with shipping, application equipment
  - f) Labor and/or equipment requirements for on-farm compost production (see Unit 1.7, Making and Using Compost)
  - g) National Organic Program (NOP) standards for on-farm compost production: The NOP has strict standards for compost production and use. Consult with your certification agency or see the NOP web site.
  - h) Transportation issues
    - i. Local/regional availability and costs
    - ii. Variability in quality
2. Manure
  - a) The use of fresh and undecomposed manure in agricultural systems: Cropping in soils with fresh and/or undecomposed manures may result in nitrogen “burns” (due to high ammonium levels) and nitrate depression/net immobilization, respectively
  - b) Restrictions on the use of manure under National Organic Standards of 2002 (see Resources reference on National Organic Program)
  - c) Variations in the nutrient profiles of animal manures: The nutrient profile of fresh manures range from approximately .75-.75-.75 (horse manure) to 2-2-2 (poultry manure). See the *Rodale Book of Composting* in the Resources section for more information.
  - d) Handling and storage of animal manures for the conservation of nutrients: Fresh animal manures should be temporarily stored and protected from sun and rain by covering with tarps
  - e) Food safety issue: NOP guidelines designed to prevent contamination by E. coli and other disease-causing organisms

## D. Soil Amendments and Supplemental Fertilizers in Sustainable Agriculture

1. Soil fertility management and nutrient budgets: Balancing nutrient inputs with nutrient outputs each year
  - a) Inputs > outputs = accumulation. Potential risk of excess nutrients leading to nonpoint source pollution through leaching and runoff, and can increase disease and pest problems.
  - b) Inputs < outputs = soil depletion. Potential risk of plant nutrient deficiencies and stress, reduced yield, and increased susceptibility to pests and pathogens.
  - c) Goal: Balance inputs and outputs once you have achieved desired/optimal nutrient levels and ratios (see Unit 1.11, Hands-on Exercise 1: Reading and Interpreting Soil Analysis Reports)
  - d) Example of inputs factored into budget for nitrogen
    - i. Inputs = imported fertilizers and amendments (including compost) + N fixation through cover crops
    - ii. Outputs = N exported in crop harvest + N lost through leaching, erosion, and denitrification
    - iii. Calculating nutrient budgets: See Unit 1.11, Reading and Interpreting Soil Test Reports
2. Organic amendments
  - a) OMRI/NOP-certified materials in certified organic farming systems (covered in detail in Unit 1.11, Reading and Interpreting Soil Test Reports)
  - b) Nutrient budgeting in Unit 1.11, Reading and Interpreting Soil Test Reports
3. Supplemental fertilizers
  - a) Supplemental fertilizers are used to prevent or remedy acute soil or plant nutrient deficiencies identified through soil analysis reports, plant tissue testing, and/or plant growth observations
4. Application of nutrient budgets in assessing the health of larger-scale units: Watersheds, regions. Example of accumulation and depletion: Confinement animal production facilities import nutrients as feed from large areas, and concentrate waste disposal in small areas.

## E. Crop Rotation in Sustainable Agriculture

1. Crop rotations
  - a) Crop rotation defined: The movement of crops from site to site on the farm in a planned sequence
  - b) Rationale behind crop rotation: Interrupts pest-host cycles and prevents the buildup of pests, weeds, and pathogens. Allows crops to access nutrients from different soil depths.
2. Rotation considerations
  - a) Try to avoid rotation of crop species that share similar pests and diseases. Intersperse with different crops to break pest cycles.
    - i. Example: Solanaceae rotation. It is common practice to change the location of Solanaceae family crops each year. Because these crops (tomatoes, eggplants, peppers, potatoes, etc.) share common pests and pathogens, repeated cropping in the same location can lead to the buildup of pest populations.
  - b) Rotation of crops to maximize use of nutrient inputs and distribute nutrient demand placed on the soil
    - i. Examples of multi-year crop rotations (see Coleman 1995)
  - c) Fallow periods and perennial cover crop rotations. Fallow periods—areas intentionally left uncultivated and planted to perennial cover crops (e.g., perennial rye grass)—allow the soil to remain undisturbed and the aggregation processes to proceed uninterrupted. This can help restore the desired physical properties of agricultural soils.

# Assessment Questions

1) What is certified organic agriculture?

2) Describe the goals of a sustainable soil fertility management program.

3) Define soil fertility.

4) Describe the relationship among soil fertility, plant health, and the resistance and resilience of crop plants to pest and pathogens.

5) What are the major components of a sound soil fertility management program? How does each component function to maintain soil fertility and quality?

# Assessment Questions Key

## 1) What is certified organic agriculture?

*A certified organic production system is a farming system managed in accordance with The Organic Foods Production Act and the National Organic Standards of 2002. The production system is to be designed and managed to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity. Further, it is a system of agriculture that encourages healthy soil and crops through such practices as nutrient and organic matter recycling, crop rotations, proper tillage, and the strict avoidance of synthetic fertilizers and pesticides for at least three years prior to certification. Certified organic farming operations are required to develop and submit an “organic system plan” to their certifying agency detailing how an operation will achieve, document, and sustain compliance with all applicable provisions in the OFPA/NOP. The certifying agent must concur that the organic system plan and ongoing management practices fulfill the NOP requirements.*

## 2) Describe the goals of a sustainable soil fertility management program.

- *To sustain high crop productivity and crop quality in food and fiber production*
- *To minimize environmental quality and human health risks associated with agricultural production*

## 3) Define soil fertility.

*The capacity of a soil to provide nutrients required by plants for growth. This capacity to provide nutrients to crop plants is in part influenced by the physical properties of soils and is one component of soil fertility. Desirable soil physical properties and the capacity of the soil to provide nutrients for growing crops are both soil quality indicators.*

## 4) Describe the relationship amongst soil fertility, plant health, and the resistance and resilience of crop plants to pest and pathogens.

*Crops grown in fertile soils are higher quality, better yielding, and are more resistant and resilient to pests and pathogens*

## 5) What are the major goals of a sound soil fertility management program?

1. *Improve and maintain physical and biological properties of soil*
  - *Organic matter inputs: Compost and cover crops*
  - *Fallow periods*
  - *Properly timed irrigation and tillage*
  - *Soil testing and proper soil amending*
2. *Improve and maintain chemical properties of soil*
  - *Organic matter inputs: Compost and cover crops*
  - *Soil testing and proper soil amending*
  - *Supplemental fertilizing when necessary*
  - *Avoid leaving soils exposed*
  - *Proper irrigation to avoid leaching of nutrients*
3. *Minimize disease/pest susceptibility*
  - *Design appropriate crop rotations and fallow periods*
  - *Polycultures/non-monoculture production*
  - *Use appropriate preventive and active biocontrol practices*
  - *Provide optimal level and balance of nutrients for good plant health*

# Resources

## PRINT RESOURCES

Chaney, David E, Lori E. Drinkwater, and Stuart Pettygrove. 1992. *Organic Soil Amendments and Fertilizers*. Publication 21505, UC Sustainable Agriculture Research and Education Program. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A concise overview of the materials commonly used in certified organic farming systems to improve and maintain soil fertility. Addresses the role of soil organic matter in farming systems and how to evaluate organic materials for on-farm use. Briefly profiles each of the types of organic amendments and fertilizers commonly available.*

Colemann, Eliot. 1995. *The New Organic Grower: A Master's Manual of Tools and Techniques for the Home and Market Gardener*. White River Junction, VT: Chelsea Green Publishing Co.

*An overview of intensive organic production methods on a small scale. Good section on crop rotation planning.*

Magdoff, Fred, and Harold Van Es. 2000. *Building Soils for Better Crops. Second Edition*. Handbook Series Book 4, Sustainable Agriculture Network. Beltsville, MD: National Agricultural Library.

*An introductory overview of organic management of soil fertility covering the basics of soil organic matter, physical, and chemical properties of soil, ecological soil and crop management. Practical and accessible information. Available from [www.sare.org](http://www.sare.org).*

Michigan State University Extension. 1998. *Michigan Field Crop Ecology*. Extension Bulletin E-2646.

*A well-illustrated 85 page publication covering the soil ecosystem processes managed in agricultural systems (e.g., major nutrient cycles, soil biology, pest and disease management).*

Sustainable Agriculture Network. 1998. *Managing Cover Crops Profitably, Second Edition*. Handbook Series Book 3, Sustainable Agriculture Network. Beltsville, MD: National Agricultural Library.

*Very useful information on the characteristics, costs, seeding rates, and management of different cover crop species. Available from [www.sare.org](http://www.sare.org).*

Van Horn, Mark. 1995. *Compost Production and Utilization: A Growers Guide*. Publication 21514. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A short publication focusing exclusively on on-farm composting for growers. Includes sample calculations for achieving optimal C:N ratios, suggestions on compost management, nutrient profiles, and nutrient release patterns of composts.*

## WEB RESOURCES

Alternative Farming Systems Information Center, USDA

[www.nal.usda.gov/afsic/](http://www.nal.usda.gov/afsic/)

*Technical information on organic farming, sustainable agriculture, community supported agriculture. Access to National Agricultural Library to research journal article abstracts and order articles.*

Appropriate Technology Transfer for Rural Areas (ATTRA)

[www.attra.org/](http://www.attra.org/)

*A national sustainable farming information center. Information on sustainable farming production practices, alternative crop and livestock enterprises, innovative marketing.*

California Agriculture Teachers Association (CATA)  
Sustainable Agriculture Curriculum and PowerPoint  
Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see “Course Curriculum”)

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

Organic Farming Compliance Handbook:  
A Resource Guide for Western Regional Agricultural Professionals

[www.sarep.ucdavis.edu/organic/compliance-guide/](http://www.sarep.ucdavis.edu/organic/compliance-guide/)

*Developed to help agricultural professionals in the Western U.S. understand effective practices, materials, and processes that comply with organic standards; access expertise and informational resources on organic farming, and answer questions from their clientele regarding effective practices that meet organic standards. Includes information on organic systems plans, principles of organic production, and organic marketing and economics.*

Organic Materials Review Institute (OMRI)

[www.omri.org](http://www.omri.org)

*List of materials compatible in organic farming, brand name review, technical information.*

Soil Quality Institute—NRCS

[soils.usda.gov/sqi/](http://soils.usda.gov/sqi/)

*Identifies soil quality research findings and practical technologies that help conserve and improve soil, and enhance farming, ranching, forestry, and gardening enterprises. The Institute works with researchers, conservation-ists, and land managers to develop these technologies and make them readily available.*

UC Sustainable Agriculture Research and Education Program (SAREP)

[www.sarep.ucdavis.edu/](http://www.sarep.ucdavis.edu/)

*Sustainable agriculture news, technical information, grant programs, Biologically Integrated Farming Systems program.*

USDA National Organic Program

[www.ams.usda.gov/nop/](http://www.ams.usda.gov/nop/)

*Regulations on certification, materials, and labeling for organic producers and processors.*



# 1.2 Garden and Field Tillage and Cultivation

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# Introduction: Soil Tillage and Cultivation

## UNIT OVERVIEW

*Correct tillage practices are essential to developing and maintaining soil fertility and tilth. This unit introduces students to the tools, techniques, and rationale behind traditional French-intensive organic gardening, and mechanized/field-scale soil cultivation. Beginning with the concepts of soil cultivation and soil tillage, students will learn about the aims of cultivation, the appropriate applications of primary and secondary tillage techniques, and the principal features of both the traditional French-intensive method of soil preparation, and contemporary mechanical tillage methods. The factors influencing the type and timing of cultivation will be introduced along with the intended and unintended effects of soil tillage on the soil ecosystem. The lecture also discusses field-scale tillage tools, along with tillage sequences commonly used in mechanized farming operations. Through demonstrations and a hands-on exercise, students will develop the thinking and technical skills needed to cultivate French-intensive raised beds using both primary and secondary tillage tools and techniques.*

## MODES OF INSTRUCTION

- > LECTURE (1 LECTURE, 1.5 HOURS)  
The lecture outline covers the definition of cultivation and tillage, the general aims of soil cultivation, the factors influencing cultivation approaches, and the tillage techniques used in the French-intensive method of soil preparation. The lecture also includes an overview of tillage techniques used in field-scale mechanized production systems.
- > DEMONSTRATION 1: FRENCH-INTENSIVE CULTIVATION (1.5 HOURS)  
Demonstration 1 outlines the steps for preparing a site and demonstrating the cultivation and maintenance of French-intensive permanent raised beds.
- > HANDS-ON EXERCISE: GARDEN BED CULTIVATION (1 HOUR)  
In this exercise, students practice cultivating permanent raised beds using traditional French-intensive cultivation techniques.
- > DEMONSTRATION 2: MECHANICAL TILLAGE AND CULTIVATION (1.5 HOURS)  
The Demonstration 2 outline details the steps for demonstrating tractor-mounted tillage and cultivation equipment.
- > ASSESSMENT QUESTIONS (1 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The definitions of cultivation and soil tillage
- The objectives of soil tillage
- The factors influencing the timing and type of tillage used
- The primary features and rationale behind the French-intensive raised bed method of tillage
- The primary features and rationale behind modern mechanical/field-scale methods of soil tillage
- The positive and negative effects of tillage on the physical, chemical, and biological properties of the soil
- Definitions and applications of primary and secondary tillage techniques
- Field equipment and common soil preparation sequence used in primary and secondary tillage

### SKILLS

- How to evaluate and adjust soil moisture to within a proper range prior to soil cultivation
- How to evaluate soil conditions to determine the need for/type of cultivation
- How to use primary and secondary soil cultivation techniques to develop and maintain French-intensive raised beds

# Lecture Outline: Soil Tillage and Cultivation

## *for the instructor*

### A. Pre-Assessment Questions

1. What is soil cultivation?
2. What is tillage?
3. Why till the soil?
4. What are some possible negative impacts of intensive and frequent tillage on soil quality?

### B. Defining Soil Cultivation and Soil Tillage

1. Cultivation
2. Tillage

### C. Aims of Soil Cultivation

1. To promote and maintain good soil structure and tilth
  - a) Soil structure
  - b) Soil tilth
2. To prevent or break up soil pans
  - a) Clay pans
  - b) Plow pans
  - c) Traffic pans
  - d) Other:
3. To aerate the soil
  - a) Increase soil air/gas exchange with the atmosphere
    - i. Nitrogen ( $N_2$ )
    - ii. Oxygen ( $O_2$ )
    - iii. Carbon dioxide ( $CO_2$ )
  - b) Increase water infiltration and percolation
  - c) Balance water retention and drainage characteristics
  - d) Increase the rate of mineralization of organic matter and the release of nutrients
4. To increase the temperature of cold soils in the spring
5. To incorporate soil amendments
  - a) Composts, manures
  - b) Mineral amendments
6. To manage crop residues and cover crops
  - a) Crop residues
  - b) Cover crops
7. To control weeds
  - a) Pre-transplant
  - b) Post-transplant
8. To create particulate seed beds and root beds
  - a) Seed bed preparation
  - b) Root bed preparation

9. To manage plant pathogens and insect pest populations
  - a) Plant pathogens
  - b) Insect pests
10. To retain soil moisture
  - a) Interrupt capillary action

#### **D. Types of Soil Cultivation**

1. Primary tillage
2. Secondary tillage
3. Surface cultivation

#### **E. Factors Influencing Timing and Type of Cultivation**

1. Soil moisture (see appendix 1, Estimating Soil Moisture By Feel)
  - a) High soil moisture
  - b) Low soil moisture
  - c) Optimal range of soil moisture
2. Soil texture classification
  - a) Sandy soil
  - b) Clay soils
  - c) Other
3. Climate
  - a) Arid climate
  - b) Temperate climate
  - c) Tropical climate
4. Season
  - a) Spring
  - b) Summer
  - c) Fall
  - d) Winter
5. Cropping system
  - a) Annual
  - b) Perennial
  - c) Orchard system
6. Soil condition
  - a) Soils of good tilth
  - b) Soil with physical properties of low quality

#### **F. Possible Consequences of Frequent and Intensive Soil Cultivation**

1. Decreases in soil organic matter content
2. Eventual reduction in soil biological activity and diversity
3. Destruction of soil aggregates
4. Reduction in nutrient- and water-holding capacity of the soil
5. Loss of soil pore space and decreased gas exchange
6. Reduction in drainage
7. Increased susceptibility to soil erosion
8. Disruption of earthworm habitat
9. Reduced soil quality and increased susceptibility to pests and pathogens

## G. The French-Intensive System of Soil Cultivation

1. Primary features of the French-intensive system
  - a) Deep cultivation with hand tools
  - b) Concentration of organic matter and mineral amendments
  - c) High application rates of fully mature compost
  - d) Permanent growing beds and pathways
2. Implements used in French-intensive soil cultivation (see appendix 2, Tillage and Planting Implements)
  - a) Primary cultivation tools
    - i. Applications and effects
  - c) Secondary cultivation tools
    - i. Applications and effects
3. Common tillage sequence used in French-intensive soil cultivation (see appendix 3, Double-Digging Sequence)
  - a) Primary tillage in unimproved soil
  - b) Primary tillage in improved soil
  - c) Secondary cultivation
4. Potential benefits of the French-intensive system of cultivation
  - a) Rapid improvements in soil fertility
  - b) High density spacing of crops results in high yields per surface area
  - c) Living mulch microclimate results in decreased evapotranspiration, reduced oxidation of organic matter, and decreased weed competition
  - d) Hand tools eliminate necessity of heavy machinery on a small scale
5. Potential disadvantages of the French-intensive system
  - a) Requires large volume of organic matter inputs
  - b) Scale/production limitations

## H. Mechanical/Field-Scale Tillage Systems

1. Conventional tillage
  - a) Defined: Combined primary and secondary tillage operations normally performed in preparing a seedbed for a given crop
  - b) Conventional tillage equipment and operations (see appendix 2)
    - i. Disc: Incorporates cover crop seed, cover crops, and crop residue
    - ii. Spader: Incorporates cover crops and crop residue
    - iii. Plow: Opens soils, incorporates crop residue
    - iv. Rototiller: Incorporates crop residue and prepares seedbed
    - v. Ring roller: Firms soil, reduces soil moisture loss, breaks large soil clods
    - vi. Chisels (for sub-soiling): Break up compacted sub-soils and allow rainfall to penetrate
    - vii. Lister bars and bed markers: Shape soil surface into beds and furrows
    - viii. Bedders/bed shapers: shape beds for planting
    - ix. Knives and sweeps, reverse disc hillers, furrow chisels: Cultivate row crops post-planting
    - x. Spring-toothed harrow: Light weed cultivation, soil aeration, and covering cover crop seed and bringing up perennial weeds to surface

2. Minimum tillage (a.k.a. optimum, reduced, or economy tillage)
  - a) Defined: Combined primary and secondary tillage operations that use fewer operations than conventional tillage to prepare a seedbed for a given crop or area
  - b) Types of conservation tillage
  - c) Advantages: Reduced soil erosion and loss of soil organic matter
  - d) Disadvantages: Reduced mineralization rates (nutrient availability)
  - e) Application of no-till systems
    - i. Steep slopes
  - f) Tools and practices used in minimum tillage
    - i. Conservation tillage: Use of subsurface tillage equipment
    - ii. No-till: Use of special planters
3. Common tillage sequences in small-scale mechanized farming systems
  - a) Primary tillage: Incorporation of cover crop residue in spring
  - b) Secondary tillage: Seedbed establishment
  - c) Bed formation and planting
  - d) Cultivation for weed control
  - e) Incorporation of crop residue

# Detailed Lecture Outline: Soil Tillage and Cultivation

## *for students*

### **A. Pre-Assessment Questions**

1. What is soil cultivation?
2. What is tillage?
3. Why till the soil?
4. What are some possible negative consequences of intensive and frequent soil tillage on soil quality?

### **B. Defining Soil Cultivation and Soil Tillage**

1. Cultivation: The total assemblage of tools and techniques used to develop and maintain soil fertility and crop production in garden and farm systems
2. Tillage: The operation of implements through the soil to prepare seedbeds and rootbeds

### **C. Aims of Soil Cultivation**

1. To promote and maintain good soil structure and tilth  
Primary cultivation loosens and opens untilled or compacted soils, allowing greater ease of root penetration and more desirable air/gas and water relations. Aids in the process of aggregation by allowing for the vertical distribution of organic matter and mineral soil amendments, which provide energy and nutrients to the soil organisms responsible for soil aggregate formation. The rearrangement of soil particles encourages the formation of chemical bonds that also create soil aggregates. Secondary cultivation decreases surface soil particle size to produce a quality seedbed.
2. To prevent or break up soil pans  
Deep cultivation can physically fracture compacted and otherwise impervious soil layers, allowing more thorough aeration, the incorporation of soil amendments, and greater ease of root development. There are both naturally occurring and human created hard pans.
  - a) Clay pan: Produced when clay particles leach downward and settle, forming a distinct dense soil layer (e.g., alluvial soils)
  - b) Plow pan: Created by repeated mechanical tillage to a similar depth
  - c) Traffic pan: Produced through repeated traffic or animal grazing, especially when soils are moist
3. To aerate the soil
  - a) Cultivation increases soil air/gas exchange with the atmosphere. Appropriately timed cultivation immediately increases soil pore space and aeration, allowing for the rapid diffusion of atmospheric gases into the soil. The combination of proper cultivation techniques and the addition of mineral and organic matter soil amendments encourages the development of good crumb structure. This creates a more permanent network of pore spaces, allowing for the continual, passive exchange of atmospheric and soil gases.
    - i. Nitrogen ( $N_2$ ): Increased atmospheric nitrogen ( $N_2$ ) levels in the soil can be used by both soil and root bacteria to fix plant-available forms of nitrogen such as nitrate and ammonium



- ii. Oxygen (O<sub>2</sub>): When combined with organic matter inputs, elevated soil oxygen levels may increase soil biological diversity, stimulate soil biological activity, and increase the rate of mineralization. Soil aeration replenishes the soil oxygen reservoir that is continually being taken up through plant roots for use in respiration.
    - iii. Carbon dioxide (CO<sub>2</sub>): Cultivation allows for the movement of CO<sub>2</sub> out of the soil, to be replaced with oxygen and nitrogen
  - b) Increase water infiltration, percolation, retention and drainage characteristics. A soil made more permeable through proper tillage allows water to infiltrate the soil and percolate slowly downward, draining into the subsoil at rates optimal for both crop plants and soil microbes.
  - c) Soil aeration increases the rate of mineralization and the release of plant-available nutrients into the soil solution for uptake by plant roots
4. To increase the temperature of cold soils in the spring
- Soil air warms more quickly than soil water and soil solids. Soils with well-developed aggregations and adequate pore space maintain more desirable drainage characteristics and therefore dry and increase in temperature more rapidly than soils having fewer pore spaces. Biological activity and biogeochemical reactions increase at higher soil temperatures, with soil temperatures of 50–55°F being a threshold below which mineralization rates and plant growth dramatically slow.
5. To incorporate mineral and organic matter soil amendments
- Cultivation is a practical means of incorporating organic matter and mineral amendments, cover crops, and crop residues. Cultivation may be used to incorporate soil amendments to desired soil depths in order to increase the immediate or long-term availability of essential plant nutrients or to improve the physical and/or chemical properties of the soil.
- a) Composts, manures, and fertilizers: Tillage and cultivation techniques are needed to incorporate organic matter amendments beneath the soil surface in order to avoid the loss of carbon and volatile nitrogen compounds through surface oxidation. Tillage may also be used to evenly distribute organic matter amendments for general soil improvement or to place fertilizers in particular locations for specific short-term crop nutrient requirements (i.e., banding).
  - b) Incorporation of mineral amendments: Mineral soil amendments must be incorporated into the soil to allow for additional biological or chemical decomposition and to liberate and cycle essential plant nutrients
6. To manage crop residues and cover crops
- a) Crop residues: Tillage is used primarily in mechanized systems to incorporate crop residues. This process cycles the organic matter and nutrients held in the crop tissues back into the soil and prepares the site for subsequent cropping.
  - b) Cover crops: Tillage is also used to incorporate cover crops in order to cycle organic matter and nutrients held in the cover crop tissues back into the soil and to prepare the site for subsequent cropping. The nutrients liberated as cover crops decompose may be a significant source of essential plant nutrients for a given season's crop production.
7. To control weeds
- Cultivation is a practical means of destroying annual weeds and weakening crowns and rhizomes of perennial weeds. Because cultivation stimulates germination of annual weed seeds, multiple cultivations prior to transplanting or direct sowing may be used to reduce the soil weed seed bank and thereby reduce weed competition with cultivated crops.
8. To create particulate seed beds and root beds

Secondary tillage techniques may be used to render surface soil particle sizes in proper proportion to the size of the transplant or seed being sown. Fine-seeded crops (e.g., carrots, spinach, arugula) and small, weak, or inefficient rooted crops (e.g., lettuce, alliums) require a fine or small surface soil particle size. Large-seeded crops (e.g., squash, beans, corn) and large, vigorous transplants (e.g., tomatoes) may be placed in a more coarsely tilled soil.

9. To manage plant pathogens and insect pests

Timely plowing under of crop residues is an effective means of controlling certain insect pest and plant pathogens

10. To retain soil moisture

Secondary tillage techniques may be used to intentionally pulverize the surface soil. This practice creates a fine dust layer that interrupts the capillary action of water, thereby reducing the loss of soil moisture to the atmosphere through evaporation. Such methods are frequently used to conserve soil moisture in non-irrigated (dry-farmed) farming operations.

#### **D. Types of Soil Tillage**

1. Primary tillage

- a) Defined: Course and deep tillage that cuts, fractures, and mixes the soil. Often accomplished with an implement such as plow, spader, chisels, offset discs, rotary tiller, lister plow (or spade and fork or U-bar in the garden) that inverts, sifts, or mixes the top six inches to two feet or more of soil. Primary tillage is applied to soils in order to eliminate soil pans, incorporate organic matter and mineral soil amendments, incorporate cover crops and crop residues, and aerate soils.

2. Secondary tillage

- a) Defined: Shallow and fine tillage. Secondary tillage produces a fine seed or root bed by a series of operations that reduces the surface soil particle size. Secondary tillage tools and techniques are applied to the top 3 to 4 inches of soil and used to form fine, level, firm planting beds following primary cultivation. Secondary tillage employs disc harrows, spring- and spike-toothed harrows, and landplanes in the field, and forks and rakes in the garden.

3. Surface cultivation or cultivation tillage

- a) Defined: Shallow, post-planting tillage used to loosen and aerate compacted soils, hill soil, and/or eradicate unwanted vegetation growing around cultivated crops. Cultivation tillage employs power incorporators and large rototillers, cutting knives and sweeps, and spring-toothed harrows (see Appendix 2, Tillage and Planting Implements).

#### **E. Factors Influencing Timing and Type of Tillage**

1. Soil moisture

Soil tillage should take place only within the soil moisture range of 50–75% of field capacity (see appendix 1, Estimating Soil Moisture By Feel). Tillage executed at soil moistures higher than 75% of field capacity can increase soil compaction. Soil tillage undertaken when soil moisture is below 50% of field capacity may pulverize soil aggregates, resulting in poor soil structure and increasing the risk of soil erosion.

## 2. Soil texture classification

- a) Sandy soil: Sandy soils with relatively large particle size and large pore spaces are often naturally well drained, aerated, and friable. These features, combined with the relatively inert nature of the sand particles, lead to soil conditions in which organic matter oxidizes rapidly and unstable soil aggregates form. Though less susceptible to compaction when tilled outside of the ideal moisture range, tillage systems in sandy soils must generally be conservative in order to retain soil aggregates and maintain desirable soil physical properties.
- b) Clay soil: Soils with a high percentage of clay (>40%) have many micropore spaces and often exhibit poor drainage and gas exchange characteristics. Heavy clay soils often require an extended period (5–7 or more years) of frequent, deep tillage in order to incorporate adequate amounts of mineral soil amendments and organic matter to create the desirable soil physical conditions. Clay soils must be worked at optimal soil moistures (50–75% field capacity) to avoid creating clods—large and compacted soil masses—that lead to soil physical properties of poor quality.

## 3. Climate

Temperature, evaporation, and precipitation strongly influence soil development, so that Arctic, tropic, temperate, and arid regions all tend to develop different types of soil. Temperature, evaporation, and precipitation influence the degree and duration of seasonal soil biological activity, which in turn determines the mineralization rates of soil organic matter and the degree of organic matter accumulation in a given soil. Generally, the greater the number of days with soil temperatures below 50°F and the higher the annual amounts of precipitation, the greater the accumulation of soil organic matter.

- a) Arid climates: Low annual precipitation resulting in sparse vegetation and little organic matter accumulation. Cultivation should be limited to preserve soil organic matter. Due to low precipitation and reduced nutrient leaching, arid soils are often potentially very fertile with the addition of irrigation and organic matter inputs.
- b) Temperate climates: Cooler temperatures and high organic matter accumulation. Spring tillage is often necessary to increase soil temperatures and improve drainage through soil aeration.
- c) Tropical climates: High annual temperatures, precipitation, and humidity tend to maintain soil biological activity and the continual oxidation of soil organic matter. Nutrients and organic matter are often disproportionately held in the vegetative cover. Cultivation should be minimized to reduce additional losses of soil organic matter. Cultivated soils in areas with heavy rainfall should be protected from the erosive effects of heavy rains through the use of mulches and cover crops.

## 4. Season (temperate climate)

- a) Spring: Period of most extensive cultivation in temperate region. Deep tillage is often used to remove or incorporate cover crops, aerate and warm cold soils, incorporate mineral and organic matter soil amendments, and create planting beds for seed or transplants.
- b) Summer: Period of light tillage and surface cultivation for successive cropping
- c) Fall: Deep cultivation is frequently used to prepare soils for fall and overwintering crop production in moderate climates with high annual winter rainfall. Deep cultivation counters the cumulative soil-compacting effects of rains and helps assure adequate winter drainage. Tillage is often used in the fall to incorporate mineral and organic matter soil amendments prior to sowing cover crops.
- d) Winter: Period of little or no cultivation

5. Cropping system
  - a) Annual cropping system: Annual cropping systems feature intensive cropping of nutrient-demanding plants, which necessitates a high frequency of soil tillage, resulting in both organic matter and plant nutrient losses. Annual cropping systems demand high inputs of organic matter and mineral amendments to counter losses.
  - b) Perennial cropping system: Perennial cropping systems require little or no tillage after initial planting and demand only periodic surface cultivation or mowing to manage competing vegetation
6. Soil condition
  - a) Soils of good tilth: Soils with well-developed physical and chemical properties often require less intensive tillage and are maintained by incorporating soil amendments into the top 4–12 inches of soil. The physical properties of such soils should be monitored and, when necessary, periodically deeply tilled to disrupt soil compaction and incorporate organic matter soil amendments, which encourage soil aggregate formation.
  - b) Soils with physical properties of low quality: Untilled ground and soils with surface or sub-soil compaction are initially deeply tilled each year, using double digging on a garden scale and mechanical spading or chisel plowing on a field scale. This deep tillage—combined with planting deep-rooted cover crops—fractures compacted soil layers and distributes soil amendments throughout the soil profile, encouraging development of soil aggregates and reducing soil bulk density. Once the physical properties of the soil have been developed/improved, less intensive tillage techniques may be used for maintenance purposes.

#### **F. Possible Impacts of Frequent and Intensive Soil Cultivation**

1. Decreases in soil organic matter content: Intensive cultivation in irrigated soils increases and sustains the oxidation rate of soil organic matter. Without periodic replacement of organic matter, soils subjected to intensive tillage will become exhausted of their active humus content, leading to the degradation of soil biological, physical, and chemical properties.
2. Eventual reduction in soil biological activity and diversity: Soil organic matter is the energy source for many soil organisms. Soils with low or exhausted soil organic matter cannot support large populations or a great diversity of soil microbes, which are responsible for the liberation of plant nutrients, disease suppression, and the development and maintenance of certain physical properties of the soil.
3. Destruction of soil aggregates: Soil aggregates may also be pulverized, compacted, or degraded through oxidation during tillage. Excessive tillage or continuous tillage without the replenishment of organic matter will result in the eventual loss of soil organic matter.
4. Reduction in nutrient- and water-holding capacity of the soil: Soil organic matter is a reservoir of all essential plant nutrients, significantly contributing to the cation exchange capacity of the soil. Soil organic matter holds many times its weight in water, buffering the soil against extreme moisture variations.
5. Loss of soil pore space and decreased gas exchange: Loss of soil organic matter and degradation of soil structure result in loss of soil pore space and reduce the soil's ability to passively exchange gases with the atmosphere
6. Reduction in drainage: Loss of soil organic matter and degradation of soil structure reduce the soil's ability to readily drain excess moisture

7. Increased susceptibility to soil erosion: The loss of soil organic matter from excessive tillage results in an overall reduction and weakening of soil aggregates and reduces soil's ability to hold together as a cohesive mass. Soils with few or unstable aggregates are not as resistant to the erosive forces of irrigation or rainwater and easily detach and travel with moving surface water.
8. Disruption of earthworm habitat: Frequent and deep cultivation and the aeration of the soil environment disrupt earthworm habitat, kill some earthworms in the process of cultivation, and expose others to predation
9. Decline of soil quality and increased susceptibility of crop plants to pests and pathogens

## G. The French-Intensive Method of Soil Cultivation

1. Primary features of the French-intensive system
  - a) Deep cultivation with hand tools: Cultivation depths may be as great as 24 inches; this process distributes organic matter and mineral amendments through the soil horizons, and eventually increases topsoil depth. Deep cultivation allows for greater vertical development of crop root systems, affording higher density planting and thus higher yields per surface area of land.
  - b) Concentration of organic matter and mineral amendments into permanent growing beds: High application rates of mineral and organic matter amendments rapidly improve soil physical and chemical properties. Compost application rates may range from 10 to 20 tons/acre/year (0.5–1 pound/square foot) for maintenance purposes and up to 2 pounds/square foot for soil development purposes.
  - c) Use of fully mature compost: Allows for immediate nutrient availability to crops and affords a more rapid spring turnover from cover crops to planting cash crops
  - d) Permanent growing beds and pathways: Permanent cropping areas and pathways restrict traffic and soil compaction to pathways and allow for more rapid development of soil fertility
2. Implements used in French-intensive soil cultivation (see appendix 2, Tillage and Planting Implements)
  - a) Primary cultivation tools: Spade, fork, U-bar, manure/pulling fork
  - b) Applications and effects
    - i. Spade: Used in double digging to remove and shift soil
    - ii. Fork: Used in double digging to fracture surface and sub-soil layer; to incorporate mineral and organic matter amendments into surface soil following deep digging; to incorporate amendments into the surface of improved soils when deep cultivation is no longer necessary.
    - iii. U-bar: Used for rapid and coarse tillage to 16 inches in situations where deep cultivation is no longer necessary or desired
    - iv. Pulling/manure fork: Used as primary cultivation tool to incorporate amendments into the surface of improved soils through chopping motion
  - c) Secondary cultivation tools: Bow and leaf rakes
  - d) Applications and effects
    - i. Rakes: Used to shape garden beds after primary cultivation and reduce, when necessary, the surface soil particle size in preparation for transplanting or direct sowing of crops
3. Common tillage sequences used in French-intensive soil cultivation (see appendix 3, Double Digging Sequence)
  - a) Primary cultivation (unimproved soil)
    - i. Spread compost over surface of bed at a rate of ~1 pound/square foot
    - ii. Fracture surface soil of garden bed with garden fork to depth of tines to allow for greater ease of digging

- iii. Remove trench of soil and set aside
- iv. Shift soil forward filling trench via double digging process using spade and digging board
- v. Spread ~1 pound/square foot of additional organic matter and fracture sub-soil layers with garden fork
- vi. Repeat process to end of bed
- b) Primary cultivation (improved soil)
  - i. Spread mineral and organic matter soil amendments evenly onto the the surface of the garden bed
  - ii. Articulate edge of bed and pathways with garden fork
  - iii. Incorporate soil amendments into top 4–6 inches of surface soil with garden fork
- c) Secondary cultivation
  - i. Incorporate additional mineral and organic matter soil amendment into top 4–6 inches of surface soil with a garden fork following deep digging of unimproved soils
  - ii. Use a garden fork or leaf rake to reduce the surface soil particle size, when necessary, and shape garden beds after primary cultivation in preparation for transplanting or direct sowing of crops
  - iii. Further reduce surface soil particle size with leaf rake in preparation for direct sowing of small-seeded crops
- 4. Potential benefits of the French-intensive system
  - a) Rapid improvements in soil fertility. French-intensive cultivation methods may increase the rate of top soil development to 60 times that of non-human-mediated soil formation processes.
  - b) The increased ability of the soil to support cultivated plant growth at high-density spacing results in high yields per surface area of land used
  - c) High-density spacing of cultivated plants creates a living mulch microclimate that reduces rates of evapotranspiration and organic matter oxidation. High-density plantings reduce weed competition by shading competing plant species.
  - d) The exclusive use of hand tools reduces or eliminates the need for energy-intensive heavy machinery
- 5. Potential disadvantages of the French-intensive system
  - a) Requires large volume of organic matter inputs. Traditional French-intensive systems use, on average, 24 tons per acre of compost for maintenance and 48 tons per acre during the initial stages of soil development. This poses a significant management, labor, and potential cost burden for a commercial operation.
  - b) Intensive manual labor limits scale of production. Labor-intensive nature of system is often not practical/competitive on a commercial scale.

## H. Mechanical/Field-Scale Tillage Systems

- 1. Conventional tillage
  - a) Defined: Combined primary and secondary tillage operations normally performed in preparing a seedbed for a given crop or area
  - b) Conventional tillage implements and operations (see appendix 2)
    - i. Disc: Primary tillage implement used to incorporate cover crop seed and cover crop and crop residue
    - ii. Spader: Primary tillage implement used to incorporate cover crop and crop residue. Very slow speed of operation. Deep tillage (14+ inches) without soil inversion. Similar effect on soil as double-digging.

- iii. Plow: Primary tillage implement used to open soils, incorporate crop residue. Inverts soil and may create hard pan. Less commonly used.
  - iv. Rototiller: Primary or secondary tillage implement used to incorporate crop residue. Used for seedbed preparation. Pulverizes soil and produces a fine surface texture. May degrade aggregates and create hard pan through repeated use.
  - v. Ring roller: Secondary tillage implement that is pulled behind disc or chisel to firm soil to reduce loss of soil moisture and break large soil clods. Also used to incorporate small cover crop seed.
  - vi. Chisels (for sub-soiling): Primary tillage implement composed of long shanks that are pulled behind tractor to break up compacted sub-soils and allow rainfall to penetrate to greater depths
  - vii. Lister bar and bed markers: Secondary tillage equipment used to roughly shape beds following primary tillage
  - viii. Bedders/bed shapers: Used to shape beds for planting; seeders and rolling markers may be mounted to rear
  - ix. Knives and sweeps, reverse disc hillers, and furrow chisels: Close cultivation equipment used in row crops post-planting
  - x. Spring-toothed harrow: Used for light weed cultivation, soil aeration, and covering cover crop seed; brings up perennial weeds to surface
2. Minimum tillage (a.k.a. optimum, reduced, conservation, or economy tillage)
- a) Defined: Combined primary and secondary tillage operations that use fewer operations than conventional tillage in preparing a seedbed for a given crop or area
  - b) Types of conservation tillage
    - i. Conservation/mulch tillage: Tillage or preparation of the soil in such a way that plant residues or other mulching materials are left on or near the soil surface to conserve soil moisture and prevent soil erosion
    - ii. No-till and strip-till systems: Planting into a minimally prepared seed bed. Planting without tillage throughout the growing season.
  - c) Advantages
    - i. Reduces soil organic matter losses
    - ii. Reduces soil erosion rates
    - iii. Conserves energy
    - iv. Saves time and labor inputs
  - d) Disadvantages
    - i. Less aeration and soil warming resulting in reduced mineralization rate of organic matter = reduced nutrient availability and lower yields for certain crops in cooler climates
    - ii. Strip till encourages easy access to crop by gophers, moles, etc.
    - iii. Requires increased use of herbicides or close cultivation and/or hand weeding
  - e) Application of no-till systems
    - i. Steep slopes: Planting on slopes too steep for conventional tillage
  - f) Tools and practices used in minimum tillage
    - i. Conservation tillage: Use of subsurface tillage equipment such as sub soiler or chisels to till root zone but minimally disturb surface soil
    - ii. No-till: Use of special planters that cut thorough surface trash ahead of planter

3. Common tillage sequences used in small-scale mechanized farming systems (spring to fall)
  - a) Primary tillage: Incorporation of cover crop residue in spring
    - i. Mowing (flail or rotary)
    - ii. Apply compost with manure spreader prior to residue incorporation, if necessary
    - iii. Incorporate cover crop residue and compost with spader or off-set wheel disc
    - iv. Rototill or disc field to improve surface uniformity following residue breakdown
  - b) Secondary tillage: Seedbed establishment
    - i. Form beds with lister bar and shovels or rolling cultivator
    - ii. Shape bed with bed shaper
  - c) Bed formation and planting
    - i. Plant beds with seeder, transplanter, or by hand
  - d) Cultivate planted beds with sweeps, knives, or rolling cultivator at timely intervals to minimize weed pressure
  - e) Incorporation of crop residue for cover cropping or fall crop planting
    - i. Mow crop residue
    - ii. Incorporate crop residue
    - iii. Chisel or subsoil, if necessary
    - iv. Plant cover crops
    - iv. Disc and roll
    - v. Reshape and plant beds for fall cropping





# Demonstration 1: French-Intensive Soil Cultivation

## *for the instructor*

### OVERVIEW

*The following demonstration introduces the tools, techniques, and rationale behind the use and practice of the French-intensive method of soil cultivation. Following this demonstration and with the help of step-by-step instructions, students will be asked to prepare a garden bed using French-intensive tillage techniques.*

### SITE PREPARATION AND MATERIALS

1. At the demonstration site, string and stake a well-developed garden bed (if available) and an undeveloped site to illustrate techniques used in the initial stages of soil development and those used to maintain well-developed soils. Have samples of unimproved and improved soils at the demonstration site.
2. In advance of the tillage demonstration, pre-irrigate the demonstration site soil (where necessary) in order to have the site within the optimal range of 50–75% of field capacity by the day of the demonstration. To illustrate soil moisture extremes, pre-irrigate an additional area to saturation just prior to the demonstration. Also identify soils with moisture content below 50% of field capacity. The above three examples may be used to gauge soil moisture with students and to illustrate the importance of tillage operations within the range of optimal soil moisture.
3. In advance of the demonstration, divide the pre-existing garden bed into 5\* or more 6-foot sections (\*may be more or less depending upon number of techniques to be modeled). In the front 3 feet of each 6-foot section, pre-till sample sections using the following tools and techniques: double digging, single digging, deep forking, U-bar/broad fork, pull fork, other. Pre-tilled examples may be used to illustrate both the effects on the soil of the individual techniques and to compare/contrast effects of different techniques. The remaining 3-foot sections of untilled soil may be used to demonstrate each of the techniques listed above.
4. Assess existing compost piles for samples of stabilized, finished compost and those at varying stages of decomposition. Use these samples to illustrate which compost to use and problems associated with incorporating undecomposed organic matter into the soil.
5. On the day of the demonstration, gather tools, materials, and handouts: spade, garden fork, u-bar/broad fork, pull fork, digging board, mineral soil amendments, finished compost/aged manure, and the soil moisture chart (appendix 1).

6. If available, standing cover crops may be used to demonstrate skimming/clearing or incorporation of cover crops into the soil with hand tools and/or the incorporation of cover crops into the trench during the double digging process.

**PREPARATION TIME**

1.5 hours

**DEMONSTRATION TIME**

1.5 hours

## DEMONSTRATION OUTLINE

### A. Plan the Cultivation with Students

#### 1. Assess soil prior to cultivation

Ask student to consider the necessary or desired method and timing of cultivation for:

- a) Soil moisture
    - i. With the students, determine the current soil moisture content (in % field capacity) of various soil samples (wet, dry, and optimal) using the soil moisture charts (see appendix 1)
    - ii. Ask student to decide which of the soil samples are within the optimal range of soil moisture for cultivation. Define optimal soil moisture range and provide example.
    - iii. Discuss problems associated with tillage outside of this optimal range
    - iv. Look at results of or attempt to dig in soil that is too wet or too dry
    - v. Discuss/ask how to adjust soil moisture when too moist or too dry
  - b) The stage of soil development
    - i. Review/ask the influence of soil development on tillage strategies
    - ii. Discuss/ask students how tillage approaches may differ on: unmodified, well-developed and degraded soils. Provide examples of each and physical indicators that students may use in determining tillage approaches.
    - iii. Discuss/ask how a given method of cultivation may improve or degrade the existing soil structure of the examples provided
    - iv. Discuss/ask how tillage techniques may evolve and change as soil fertility develops over time
  - c) The soil texture
    - i. Have students approximate the soil texture by feel
    - ii. Discuss/ask students how and why tillage approaches may differ on: sand, silt and clay soils. Provide examples of each.
    - iii. Discuss/ask how a given method of cultivation may improve or degrade the existing soil structure of the examples provided
  - d) Type of crop to be grown
    - i. Discuss/ask students how the seed size, transplant size, and vigor, as well as the rooting depth of crops, may influence the type of primary tillage and the degree of secondary tillage. Provide examples of crops requiring deep tillage, course secondary tillage, and those requiring a fine seedbed for optimal germination or early growth of transplants.
- #### 2. Discuss considerations for determining the quantity, quality, timing, and type of soil amendments to be applied during cultivation
- a) What mineral amendments to apply
    - i. Discuss/review the use of laboratory soil analysis results and the resources in this manual (see Unit 1.11, Reading and Interpreting Soil Test Reports) as you identify the need for, type, and application rates of accepted mineral and/or organic matter amendments
  - b) How much compost to apply
    - i. Review compost quality (see Unit 1.7, Making and Using Compost)
    - ii. Discuss/ask students how application rates may differ on unmodified, well-developed, or degraded soils
    - iii. Discuss/ask how application rates may change as soil fertility develops over time

- iv. Discuss the amount of compost needed to develop and maintain both physical and chemical soil properties (up to 2 pounds per square foot for development and ~0.5–1 pound per square foot for maintenance)
- v. Discuss the varying nutrient demands of specific crops (provide reference) and the question of amending soil following each cropping sequence
- c. Where to apply and incorporate soil amendments
  - i. Discuss/ask how the placement and distribution of amendments may change as soil fertility develops over time

## **B. Demonstrate Site Preparations**

1. Removal and storage of cover crops, crop residue, and weed cover
  - a) Demonstrate skimming techniques used to remove and store cover crops and/or crop residues
2. Bed layout
  - a) Demonstrate and discuss garden bed layout by staking and stringing a garden bed with students. Note: Emphasize the importance of soil amendments and tillage techniques always being evenly applied to the entire marked area; garden bed delineation (stringing) serves as a visual guide in this process.

## **C. Demonstrate Proper Tool Techniques for Outcome, Safety, and Efficiency**

1. Discuss tools used and why
2. Demonstrate proper use of each tool

## **D. Demonstrate and Discuss Primary Cultivation Steps (see appendix 3)**

1. Double digging
  - a) Step 1: Spread organic matter and mineral amendments evenly over surface of garden bed
  - b) Step 2: Articulate edges of bed with a garden fork
  - c) Step 3: Fracture and loosen surface soil with garden fork
  - d) Step 4: Use a spade to create first trench across the width of the bed. Soil storage.
  - e) Step 5: Add additional compost on the bottom of the trench
  - f) Step 6: Fracture and loosen the subsoil in the bottom of the trench
  - g) Step 7: Use a digging board and spade to shift the surface soil forward in order to stir soil, incorporate amendments and create the second trench
  - h) Repeat steps 5–7 along the length of the bed
  - i) Step 8: Replace soil removed from first trench in the last trench
  - j) Step 9: Incorporate additional soil amendments into the top 4–6 inches of the surface soil using the “Deep Forking” steps (see below)
  - k) Discuss/ask student under which circumstances the above technique is used
    - i. The use of secondary tillage techniques
    - ii. Discuss/ask students about the probable effects on soil organisms, root activity water movement/retention, gas exchange, temperature, etc.
2. Deep forking
  - a) Step 1: Spread organic matter and mineral amendments
  - b) Step 2: Articulate edges of bed with a garden fork
  - c) Step 3: Fracture and loosen surface soil with garden fork
  - d) Step 4: Sift the soil with garden fork to incorporate soil amendments into the top 4–6 inches of the soil surface (see appendix 4, Side Forking)
  - e) Discuss/ask student under which circumstances the above technique is used

3. Alternative cultivation tools: Advantages and disadvantages

- a) U-bar/broad fork
- b) Roto-tiller
- c) Pulling fork
- d) Others

**E. Demonstrate and Discuss Secondary Cultivation Steps**

1. Step 1: Sift the soil with garden fork to incorporate soil amendments into the top 4–6 inches of the surface soil
2. Step 2: Use the bow rake to shape the surface of the recently tilled bed into a flat or slightly convex form
3. Step 3: Fracture large soil clusters with fork or rake to reduce surface soil particle size in proper proportion to the size of the seed or transplant to be grown
4. Step 4: Use the leaf rake to remove large soil clusters resistant to fracturing
5. Discuss/ask students under which circumstances is the above technique used

**F. Discuss Evaluation Process**

1. Has there been consistent and optimal soil moisture throughout the cultivated area? If not, how might this be addressed?
2. Has the tillage been thorough and even in depth and width?
3. Have the soil amendments been thoroughly and evenly incorporated?
4. Effects on the physical properties of the soil: Discuss/ask students how have these properties have been altered by this tillage technique or tillage sequence. How might these techniques affect the biological activity and nutrient cycling in the soil? How might they affect plant growth?
5. Discuss improvements in efficiencies that could be made



# Demonstration 1: French-Intensive Soil Cultivation

## *step-by-step instructions for students*

### **INTRODUCTION**

*A key component to developing and maintaining fertile garden soil is the proper use of tillage and soil amendments. The following step-by-step instructions will guide you through the planning, execution, and evaluation of French-intensive tillage operations. Follow the steps outlined below when developing and maintaining French-intensive raised beds.*

### **PREPARATION AND MATERIALS**

- Soil moisture chart (appendix 1)
- Tools: Garden spade and fork, U-bar/broad fork, stakes and string, wheelbarrow or buckets, tape measure, digging board, bow or leaf rake
- Any needed mineral amendments
- Stabilized compost

Collect and organize the materials listed above.



## A. Cultivation Planning

1. Assess soil prior to cultivation
  - a) Soil moisture
    - i. Assess the current soil moisture content using the soil moisture chart
    - ii. The optimal range of soil moisture for cultivation is between 50–75% of field capacity. If soil moisture is <50% of field capacity, pre-irrigate, bringing the top 24 inches of soil to field capacity. Wait for the soil moisture to fall within the optimal range, then till as described below.
  - b) The stage of soil development/soil fertility
    - i. Undeveloped, compacted soils or those indicating the need for significant additions of organic matter or corrections to soil chemistry should receive a thorough double digging, during which soil amendments are incorporated throughout the soil profile
    - ii. Loose and friable soils with well-developed soil aggregations, adequate organic matter and mineral amendments, and no nutrient imbalances or organic matter deficiencies (as indicated by the soil test) may be prepared using a deep forking technique where soil amendments needed for soil fertility maintenance are incorporated into the top 4–6 inches of topsoil
  - c) The soil texture
    - i. What is the soil texture? If unknown, use the exercise in Unit 2.1, Soil Physical Properties, to determine the soil texture.
    - ii. Soils with a high clay content often require the long-term application of deep tillage to improve the physical and biological properties of the soil. The physical properties of sandy soils are both more rapidly improved and degraded by extensive tillage and should be tilled shallowly, using the deep forking method, once improved.
  - d) Type of crop to be grown
    - i. Secondary tillage techniques should be used to render the surface soil particle size in proper proportion to the size of the transplant or seed being sown
      - Directly seeded crops and small, weak, or inefficiently rooted transplants require a fine surface soil particle size
      - Large, vigorous transplants may be transplanted into a more coarsely tilled soil
2. Determine need for the application of soil amendments during cultivation
  - a) Mineral amendments
    - i. Review laboratory soil analysis results for nutrient deficiencies or imbalances. Using the exercise in Unit 1.11 of this manual (Reading and Interpreting Soil Test Reports), select mineral amendments and application rates.
  - b) Compost
    - i. Thoroughly decomposed compost should be applied at a rate of 2 pounds per square foot during the initial stages of soil development and 0.5–1 pound\* per square foot per year to maintain physical and chemical soil properties (\*this amount will vary depending on intensity and types of crops grown). In well-improved garden soils the general rules apply:
      - From a heavy to a heavy feeding crop sequence: Apply an additional 1 pound per square foot of compost
      - From a heavy to light feeding crop: No compost required
      - From a light to light feeding crop: No compost required
      - From a light to heavy feeding crop: No compost required
      - From a moderate to moderate feeding crop: 0.5 pound per square foot
      - From a moderate to light feeding crop: No compost required
      - From a moderate to heavy feeding crop: 0.5 pound per square foot

3. Apply and incorporate soil amendments (when necessary)
  - a) Initial stages of soil development: Organic matter and mineral amendments are often applied both to the surface of the soil (prior to tillage) and to the exposed sub-soil during the deep tillage process. Additional compost is incorporated into the top 4–6 inches of the surface soil using the deep forking technique, helping to assure immediate plant nutrient availability.
  - b) Well-developed soils: Soils indicating no nutrient deficiencies or significant chemical imbalances often require only periodic deep tillage. Maintenance applications of compost or mineral amendments in such soils proceed by incorporating amendments into the top 4–6 inches of the surface soil, thereby assuring the availability of essential plant nutrient in the root zone of the crop.

## **B. Soil Cultivation Preparations**

1. Remove and properly store cover crops, crop residue, or weed cover
  - a) Removal
    - i. With a spade, skim standing vegetation at soil surface
    - ii. Coarsely hand weed remaining vegetation
    - iii. Root systems of cover crops, crop residue, and weed cover may be removed during the cultivation process
  - b) Storage
    - i. All succulent, green vegetation should be removed and stored at the composting site
2. Lay out garden bed
  - a) Staking
    - i. Mark the four corners of the bed with stakes pounded firmly into ground
    - ii. French-intensive beds are commonly 48 inches wide or two times the length of the gardener's arm, allowing for ease of access to center of the bed for weeding, harvesting, etc.
  - b) Stringing
    - i. Stretch string along the length of the growing bed to serve as a visual guide. Soil amendments and cultivation techniques should always be consistently and evenly applied to this entire area.

## **C. Proper Tool Techniques for Outcome, Safety, and Efficiency**

1. Assemble needed tools and materials
2. Review proper tool techniques for outcome, safety, and efficiency
  - a) Warm up before working with movement and stretching
  - b) Use tools and techniques that allow you to keep your back straight at all times when working
  - c) Use tools to shift soil not lift soil (see below)
  - d) When lifting, use only your legs and not your back muscles
  - e) Always wear closed-toed shoes when working

## D. Primary Cultivation Steps

1. Double digging (see appendix 3)
  - a) Step 1: Spread needed organic matter and mineral amendments evenly over soil surface
  - b) Step 2: Using string line as guide, articulate edges of bed with a garden fork
  - c) Step 3: Fracture and loosen surface soil with garden fork to the depth of the tines
  - d) Step 4: Using a spade, create a trench 1 foot deep by 1 foot wide across the width of the bed. Place this soil in wheel barrow or buckets and set aside.
  - e) Step 5: Spread additional compost on the bottom of the trench
  - f) Step 6: Standing on the path and working from the center of the garden bed outward, fracture and loosen the soil in the bottom of the trench. Repeat this process on both sides of the bed.
  - g) Step 7: Using a digging board as a fulcrum, shift the surface soil forward filling the first trench, creating a second trench 1 foot deep and 1 foot wide
  - h) Repeat Steps 5–7 along the length of the bed until the end of the bed is reached
  - i) Step 8: Place soil removed from first trench into the last trench created
  - j) Step 9: Using a garden fork, incorporate additional soil amendments needed into the top 4–6 inches of the surface soil (see “Deep forking” steps 1–4, below)
2. Deep forking
  - a) Step 1: Spread needed organic matter and mineral amendments evenly on soil surface
  - b) Step 2: Using string line as guide, articulate edges of bed with a garden fork
  - c) Step 3: Working from the center of the garden bed outward, fracture and loosen large surface soil clusters with garden fork to the depth of the tines. (This will permit greater ease of digging in subsequent tillage steps.)
  - d) Step 4: Using a garden fork and working from the center of the garden bed outward toward the pathway, force garden fork into soil to the depth of the tines. Scoop and lift soil above soil surface and with a gentle jerking motion allow soil and compost to fall and sift through the tines of the fork (see appendix 4).
3. Alternative cultivation tools: Advantages and disadvantages
  - a) U-bar/broad fork
  - b) Roto-tiller
  - c) Pulling fork
  - d) Others

## E. Secondary Cultivation Steps

1. Step 1: Sift the soil with garden fork to incorporate soil amendments into the top 4–6 inches of the surface soil
2. Step 2: Use the bow rake to shape the surface of the recently tilled bed into a flat or slightly convex form
3. Step 3: Fracture large soil clusters with fork or rake to reduce surface soil particle size in proper proportion to the size of the seed or transplant to be grown
4. Step 4: Use the leaf rake to remove large soil clusters resistant to fracturing
5. Under which circumstances is the above technique used?

## F. Evaluation

1. Have all of the soil amendments been thoroughly incorporated into the soil?
2. Has the entire garden bed been thoroughly and evenly tilled in depth, width, and length?
3. How have the physical, chemical, and/or biological properties of the soil been altered by this tillage?
4. How might one improve the efficiency of this process?

# Hands-On Exercise: French-Intensive Soil Cultivation

## *for the student*

*The following tillage exercise will help you develop the skills needed to cultivate and maintain traditional French-intensive raised garden beds. In this exercise you will be asked to evaluate distinct soils—both unimproved and improved—for their tillage needs and, from start to finish, execute the necessary steps to develop soils for horticultural purposes. Please document the rationale for each tool, technique, and sequence used during this exercise. This information will later be shared with your instructor. During the exercise your instructor should observe and critique your tillage skills.*

### **PREPARATION AND MATERIALS**

- Step-by-step instruction sheet (pp. 25–28, Demonstration 1)
- Soil moisture chart
- Tools: Spade, fork, or U-bar; stakes and string, wheelbarrow, tape measure
- Stabilized compost

### **EXERCISE**

Document the rationale for each tool, technique, and sequence used during each of the following tasks:

- Prepare 10 feet of unimproved garden soil using necessary soil improvement techniques
- Prepare 25 feet of an improved garden bed using necessary soil maintenance techniques



# Demonstration 2: Field Demonstration of Mechanical Tillage and Cultivation

*for the instructor*

## **OVERVIEW**

*For this field demonstration the instructor should have access to a wide range of tractor-mounted or drawn tillage and cultivating implements and the appropriate tractors for each of the implements. The demonstration also requires access to tillable land and existing diverse cropping systems and/or formed fallow beds spaced to match the equipment.*

## **PREPARATION AND MATERIALS**

The implements and tractors should be set up adjacent to the demonstration site and parked to allow fast hook up and drop off.

## **PREPARATION TIME**

1 hour

## **DEMONSTRATION TIME**

1.5 hours

## **DEMONSTRATION OUTLINE**

### **A. Demonstration of Primary Tillage Implements**

1. Evaluate soil moisture with students and assess whether it is appropriate for tillage
2. Do field demonstration of mechanical spader
  - a) Explain fundamentals of 3 point hitch
  - b) Explain fundamentals of PTO (power take off)
  - c) Discuss ground speed, working depth, and advantages/disadvantages of spaders in contrast to other primary tillage implements
  - d) Examine soil condition, depth of tillage, and residue incorporation behind spader
3. Do field demonstration of offset wheel disc and roller
  - a) Explain fundamentals of drawbar implements
  - b) Explain fundamentals of auxillary hydraulic systems
  - c) Discuss ground speed, traction requirements, working depth, and advantages/disadvantages of discs in contrast to other primary tillage implements
  - d) Examine soil condition, depth of tillage, and residue incorporation behind disc
4. Examine 3 point chisel
  - a) Explain use of chisels
  - b) Discuss working depths, soil moisture requirements, traction requirements, and advantages/disadvantages of chisels in contrast to other primary tillage implements.

### **B. Demonstration of Secondary Tillage Implements**

1. Do a field demonstration of a rotovator (3 point rototiller)
  - a) Explain the use of rotovators
  - b) Discuss ground speed, working depth, and advantages/disadvantages of rotovators in contrast to other secondary tillage implements
2. Examine spring tooth harrow
  - a) Explain use of harrows
  - b) Discuss working depths and advantages/disadvantages of spring tooth harrows in contrast to other secondary tillage implements

### **C. Demonstration of Row Crop Cultivation Implements**

1. Examine lister bar, markers, and shovels
  - a) Explain the use of listers for bed formation
  - b) Discuss other options for forming beds
  - c) Explain the use of bed shapers
2. Do a field demonstration of rolling cultivator
  - a) Run rolling cultivator down fallow beds
  - b) Discuss the various uses of the rolling cultivators for weed management in fallow and cropped systems
3. Do a field demonstration of row crop cultivator set up with sweeps and knives
  - a) Run cultivator down crop row
  - b) Discuss the various components of cultivator operation and set up





# Assessment Questions Key

- 1) List four objectives of soil tillage.
  - *Increase soil aeration*
  - *Increase soil temperature*
  - *Increase gas exchange*
  - *Stimulate soil biological activity/ increase rate of mineralization*
  - *Improve drainage characteristics: Infiltration and percolation*
  - *Incorporate soil amendments*
  - *Control of pests and diseases*
  - *Break up hard pans*
  - *Incorporate crop residue and/or cover crops*
  - *Create planting bed for transplants and seeds*
  - *Soil moisture conservation*
- 2) What are two possible problems associated with tilling soil when it is too wet or too dry?
  - *Soil compaction (the compression of pore space)*
  - *Soil pulverization (the degradation of soil aggregates)*
  - *Difficult to work*
- 3) What is the optimal range of soil moisture (in % field capacity) for tillage operations?
  - *Between 50% and 75% of field capacity*
- 4) What are you attempting to achieve through the double-digging process? In what situations is this technique best applied?
  - *Stimulation of biological activity and diversity through organic matter inputs*
  - *The rapid improvement of soil physical properties through soil aeration and the alleviation of compacted soil*
  - *The rapid improvement of soil chemical properties through deep incorporation of generous amounts of organic matter and mineral amendments*
  - *Used during the initial stages of soil development*
- 5) What are the common tillage sequences used in preparing ground in the spring? Please give steps for both French-intensive (double digging) and mechanical cultivation.
  - *Double digging*
    - a) *Step 1: Spread needed organic matter and mineral amendments evenly over soil surface*
    - b) *Step 2: Using string line as guide, articulate edges of bed with a garden fork*
    - c) *Step 3: Fracture and loosen surface soil with garden fork to the depth of the tines*
    - d) *Step 4: Using a spade, create a trench 1 foot deep by 1 foot wide across the width of the bed. Place this soil in wheel barrow or buckets and set aside.*
    - e) *Step 5: Spread additional compost on the bottom of the trench*
    - f) *Step 6: Standing on the path and working from the center of the garden bed outward, fracture and loosen the soil in the bottom of the trench. Repeat this process on both sides of the bed.*
    - g) *Step 7: Using a digging board as a fulcrum, shift the surface soil forward filling the first trench, creating a second trench 1 foot deep and 1 foot wide.*
    - h) *Repeat Steps 5–7 along the length of the bed until the end of the bed is reached*
    - i) *Step 8: Place soil removed from first trench into the last trench created*
    - j) *Step 9: Using a garden fork, incorporate additional soil amendments needed into the top 4–6 inches of the surface soil*

- *Mechanical cultivation*
  - a) *Primary tillage: Incorporation of cover crop residue in spring*
    - i. *Mowing (flail or rotary)*
    - ii. *Apply compost with manure spreader prior to residue incorporation, if necessary*
    - iii. *Incorporate cover crop residue and compost with spader or off-set wheel disc*
    - iv. *Rototill or disc field to improve surface uniformity following residue breakdown*
  - b) *Secondary tillage: Seedbed establishment*
    - i. *Form beds with lister bar and shovels or rolling cultivator*
    - ii. *Shape bed with bed shaper*
  - c) *Bed formation and planting*
    - i. *Plant beds with seeder, transplanter, or by hand*
  - d) *Cultivate planted beds with sweeps, knives, or rolling cultivator at timely intervals to minimize weed pressure*
  - e) *Incorporation of crop residue*
    - i. *Mow crop residue*
    - ii. *Incorporate crop residue*
    - iii. *Chisel or subsoil, if necessary*
    - iv. *Disc and roll*
    - v. *Reshape and plant beds*

# Resources

## PRINT RESOURCES

Jeavons, John. 2002. *How To Grow More Vegetables, Fruits, Nuts, Berries, Grains, and Other Crops Than You Ever Thought Possible on Less Land Than You Can Imagine, Sixth Edition*. Berkeley, CA: Ten Speed Press.

*An overview of the French-intensive method of horticulture.*

Plaster, Edward. 1985. *Soil Science and Management*. Paperback instructor edition, Delmar Publishing.

*Contains a chapter on tillage and cropping systems.*

## WEB RESOURCES

Agricultural Network Information Center

[www.agnic.org/](http://www.agnic.org/)

*AgNIC is a guide to quality agricultural information on the Internet as selected by the National Agricultural Library, Land-Grant Universities, and other institutions.*

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

Good Fruit Grower

[www.goodfruit.com/buyers/equipment.html](http://www.goodfruit.com/buyers/equipment.html)

*Listing of national equipment retailers.*

Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln

[www.ianr.unl.edu/pubs/fieldcrops/g1046.htm](http://www.ianr.unl.edu/pubs/fieldcrops/g1046.htm)

*Tillage system descriptions and comparisons.*

USDA—Agricultural Research Service

[www.florence.ars.usda.gov/research/bauer.htm](http://www.florence.ars.usda.gov/research/bauer.htm)

*Research on no-till cropping systems.*

# Glossary

## Aerobic

*Oxygen containing*

## Cultivation

*The total assemblage of tools and techniques used in the development and maintenance of soil fertility and crop production in garden and farm systems*

## Diffusion

*The dispersal of gases through a medium*

## French intensive

*A traditional method of horticulture developed in France that emphasizes intensive cultivation, high application rates of soil amendments, and high-density planting*

## Granular structure

*A specific and desirable form of soil structure*

## Humus

*Residual and decomposed organic matter held in the soil*

## Infiltration

*The absorption of water into the soil*

## Organic matter

*The material held in or on the surface of the soil that is alive or was once living tissue of plants and/or animals*

## Pan

*A horizon or layer in soils that is strongly compacted or high in clay content*

## Percolation

*The downward movement of water through soil horizons*

## Pore space

*The air spaces between soil particles*

## Primary cultivation

*Initial course cultivation used to break up soil mass into smaller particles, incorporate cover crops or soil amendments in preparation for planting seed or transplants*

## Secondary cultivation

*Soil cultivation used to further render soil into finer particle sizes in the preparation of seed and root beds. Used subsequent to primary cultivation.*

## Soil horizon

*An individual and distinct layer of soil (e.g., A horizon)*

## Soil organic matter

*Organic matter held in the soil*

## Soil separates

*Individual soil particles of sand, silt, and clay*

## Soil structure

*The physical arrangement of individual soil particles, the way they cling or aggregate*

## Soil texture

*The classification of a soil based on the relative percentages of sand, silt, and clay*

## Soil tilth

*The physical condition of a soil as related to the ease of tillage, fitness as a seedbed, and impedance to seedling and root penetration*

## Tillage

*The operation of implements through the soil to prepare seedbeds and root beds*

# Appendix 1: Estimating Soil Moisture By Feel

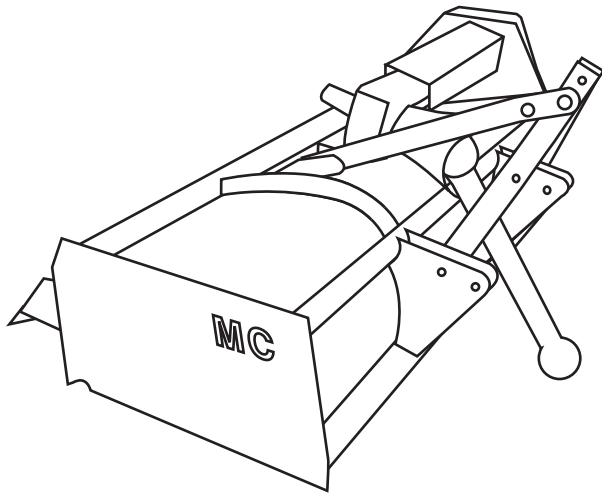
SOIL MOISTURE LEVEL (% OF FIELD CAPACITY)	COARSE (SAND)	LIGHT (LOAMY SAND, SANDY LOAM)	MEDIUM (FINE, SANDY LOAM, SILT LOAM)	HEAVY (CLAY LOAM, CLAY)
<b>0 –25%</b> No available soil moisture. Plants wilt. Irrigation required. (1 <sup>st</sup> range)	Dry, loose, single grained, flows through fingers. No stain or smear on fingers.	Dry, loose, clods easily crushed and will flow through fingers. No stain or smear on fingers.	Crumbly, dry, powdery, will barely maintain shape. Clods, breaks down easily. May leave slight smear or stain when worked with hands or fingers.	Hard, firm baked, cracked. Usually too stiff or tough to work or ribbon <sup>1</sup> by squeezing between thumb or forefinger. May leave slight smear or stain.
<b>25 –50%</b> Moisture is available, but level is low. Irrigation needed. (2 <sup>nd</sup> range)	Appears dry; will not retain shape when squeezed in hand.	Appears dry; may tend to make a cast when squeezed in hand, but seldom will hold together.	May form a weak ball <sup>2</sup> under pressure but will still be crumbly. Color is pale with no obvious moisture.	Pliable, forms a ball; will ribbon but usually breaks or is crumbly. May leave slight stain or smear.
<b>50 –75%</b> Moisture is available. Level is high. Irrigation not yet needed. (3 <sup>rd</sup> range)	Color is darkened with obvious moisture. Soil may stick together in very weak cast or ball.	Color is darkened with obvious moisture. Soil forms weak ball or cast under pressure. Slight finger stain, but no ribbon when squeezed between thumb and forefinger.	Color is darkened from obvious moisture. Forms a ball. Works easily, clods are soft with mellow feel. Will stain finger and have slick feel when squeezed.	Color is darkened with obvious moisture. Forms good ball. Ribbons easily, has slick feel. Leaves stain on fingers.
<b>75% to field capacity (100%)</b> Soil moisture level following an irrigation. (4 <sup>th</sup> range)	Appears and feels moist. Color is darkened. May form weak cast or ball. Will leave wet outline or slight smear on hand.	Appears and feels moist. Color is darkened. Forms cast or ball. Will not ribbon, but will show smear or stain and leave wet outline on hand.	Appears and feels moist. Color is darkened. Has a smooth, mellow feel. Forms ball and will ribbon when squeezed. Stains and smears. Leaves wet outline on hand.	Color is darkened. Appears moist; may feel sticky. Ribbons out easily, smears and stains hand, leaves wet outline. Forms good ball.

<sup>1</sup>Ribbon is formed by squeezing and working soil between thumb and forefinger.

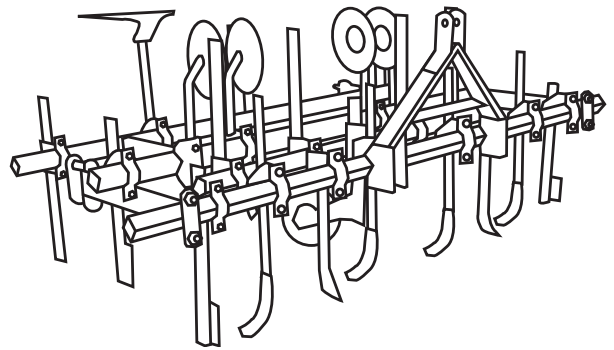
<sup>2</sup>Cast or ball is formed by squeezing soil in hand.

# Appendix 2: Tillage and Planting Implements

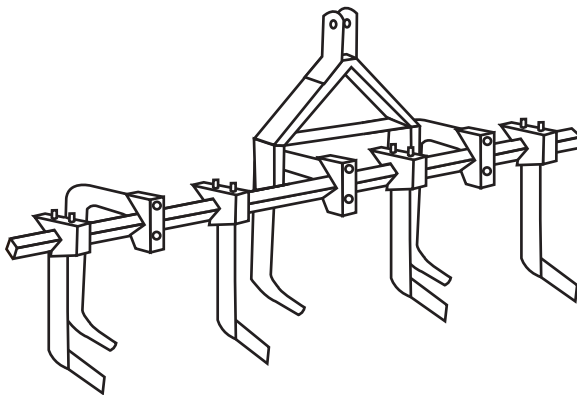
## FIELD-SCALE IMPLEMENTS



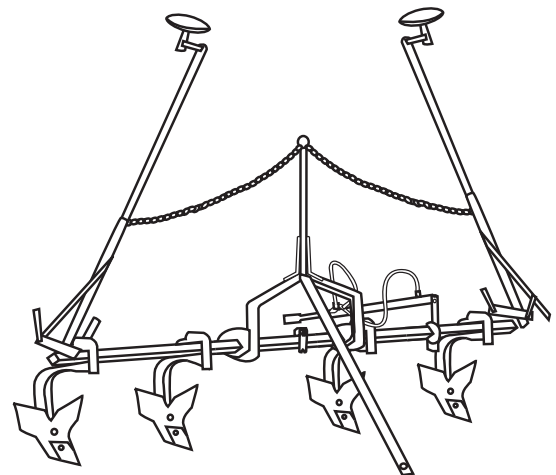
3-Point Flail Mower



3-Bar Cultivator



3-Point Chisel

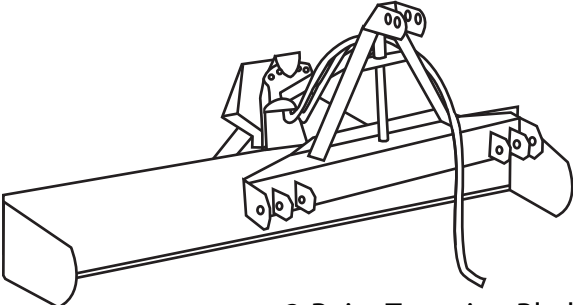


Lister Bar

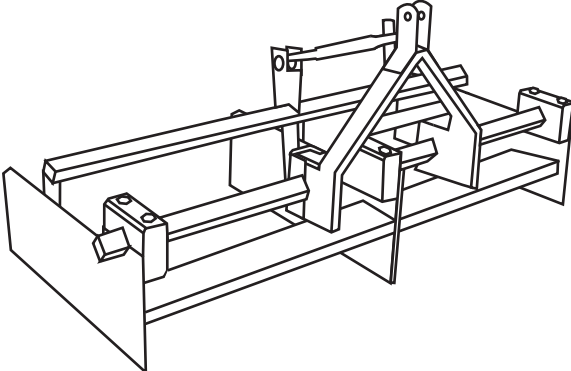
*illustrations by Cathy Genetti Reinhard; not to scale*

# Appendix 2: Tillage and Planting Implements

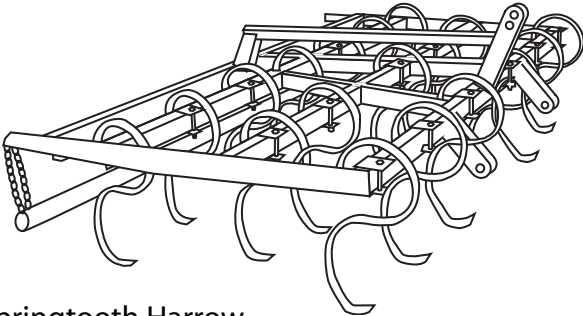
## FIELD-SCALE IMPLEMENTS



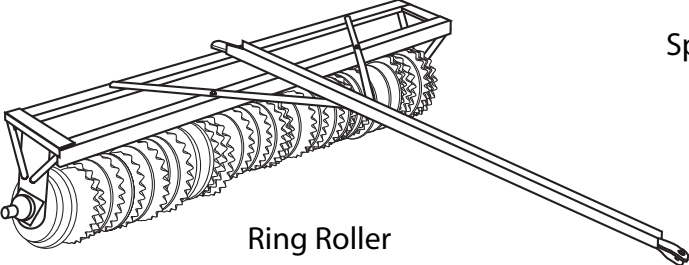
3-Point Terracing Blade



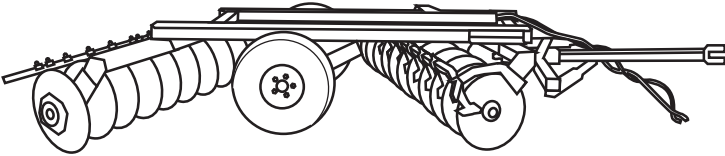
2-Row Bed Shaper



Springtooth Harrow



Ring Roller

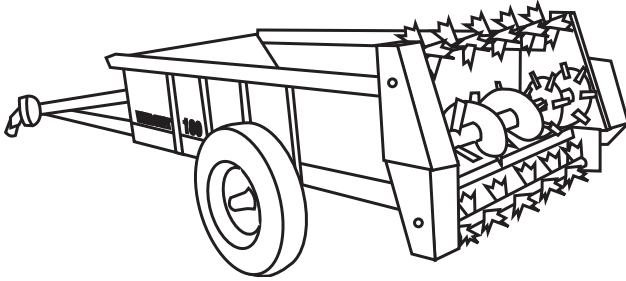


Offset Wheel Disc

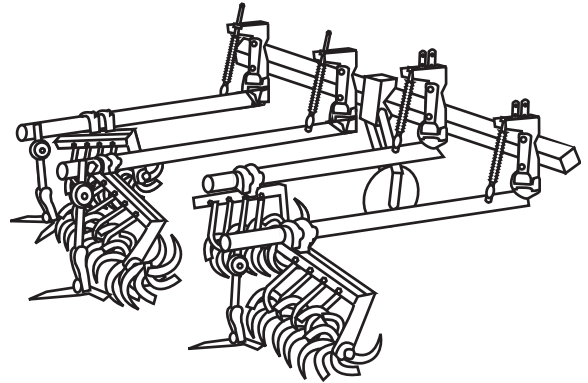
*illustrations by Cathy Genetti Reinhard; not to scale*

# Appendix 2: Tillage and Planting Implements

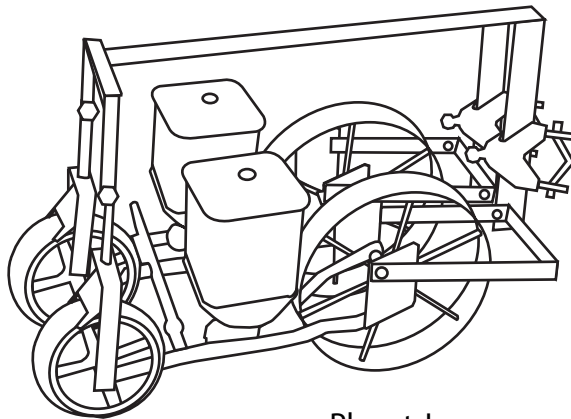
## FIELD-SCALE IMPLEMENTS



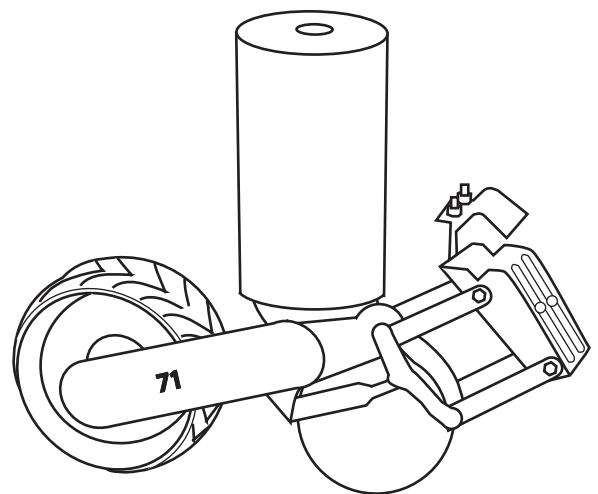
Manure Spreader



Lilliston Cultivator



Planet Jr.  
Vegetable Planter



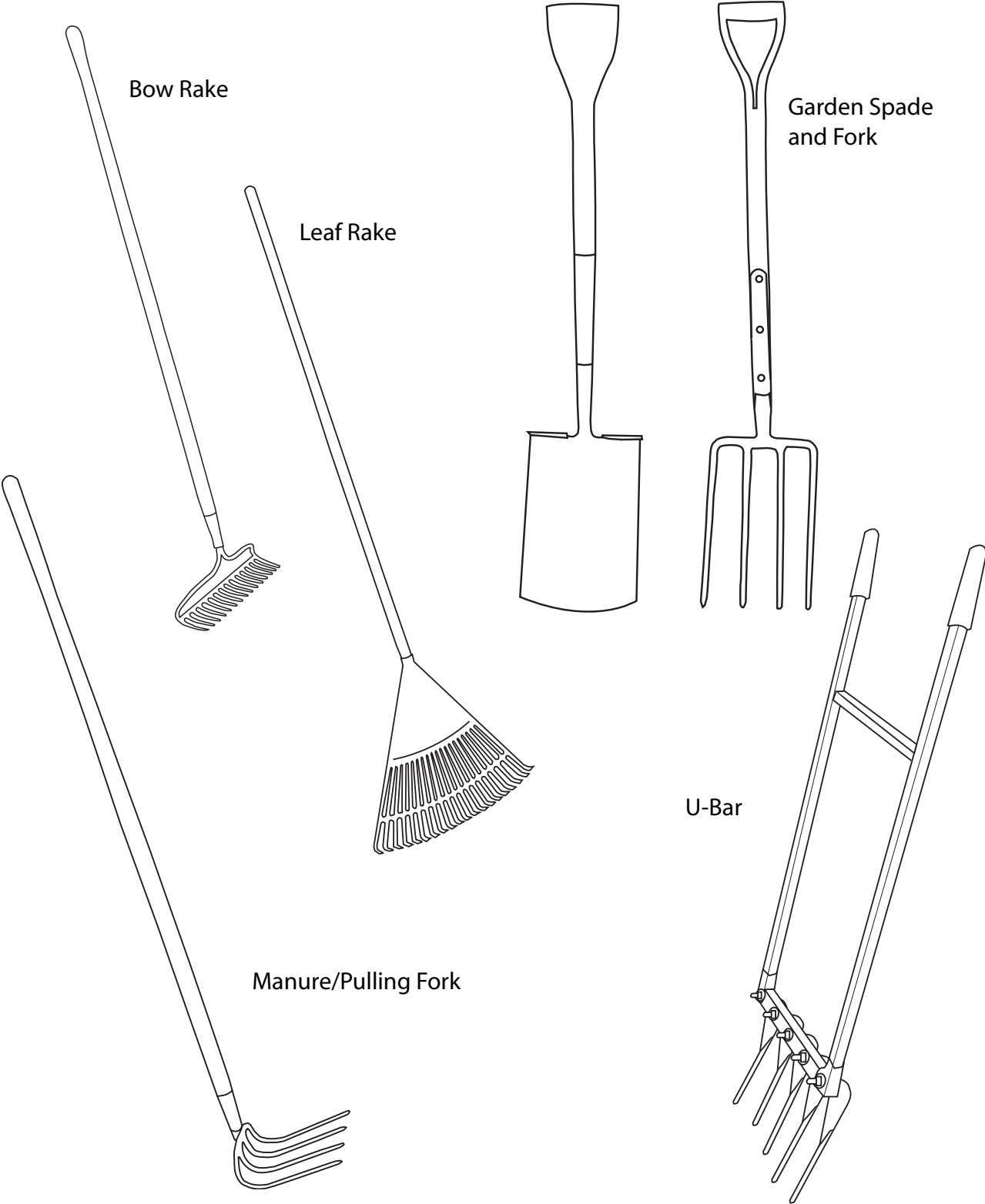
John Deere Model 71 Plate  
Planter

*illustrations by Cathy Genetti Reinhard; not to scale*



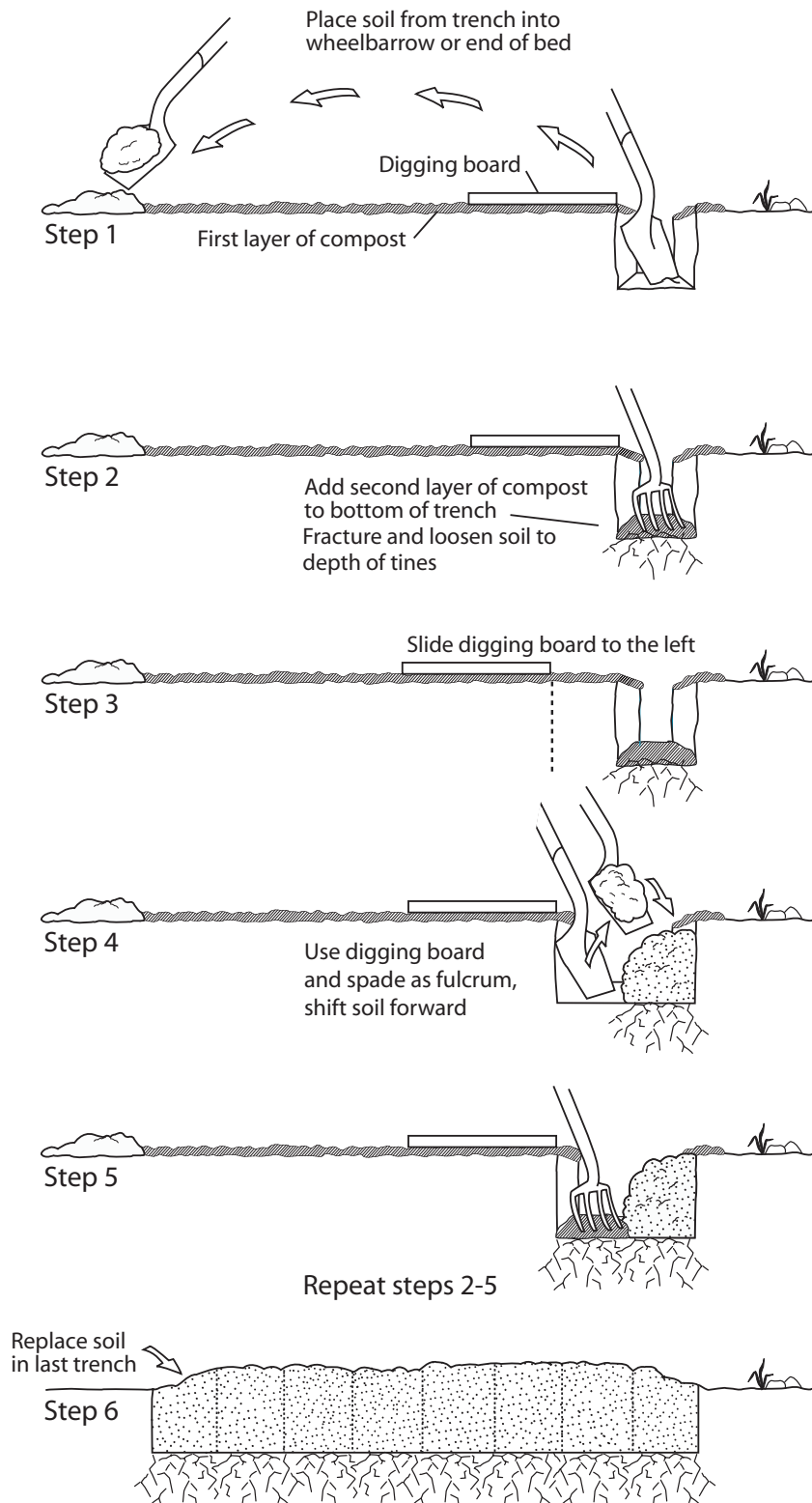
# Appendix 2: Tillage and Planting Implements

## GARDEN-SCALE IMPLEMENTS



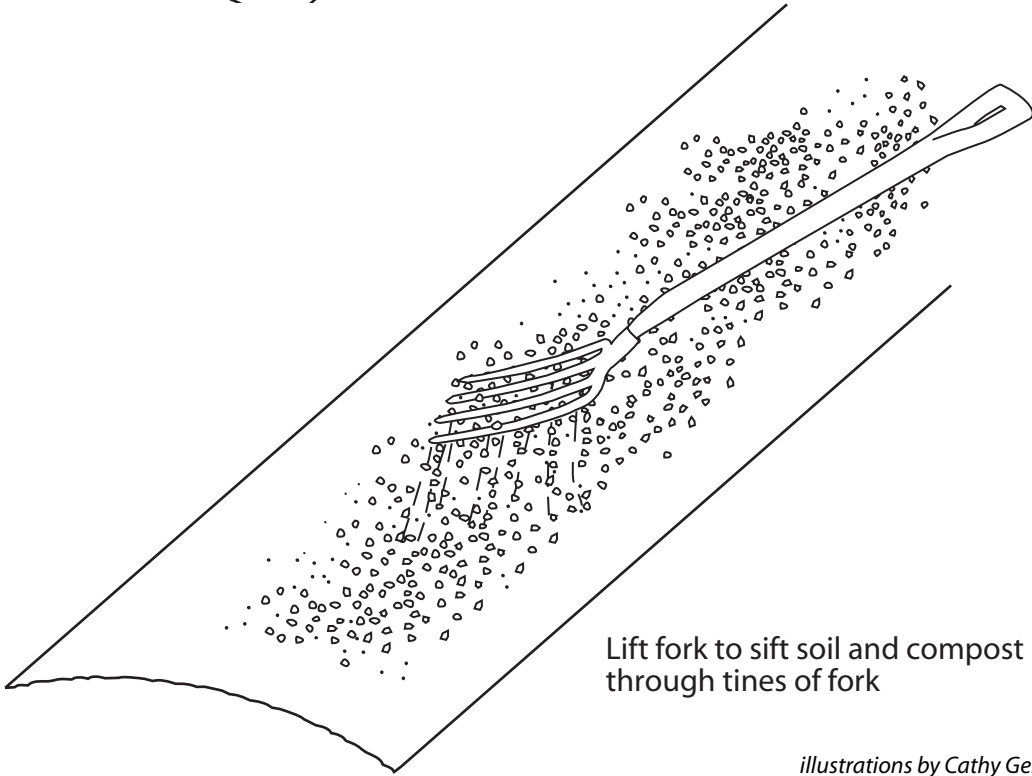
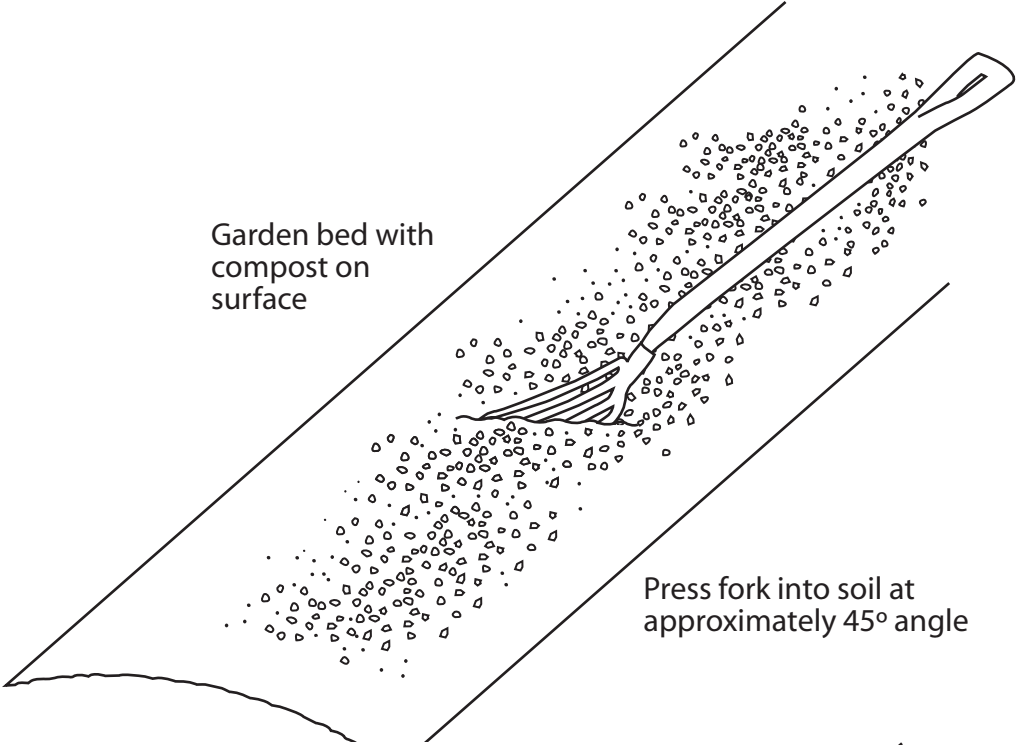
*illustrations by Cathy Genetti Reinhard; not to scale*

# Appendix 3: Double Digging Sequence



illustrations by  
Cathy Genetti Reinhard

# Appendix 4: Side Forking Technique



*illustrations by Cathy Genetti Reinhard*

# 1.3 Propagating Crops from Seed and Greenhouse Management

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# Introduction: Propagation/Greenhouse Management

## UNIT OVERVIEW

*Getting plants off to a healthy start is critical to successful crop production. This unit introduces students to the basic skills and concepts associated with the sexual propagation of crop plants. Beginning with seed and seedling biology, the first lecture introduces the cultural requirements and management practices involved in seed germination and seedling development. In the second lecture, the role and desirable characteristics of propagation media, the nature of specific soil mix ingredients, and the advantages and disadvantages of common container formats will be covered. The types of plants that are typically sexually propagated will be addressed, along with the rationale and associated costs and benefits of both passive-solar and conventional greenhouse structures. General guidelines and current resources to manage common greenhouse pests and pathogens are also reviewed. A series of demonstrations then introduces the skills involved in sowing seeds and the cultural practices used to manage passive solar greenhouses to promote successful development of organically grown seedlings.*

## MODES OF INSTRUCTION

- > LECTURE (2 LECTURES, 2 HOURS EACH)  
Lecture 1 covers seed biology, and the cultural requirements for germination. Lecture 2 addresses desirable characteristics of propagation media, common container formats, types of plants that are sexually propagated, the rationale and associated costs and benefits of solar and conventional greenhouse structures, and the prevention/management of common greenhouse pest and pathogens.
- > DEMONSTRATION 1: GREENHOUSE MANAGEMENT (1–1.5 HOURS)  
The greenhouse demonstration illustrates the way that air temperature, soil moisture, and air circulation are managed to create optimal environmental conditions for seed germination and seedling growth. Students will also be introduced to the steps used to prepare seedlings for field transplanting.
- > DEMONSTRATIONS 2–6: PROPAGATION MEDIA, SEED SOWING, TRANSPLANTING, IRRIGATION, AND SEEDLING DEVELOPMENT (1–1.5 HOURS EACH)  
The propagation demonstrations illustrate the techniques used to produce propagation media, sow seeds, transplant seedlings, and manage irrigation and seedling development.
- > ASSESSMENT QUESTIONS (0.5–1 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- Definition of sexual propagation
- Propagation media: Components, properties and ratios of materials used
- Containers: Advantages and disadvantages of commonly used formats
- Accurate documentation of propagules for trouble shooting
- Germination requirements of various crops: Seed physiology, seed treatments, temperature ranges, light, air circulation, and moisture conditions
- Physiological process of seed germination and seedling development, and its relationship to environmental conditions
- Optimal conditions for early stages of plant growth up to transplanting stage, including the hardening off process and movement of plants through facilities
- The role, timing, and tools used in supplemental fertilization
- Preventive and active pest and pathogen management

### SKILLS

- How to create propagation media
- How to sow seeds into flats and cell trays
- How to manage a greenhouse/cold frame: Maintaining optimal environmental conditions for germination and early stages of seedling growth
- How to transplant/“prick out” seedlings
- How to manage seedlings in preparation for field transplanting
- How to identify appropriate life stage for transplanting to field/garden
- When and how to deliver supplemental fertilization
- How to manage pests and pathogens: Monitoring, identification resources, and active management

# Lecture 1 Outline: Seed and Seedling Biology and Cultural Requirements

## *for the instructor*

### A. Pre-Assessment Questions

1. What conditions must be met for a seed to successfully germinate and grow into a viable seedling?
2. What are the advantages of propagating annual vegetables in a greenhouse or similar climate control structure compared to direct seeding crops?
3. Describe the optimal environmental conditions for the germination and growth of annual vegetables.
4. What are the characteristics of seedlings when ready for transplanting to the field or garden? What actions may growers take to prepare seedlings for transplanting into the garden or field?
5. What is the most effective way to manage/prevent the development of pest and diseases in a propagation facility? Where would you seek information to identify pests or pathogens and to find Organic Materials Review Institute- (OMRI-)/National Organic Program-certified active control options if pest and or diseases should affect your seedlings?

### B. Sexual Propagation

1. Definition of sexual propagation
2. Types of plants grown from seed
  - a) Annuals
  - b) Biennials
  - c) Perennials
3. Characteristics of open pollinated and hybrid seed
  - a) Open pollinated seed results in offspring closely resembling the previous generation
    - i. Self-pollinated populations
    - ii. Cross-pollinated populations
    - iii. Advantages:
    - iv. Disadvantages:
  - b) Hybrid seeds are the product of cross pollination of two different, but homogeneous inbred, stable lines
    - i. Advantages:
    - ii. Disadvantages:

### C. Seed Germination and Early Seedling Development

1. Necessary preconditions for seed germination
  - a) Viability
  - b) Physical, chemical dormancy factors must be broken
    - i. Physical dormancy (hard, thick seed coats): Can be broken by soaking, scarifying, exposure to soil microorganisms, depending on species needs



- ii. Chemical dormancy: Internal chemical/metabolic conditions that prevent seed germination until appropriate environmental conditions have been met through leaching, cold/moist stratification, fire scarification, depending on species needs
2. Environmental factors involved in germination
    - a) Temperature
    - b) Moisture
    - c) Aeration
    - d) Light
  3. Physiological steps in germination
    - a) Phase I: Imbibation
    - b) Phase II: Interim or lag phase
    - c) Phase III: Root radical emergence
  4. Early seedling development
    - a) Continued division-extension of root radical
    - b) Emergence of plumule or growing point of the shoot
    - c) Seedling weight increases, storage tissue weight decreases
    - d) Respiration and water uptake increase
    - e) Development of branched root system
    - f) Development of true leaves

#### **D. Management of Environmental Conditions During Germination, Development, and Seedling Maturation**

1. Use of propagation structures/infrastructure to optimize environmental conditions during germination
  - a) Temperatures
  - b) Air circulation
  - c) Moisture delivery
2. Continued management of environmental conditions for seedling development
  - a) Temperature management remains critical
  - b) Maintenance of good air circulation continues
  - c) Moisture delivery
  - d) Availability of light for photosynthesis
3. Seedling maturation, or hardening off through exposure to outdoor growing conditions
  - a) Day/night temperature fluctuation
  - b) No buffering from natural air circulation or prevailing wind patterns
  - c) Moisture delivery: Decrease in frequency but increase in depth/volume
  - d) Exposure to sunlight conditions comparable to field conditions

# Detailed Lecture 1 Outline: Seed and Seedling Biology and Cultural Requirements

## *for students*

### A. Pre-Assessment Questions

1. What conditions must be met for a seed to successfully germinate and grow into a viable seedling?
2. What are the advantages of propagating annual vegetables in a greenhouse or similar climate control structure compared to direct seeding crops?
3. Describe the optimum environmental conditions for the germination and growth of annual vegetables.
4. What are the characteristics of seedlings when ready for transplanting to the field or garden? What actions may growers take to prepare seedlings for transplanting into the garden or field?
5. What is the most effective way to manage/prevent the development of pest and diseases in a propagation facility? Where would you seek information to identify pests or pathogens and to find Organic Materials Review Institute- (OMRI-)/National Organic Program-certified active control options if pest and/or diseases should affect your seedlings?

### B. Sexual Propagation

1. Definition: The intentional reproduction of a new generation of plants by the germination and growth of seeds that were created in the previous generation through the fertilization of a plant ovary via the union of male and female sex cells. Results in a genetically unique plant generation.
2. Types of plants grown from seed
  - a) Annuals: Plants that germinate, grow vegetatively, flower, and produce seeds all within a single year. Sexual propagation is the only practical means of propagation.
  - b) Biennials: Plants completing their entire life cycle within two years. Growth is primarily vegetative in year one. In year two growth is directed primarily toward reproduction in response to vernalization, photoperiod, etc. Propagation by seed is the only practical means of reproducing biennial crops.
  - c) Perennials: Plants that live more than two years. Beyond the juvenile life phase, perennials grow vegetatively, flower, and produce seeds every year. The life span: three to thousands of years. Can be grown from seed. Many are reproduced asexually/vegetatively to hasten maturity, maintain genetic uniformity, and therefore retain desired morphological characteristics.
3. Characteristics of open-pollinated and hybrid seed
  - a) Open-pollinated seed: Produced when a parent plant is fertilized by another member of the same genetically stable population. Offspring bear traits or qualities that closely resemble the parent population. These seeds may come from:
    - i. Self-pollinated populations, normally of a stable homozygous genetic makeup, thus limiting problems associated with inbreeding depression
    - ii. Cross-pollinated populations, of typically heterozygous genetic makeup, which maintain their vigor and adaptability through the sharing of genetic information within a stable population

- iii. Advantages: Genetic diversity within a population provides degree of naturally occurring resistance to pathogens, climate shifts, etc. With appropriate isolation distances and population sizes, seed can be easily and inexpensively produced/saved.
  - iv. Disadvantages: In certain species uniformity, yield, overall performance may not match that of hybrid varieties
- b) Hybrid seeds: The product of cross pollination of two different, but homogeneous inbred, stable lines, each of which contribute desirable characteristics to the subsequent generation. Seeds saved from this next generation typically possess a highly heterogeneous nature and will produce offspring unlike the hybrid parent population.
- i. Advantages: Uniform characteristics throughout population (flavor, yield, pest-disease resistance, fruit quality, etc.)
  - ii. Disadvantages: Complex breeding process makes it difficult for growers to produce and save their own hybrid seeds. Though often selected for disease resistance, the genetic uniformity of a hybrid population can make them susceptible to unexpected pathogens.

### C. Seed Germination and Early Seedling Development

1. Necessary preconditions for seed germination
  - a) Viability: Seeds must contain living, healthy embryonic tissue capable of germination (see appendix 1, Seed Viability Chart)
  - b) When present, physical and chemical dormancy factors must be broken to facilitate germination
    - i. Physical dormancy (e.g., hard, thick seed coats): Can be broken by soaking, scarifying, exposure to soil microorganisms. Methods are species specific. (See Resources section for guides to propagation techniques.)
    - ii. Chemical dormancy: Growers replicate natural processes and environmental conditions to break internal chemical/metabolic conditions preventing seed germination (e.g., leaching, cold/moist stratification, fire scarification, etc.)
2. Environmental factors involved in germination
  - a) Temperature: All seeds have maximum-minimum and optimal temperature range within which germination is possible (see appendix 2, Soil Temperature Conditions for Vegetable Seed Germination)
    - i. Minimum: Lowest temperature at which seeds can effectively germinate
    - ii. Maximum: The highest temperature at which germination can occur. Above this threshold, injury or dormancy are often induced.
    - iii. Optimal temperature: The range in which germination occurs most rapidly and uniformly (see appendix 2)
  - b) Moisture: All seeds require available moisture, delivered through the soil media by capillary action, to initiate internal metabolic processes leading to germination. Field soil or propagation media should retain adequate moisture (~50%–75% of field capacity) and be of a firm, fine texture to provide good seed-to-soil contact.
  - c) Aeration: Soil/media must allow for gas exchange to and from the germinating embryo
    - i. Oxygen is required in the soil media to facilitate embryonic respiration
    - ii. Carbon dioxide, a byproduct of respiration, must be able to dissipate and move away from the seed
    - iii. Limitations on gas exchange can result from structural characteristics of the media and from poor cultural practices, especially excess moisture delivery

- d) Light
  - i. Seeds of certain species (e.g., Begonia, Primula, Coleus) require exposure to light to induce germination
  - ii. Most species germinate best under dark conditions, and in some cases (e.g., Phacelia, Allium, Phlox) germination may be inhibited by light
  - iii. Light in regards to germination requirements should not be confused with necessity of light for seedling development. All seedlings require sunlight of varying intensities for photosynthesis.
- 3. Physiological steps in germination: A three-phase process
  - a) Phase 1: Imbibation. Rapid initial uptake of water by the dry seed, softening, swelling of the seed coat.
  - b) Phase 2: Interim or lag phase. Water uptake greatly reduced while internal physiological processes begin.
    - i. Activation of mitochondria: Supporting cellular respiration
    - ii. Protein synthesis: Translation of stored RNA
    - iii. Metabolism of stored reserves to fuel development
    - iv. Enzyme production-synthesis: Loosening of cell walls
  - c) Phase 3: Root radical emergence. Initially results from cell enlargement, but soon followed by elongation of radical and cell division.
- 4. Early seedling development
  - a) Continued division-extension of root radical from base of embryo axis, and
  - b) Emergence of plumule or growing point of the shoot, from upper end of the embryo axis. Initial seedling growth follows one of two patterns, either:
    - i. Epigeous germination: Elongation of the hypocotyl, raising the cotyledons above ground where they become involved in photosynthesis, or
    - ii. Hypogeous germination: The hypocotyl does not continue to expand, and only the epicotyl emerges above ground, the cotyledons eventually ceasing involvement in metabolic activities
  - c) Overall weight of seedling increases, while weight of storage tissue decreases
  - d) Rate of respiration and water uptake steadily increases with continued cell division and elongation of roots and above-ground shoots
  - e) Development of branched root system, with continued division/elongation; root systems, except those exclusively taprooted, naturally branch, increasing surface area for uptake of water and nutrients from soil media
  - f) Development of true leaves, roughly concurrent with development of branched root system in most species, begins process of effective photosynthesis, helping to fuel continued growth

#### **D. Management of Environmental Conditions to Optimize Germination, Seedling Development, and Seedling Maturation**

- 1. Optimizing germination: Propagation structures used to manage for optimal environmental conditions (e.g., temperature, air circulation, light, and soil medium moisture)
  - a) Critical to maintain temperatures within appropriate range for chosen crops (see appendix 2)
  - b) Critical to promote adequate air circulation to mitigate against presence of fungal pathogens/"damping off" organisms
  - c) With recently sown seed and germinating seedlings, moisture delivery is typically frequent and shallow. This prevents desiccation of imbibed seeds and emerging root radicals.

2. Seedling development: Management of temperature and moisture conditions often changes from seed to seedling. Plants are often moved to alternative structures (e.g., greenhouse to hoop houses) in response to their expanding range of physiological tolerance.
  - a) Temperature management remains critical, especially when trying to extend seasonal parameters. Note: Optimal temperatures for germination and subsequent growth may differ (e.g., Brassicas) (contrast appendix 2 with appendix 5, Approximate Monthly Temperatures for Best Growth and Quality of Vegetable Crops).
  - b) Maintenance of good air circulation continues to be important to prevent disease and promote strong structural/cellular development
  - c) Moisture delivery during seedling development typically begins to decrease in frequency but increase in depth to accommodate developing root system and leaf canopy, and thus increases in transpiration rate
  - d) Availability of light for photosynthesis to manufacture nutrients and promote strong cellular growth becomes of critical importance
3. Seedling maturation and hardening off: The final step prior to transplanting. Over three days (minimum) to two weeks, seedlings are gradually exposed to conditions that most closely resemble those of the field. This process decreases the likelihood of transplant shock and promotes the accumulation of carbohydrate nutrient reserves and continued strengthening of cell walls via:
  - a) Exposure to natural day-night temperature fluctuation, promoting carbohydrate reserve buildup
  - b) Little or no buffering from natural air circulation or prevailing wind patterns, thus promoting thickening of cell walls
  - c) Moisture delivery continues to decrease in frequency but increase in depth/volume relative to specific needs of species and container type to promote maximum root development and tolerance of moisture stress
  - d) Exposure to light should also be equivalent to field conditions to build plant strength and decrease likelihood of transplant shock

# Lecture 2 Outline: Propagation Facilities, Media, and Container Formats

## *for the instructor*

### A. Propagation Facilities

1. Advantages of propagation facilities
  - a) Ability to control/modify environment (air temperature, air circulation, moisture of propagation media)
  - b) Environmental control and idealized conditions, season extension
  - c) Transplants and efficiency with seed and other resources
2. Disadvantages of propagation facilities
  - a) Added costs for infrastructure, containers, and soil media
  - b) Added labor and skills necessary
  - c) Not practical for all crops
  - d) More total days of growth
  - e) Density-concentration and risk of crop loss/damage due to pests, pathogens
  - f) Greater reliance on nonrenewable resources/materials
3. Types of propagation facilities and how environmental control is achieved
  - a) Enclosed automated greenhouses: Precise control achievable
    - i. Regulation of temperatures/air circulation by passive and active means
    - ii. Microclimatic heating
    - iii. Moisture regulation
    - iv. Solar radiation and thermal mass
  - b) Passive solar greenhouse: Good control possible
    - i. Solar radiation and thermal mass
    - ii. Use of venting systems to manage temperature
    - iii. Air circulation
    - iv. Moisture regulation
    - v. Microclimatic heating
  - c) Open hoophouse/Quonset structures: Modification of conditions possible
    - i. Temperature modification
    - ii. Air circulation
    - iii. Moisture regulation
    - iv. Initiation of hardening off process
  - d) Cold frames: Modification of environmental conditions
    - i. Temperature control: Advantages and disadvantages
    - ii. Air circulation
    - iii. Moisture delivery
    - iv. Initiation of hardening off process possible
  - e) Outdoor benches: Approximating in-ground conditions and hardening off process
    - i. Full exposure to sunlight, wind, day/night temperature flux

## B. Propagation Media and Plant Propagation

1. Role of propagation media
  - a) Create idealized structure/texture
  - b) Supply nutrients
  - c) Provide drainage
  - d) Retain moisture
  - e) Facilitate aeration
  - f) Discourage pathogens
2. Philosophical basis for propagation media
  - a) Sustainable, renewable ingredients to reduce energy use
  - b) Live, biologically active mixes to assure disease-suppressive qualities
  - c) Texture, structure, nutrients, and cultural practices to foster healthy growth
3. Conventional approach to propagation media
  - a) Drainage, aeration, moisture paramount
  - b) Sterile ingredients
  - c) Fertility: Synthetic-fertility based
  - d) Efficiency, ease of handling, lower weight for shipping and handling
4. Propagation media/ingredients: Storage and handling
  - a) Ingredients: Protect from degradation and contamination by protecting from sun and rain
  - b) Propagation mixes: Similarly protected and made in small batches
  - c) Commonly used propagation ingredients (see appendix 7, Sample Soil Mix Recipes)
    - i. Peat moss/coir fiber
    - ii. Perlite
    - iii. Vermiculite
    - iv. Sand
    - v. Compost
    - vi. Soil
5. Supplemental fertility
  - a) Uses
    - i. To compensate for nutrient deficiencies
    - ii. To stimulate biological activity and nutrient liberation
    - iii. To alleviate plant stress
    - iv. As a growth accelerant
  - b) Potential concerns
    - i. Leachability of nutrients
    - ii. Input cost
    - iii. Additional labor, filtration, application tools
    - iv. Possibility of nitrogenous, pest-susceptible growth
    - v. Philosophic compromise: Over reliance on concentrated fertilizers
  - c) Organic sources of supplemental fertilizers for propagation (see Resources section for OMRI-certified supplemental fertilizers; see Fertilizers Solutions Chart in Unit 1.11, Reading and Interpreting Soil Test Reports)
    - i. Fish emulsions and soluble fish powders for N-P-K (~4N-2P-2K)
    - ii. Kelp extracts for micro nutrients and growth stimulants
    - iii. Worm castings tea (dilute N-P-K and disease suppression)

- iv. Compost tea (dilute N-P-K and disease suppression)
- v. Other supplemental liquid fertilizers accepted under OMRI/National Organic Program standards
- d) Modes of application
  - i. Dry ingredients are blended into mixes
  - ii. Soil-based application with irrigation, i.e. “fertigation”
  - iv. Foliar spray

### C. Container Formats (see appendix 3, Examples of Propagation Containers)

1. Cell/plug trays
  - a) Advantages
  - b) Disadvantages
2. Traditional wooden flats
  - a) Advantages
  - b) Disadvantages

### D. Pests and Pathogens in Propagation Facilities

1. Preventive measures
  - a) Sanitation of tools, facilities
  - b) Propagation media as sources of contamination or disease suppression
    - i. Biologically active, disease-suppressing media
    - ii. Sterile, soilless media
    - iii. Utilize heat/steam and solar pasteurization
  - c) Seed/plant stock as source of contamination
    - i. The use of disease-free seed/propagules
    - ii. Seed pretreatment
2. Good cultural practices
  - a) The use of pest/disease-resistant varieties
  - b) Growing crops at appropriate seasonal junctures
  - c) Managing environmental conditions to mitigate against pathogens and for optimal plant growth
    - i. Temperatures
    - ii. Moisture management
    - iii. Air circulation
    - iv. Fertility management
3. Management for the early detection and treatment of pest/disease problems
  - a) Identification of pests and pathogens (see Resources section)
  - b) Establish tolerance thresholds for active treatments
  - c) Monitor at regular frequency: Plant observations, sticky traps, etc.
  - d) Rogue, cull, or quarantine infected crops and/or
  - e) Use of certified organic chemical or biological controls (see Resources section)
4. Common greenhouse pests and pathogens and their management for your area include
  - a) Pests:
  - b) Pathogens:
5. Other resources
  - a) Consulting with local growers regarding pest management strategies





# Detailed Lecture 2 Outline: Propagation Facilities, Media, and Container Formats

## *for students*

### **A. Propagation Facilities**

1. Advantages
  - a) Ability to control/modify environment
    - i. Temperature
    - ii. Air circulation
    - iii. Moisture delivery
  - b) Environmental control gives grower ability to:
    - i. Optimize growing conditions
    - ii. Extend parameters of growing season, early and late
    - iii. Produce vigorous/healthy transplants that can withstand pest pressure and variable weather conditions
    - iv. Avoid conditions wherein some seeds, especially large-seeded crops, are vulnerable to rotting in cold, wet soils
  - c) Transplants and efficiency
    - i. Efficient use of seed: Higher germination percentage under optimal conditions
    - ii. Efficient use of space and water: High plant density, concentration of resources
    - iii. Reduced growing time in ground: Early development in propagation site, thus allowing multi-cropping in same plot of ground. Increases likelihood that slow-maturing crops can complete life cycle in short-season areas.
2. Disadvantages
  - a) Added costs
    - i. Requires capital outlay for infrastructure construction and upkeep
    - ii. Requires capital outlay for containers and soil mix/ingredients
  - b) Labor
    - i. Additional labor especially early in season; significant time may be required to manage plants/facilities depending on diversity of crops and technology of system
    - ii. Sophisticated skills necessary to create/maintain idealized growing conditions
    - iii. Sowing and then transplanting requires an additional step (two steps if also pricking out seedlings)
  - c) Transplanting not practical or effective for all crops
  - d) Transplanting, in most cases, requires more total days of growth
  - e) Density of plants carries potential risk of crop loss/damage from pests/disease
  - f) Greater reliance on nonrenewable resources/materials
    - i. Greenhouse coverings: Plastics
    - ii. Containers: Plastics, styrofoam
    - iii. Soil media, mined resources: Peat, sand, perlite, vermiculite (see appendix 6, Propagation Media—Ingredients and Properties Imparted)
    - iv. Temperature regulation: Non-passive systems consume fossil fuels

3. Types of propagation facilities and how environmental control is achieved
- a) Enclosed (semi) automated greenhouses: Precise environmental control achievable
    - i. Characterized by ability to fully close growing environment, regulate temperatures/ air circulation through passive and active venting and air movement, heating/cooling by fans, furnaces, swamp cooler, etc.
    - ii. Microclimatic heating in root zone to optimize conditions via hot water pipes or electric cables on bench tops below containers
    - iii. Moisture regulation: Delivery by automated or manually controlled sprinkler systems
    - iv. Trapping solar radiation as secondary heating method
  - b) Passive solar greenhouse: Good environmental control is possible
    - i. Trapping solar radiation as primary means of warming
    - ii. Use of venting systems to affect cooling, drawing in cooler external air, exhausting warmer internal air
    - iii. Air circulation, exchange achieved by manually (typically) controlled venting design
    - iv. Moisture regulation/delivery totally under control of grower through hand delivery, manual, or automated delivery systems
    - v. Use of microclimatic heating also possible, practical with available power supply
  - c) Open hoophouse/Quonset hut structures: Give ability to partially modify existing environmental conditions
    - i. Modification of temperatures: Umbrella-like coverage creates slightly warmer day and night conditions
    - ii. Slight buffering against effects of wind, but no control over air circulation except by location of structure
    - iii. Grower still assumes full control over moisture regulation, delivery through same means as in greenhouses
    - iv. Exposure of plants to wind and greater day-night temperature fluctuation begins process of hardening off
  - d) Cold frames: Can be used like small-scale greenhouse and hoophouse facilities to modify environmental conditions
    - i. Ability to quickly heat internal air during daytime and to buffer against cold nighttime temperatures, but small air mass has limited capacity to protect and is prone to rapid temperature shifts
    - ii. Air circulation achieved through opening of frame, passive air exchange; danger of cold frame becoming too hot and humid if not vented in a timely manner
    - iii. Moisture delivery totally under grower control, usually by hand
    - iv. Through greater venting, thus more air flow, and day-night temperature fluctuation, grower can initiate hardening off process
  - e) Outdoor benches: Closely approximating in-ground conditions, completing hardening off process
    - i. Full exposure to sunlight, wind, and fluctuations in temperature stimulates the building of carbohydrate reserves and strengthening of cell walls

## B. Propagation Media and Plant Propagation

1. Role of propagation media
  - a) To provide idealized environment, suitable texture/structure to provide support/anchorage and foster healthy seedling development
  - b) Media components to supply necessary nutrients
    - i. Compost
    - ii. Soil
    - iii. Organic matter amendments and fertilizers: e.g., blood meal (N), bone meal (P)
    - iv. Mineral amendments: e.g., lime (Ca), soft rock phosphate (P), greensand (K), etc.
  - c) Media must provide adequate physical properties for drainage to prevent development of fungal pathogens, rotting roots, accomplished through the use of:
    - i. Sand
    - ii. Perlite
    - iii. To a lesser extent, drainage also provided by compost, vermiculite, peat moss, leaf mold (partially decomposed leaf litter)
  - d) Media must also allow for moisture retention, accomplished through the use of:
    - i. Compost
    - ii. Peat moss/coir fiber
    - iii. Vermiculite
    - iv. Leaf mold
    - v. To a lesser extent, moisture retention also provided by soil, sand, perlite
  - e) Media must also facilitate aeration, allowing soil pore spaces to exchange O<sub>2</sub> and CO<sub>2</sub>. This is accomplished through the addition of:
    - i. Perlite
    - ii. Sand
    - iii. Vermiculite
    - iv. Leaf mold
    - v. To a lesser extent by peat, coir fiber, and coarse composts
  - f) Media should be pathogen-free and with proper cultural practices not be conducive to pathogen development
2. Philosophical basis for propagation media
  - a) Emphasis on non-toxic, naturally occurring, renewable, non-extractive ingredients
  - b) Live, biologically active mixes, reliant principally on natural processes, diverse soil organisms to:
    - i. Release necessary nutrients
    - ii. Keep diseases in check
  - c) Texture, structure, nutrient supply combined with cultural practices are intended to foster healthy, uninterrupted growth
3. Conventional propagation media
  - a) Drainage, aeration, moisture retention still paramount but concern over energy required to produce mix is lower priority
  - b) Sterile ingredients are used to prevent pathogens
  - c) Fertility through liquid-soluble, granular, petrochemical-based sources
  - d) Efficiency, ease of handling and transport are prioritized through the use of lightweight ingredients such as peat, vermiculite

4. Media/ingredients storage and handling
  - a) Ingredients should be protected from degradation by sun, wind, rain, extreme temperatures, and stored away from potential pathogen sources in cool, well-aerated storage area
  - b) Mix media should be similarly protected and blended in small batches for near-term use. Long-term storage can lead to compaction, loss of structural properties, and diminished nutrient supply.
5. Supplemental fertility
  - a) Conditions when necessary
    - i. To compensate for poor quality, nutrient-deficient ingredients, especially immature or older, poorly stored compost
    - ii. To promote biological activity, nutrient release
    - iii. To alleviate stress, especially in cell-type containers when plants are past optimal transplant stage or showing signs of nutrient deficiency
    - iv. As growth accelerator—when trying to stimulate plant growth for a specific plant-out or sale date
  - b) Potential concerns
    - i. Possible leaching of nutrients, e.g., fish emulsion
    - ii. Input cost can be significant
    - iii. Additional labor for application, need for filtration, application tools
    - iv. Possibility of promoting highly nitrogenous, pest-susceptible growth in plants
    - v. Overreliance on highly soluble nutrient inputs
  - c) Organic sources of supplemental fertilizers for propagation (see resources section for OMRI-/NOP-certified supplemental fertilizers; see Fertilizers Solutions Chart in Unit 1.11, Reading and Interpreting Soil Test Reports)
    - i. Fish emulsions and soluble fish powders for N-P-K (~4N-2P-2K)
    - ii. Kelp extracts for micro nutrients and growth stimulants
    - iii. Worm castings tea (dilute N-P-K and disease suppression)
    - iv. Compost tea (dilute N-P-K and disease suppression)
    - v. Other supplemental liquid fertilizers accepted under OMRI/NOP standards
  - d) Modes of application
    - i. Blended into mixes at time of mix making, requires advance knowledge of need, useful with meals and powdered ingredients, typically slow acting
    - ii. Soil application, i.e. “fertigation”: Useful quick-fix approach to address nutrient deficiencies. Uses readily available, water-soluble nutrients, delivered with irrigation to root zone
    - iii. Foliar spray: Direct application to leaf stomata, another quick fix approach, with soluble nutrients

### **C. Container Formats** (see appendix 3, Examples of Propagation Containers)

1. Cell/plug type trays: Provide grower with many options in size, shape of cells. Key is to match nature of container with appropriate media, size of desired transplant, and available propagation space.
  - a) Advantages to cell/plug formats
    - i. High plant density per square foot
    - ii. Limited consumption of soil media
    - iii. Individual units readily separable for transplanting
    - iv. Little/no root disturbance with proper root knit, thus little/no transplant shock
    - v. Roots “air pruned,” promoting early branching

- b) Disadvantages of cell/plug format
  - i. Limited soil volume equals limited nutrient supply, thus increasing possible need for supplemental fertility
  - ii. Limited soil volume equals limited root run, narrows window of opportunity for optimal transplant timing
  - iii. Limited soil volume increases necessary watering frequency
  - iv. Some plug trays don't provide adequate drainage
  - v. Potential for root spiraling in non-"speedling" style trays
  - vi. Trays constructed from nonrenewable resources, i.e., plastic/styrofoam
- 2. Traditional wooden propagation flats
  - a) Advantages
    - i. Format provides large root run and this longer window of opportunity can grow large, vigorous starts resistant to pest and disease pressure, and tolerant of weather variables
    - ii. Substantial nutrient supply per plant
    - iii. Less frequent watering needs
  - b) Disadvantages
    - i. Format requires large volume of soil media, and thus increased cost
    - ii. Lower plant density
    - iii. Flats are heavy, requiring more labor
    - iv. Greater potential for root disturbance, transplant shock

#### **D. Pests and Pathogens in Propagation Facilities**

1. Management program begins prior to propagation with preventive measures, identifying and eliminating possibility of contamination
  - a) The propagation facilities: Pots, flats, hand tools, hoses, benches can all harbor plant pathogens. Sanitation measures include cleaning or disinfecting materials and facilities.
  - b) Propagation media can be another source of contamination, especially for soil borne bacteria/fungi. The grower can:
    - i. Use biologically active, disease-suppressing media, or
    - ii. Sterile, soilless media, or
    - iii. Use heat/steam and solar pasteurization methods to sterilize media
  - c) Seed/plant stock can also be a source of contamination. The grower can protect against this potential by:
    - i. Using seed/propagule material that is certified to be disease free
    - ii. Using seed pretreatment techniques such as hot water baths
  - d) Exclusion of pests from growing environment
    - i. Screening at all points of entry
    - ii. Floating row covers over cell trays
2. Good cultural practices are a critical component in the management/prevention of pest/disease challenges
  - a) Select pest- and disease-resistant varieties and avoid crops vulnerable to known potential problems. Check with local growers and extension agents.
  - b) Grow crops at appropriate seasonal junctures to facilitate healthy, vigorous, pest- and disease-resistant growth

- c) Manage environmental conditions to mitigate against the presence of pests/disease and promote vigorous, uninterrupted growth. This includes control of:
  - i. Temperatures, especially in the prevention of damping off organisms, which thrive in the 68°F to 86°F range and constantly moist conditions. While the temperate range conducive to crop growth parallels that which promotes damping off organisms, their presence can be reduced or eliminated by managing for appropriate moisture fluctuations in growing media.
  - ii. Moisture management: The timing and quantity of moisture delivered are also important. Excess soil moisture and poor drainage can reduce plant vigor and increase susceptibility. Wet-to-dry swings in soil moisture can be effective in preventing conditions that promote damping off and other fungal organisms.
  - iii. Air circulation, or oxygen exchange within the greenhouse, is also critical in the prevention of pathogen buildup, and aids in temperature flux and soil drying
  - iv. Fertility management: In concert with other cultural practices, adequate but not excessive soil fertility promotes healthy, uninterrupted growth (see appendix 7, Sample Soil Mix Recipes)
- 3. Management also includes monitoring and early detection of pest/disease problems to minimize crop loss and minimize need for intervention
  - a) Identification of pest/disease (see Flint 1998; Dreistadt 2001; [www.ipm.ucdavis.edu](http://www.ipm.ucdavis.edu))
  - b) Establish tolerance thresholds to initiate control actions
  - c) Monitor at regular frequency: Plant observations, sticky traps, etc.
  - d) Roguing (culling), or quarantining infected crops
  - e) Use of organically acceptable chemical controls, or biological control agents (see Flint 1998; Dreistadt 2001; [www.ipm.ucdavis.edu](http://www.ipm.ucdavis.edu))
- 4. Common greenhouse pests and pathogens and their management (see Flint 1998)
  - a) Pests
    - i. Aphids
    - ii. Scales
    - iii. Mealybugs
    - iv. Whiteflies
    - v. Cabbage loopers
    - vi. Flea beetles
    - vii. Mites
  - b) Pathogens
    - i. Damping off fungi
    - ii. Powdery mildews
    - iii. Downy mildews
    - iv. Root rot: Rhizoctonia, Pythium
    - v. Crown rot: Erwinia
    - vi. Rusts
- 5. Additional resources
  - a) The use of local growers as resources: The above-listed pests and pathogens can typically be found throughout the country. Speaking with local growers, cooperative extension agents, and IPM practitioners is an essential step in researching what problems to anticipate, their severity, and the probable times of year to be especially vigilant.

# Demonstration 1: Greenhouse Management

## *for the instructor*

### **OVERVIEW**

*This demonstration provides students with an understanding of the working components of the greenhouse facility and the tools available to manage environmental conditions that best meet the needs of pre-emergent and seedling crops in the facility. Students should become familiar with the fundamental skills and concepts to create ideal growing conditions, such as temperature and air circulation management.*

### **PREPARATION AND MATERIALS**

- A working greenhouse structure where the essential management tools and techniques can be discussed and demonstrated
- Thermometer and appendix 11, Greenhouse Records Sheet, to show current conditions and records of recent temperature fluctuations
- Thermometers positioned in different microclimatic zones (if applicable) to show how differences can be used to meet different plant needs under a single management regimen

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

1 hour

### **DEMONSTRATION OUTLINE**

#### **A. Managing Greenhouses**

1. Discuss and demonstrate orientation of greenhouse (i.e., solar aspect)
2. Discuss and demonstrate methods for air circulation via venting, fans, etc.
3. Discuss and demonstrate temperature management
  - a) Ideal temperature ranges (see appendix 2)
  - b) How heat is retained
  - c) The use of thermal mass in heat retention
  - d) Techniques for evaporative cooling
  - e) The role of venting in maintaining ideal temperature, humidity, and gas exchange
  - f) Active heating systems
4. Use of microclimates within greenhouse
5. Discuss and demonstrate record keeping in the greenhouse (see appendix 11, Greenhouse Records Sheet)
  - a) Date
  - b) Previous high/low
  - c) Current temperature
  - d) Weather description
  - e) Description of environmental conditions in greenhouse





# Demonstration 2: Propagation Media

## *for the instructor*

### **OVERVIEW**

*Students will examine both unblended propagation ingredients and the completed propagation media. By looking at the individual ingredients, finished propagation media, and typical garden soils in containers, students will see the components of propagation media that are critical to creating proper drainage, aeration, and moisture retention. The instructor should also emphasize the importance of proper moisture in propagation media so that root-to-soil and/or seed-to-soil contact can be achieved with only minimal additional water inputs. Instructors should be certain to discuss the importance of proper storage and handling of media to maintain fertility and protect against contamination by pathogens.*

### **PREPARATION AND MATERIALS**

1. Have both wet and dry samples of several possible raw ingredients that are used in propagation media: compost, soil, sand, perlite, vermiculite, composted wood chips, grape seed pumice, peat moss, and coir fiber, etc.
2. Have wet and dry samples of the media commonly used in your operation and perhaps others such as the Cornell Peat Lite Mix and the UC Potting Mix (see Resources section) and/or commercial propagation media for comparison.
3. Assemble necessary tools (flat head shovels, wheelbarrows) and hoses to supply moisture.
4. Assemble ingredients to make the desired mix of ingredients

### **PREPARATION TIME**

1.5 hours

### **DEMONSTRATION TIME**

1.5 hours

### **DEMONSTRATION OUTLINE**

#### **A. Propagation Media**

1. Review desirable characteristics of propagation media
2. Review individual media constituents and properties imparted by each
  - a) Show ingredients that provide nutrients (N, P, K, and micronutrients)
  - b) Show ingredients that promote drainage and aeration
  - c) Show ingredients that serve to retain moisture
3. Demonstrate the techniques of blending materials to create homogenized media
4. Assess and adjust media for appropriate moisture
5. Discuss use and proper storage techniques for propagation media



# Demonstration 3: Sowing Seed

## *for the instructor*

### **OVERVIEW**

*In this demonstration students should observe and participate in sowing a variety of different seed types and sizes in both cell trays and wooden flats. Students will review the advantages and disadvantages of each format and why certain crops may be better suited to a particular method. In this session, a discussion and look at various seed sizes will illustrate the importance of sowing seeds to appropriate depths to ensure a high percentage of germination and seedling survival.*

### **PREPARATION AND MATERIALS**

1. Assemble a selection of different cell/plug trays.
2. Assemble wooden flats suitable for seed sowing.
3. Bring both large (sunflowers, squash, etc.) and small seeds (lettuce, larkspur, snapdragon, etc.) to illustrate the range of seed sizes.
4. Bring any mechanical seeding devices such as sliding plate seeders and seeds appropriate to their use.

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

1 hour

### **DEMONSTRATION OUTLINE**

#### **A. Seed Sowing Techniques**

1. Demonstrate container-filling techniques
2. Discuss the advantages and disadvantages of each container format (see appendix 3)
3. Demonstrate sowing and coverage techniques (see appendix 1)
  - a) Discuss and demonstrate techniques for broadcasting and drilling seed into flats, including proper depth
  - b) Discuss the significance of seed density as it relates to potential future competition and timing of pricking out
  - c) Discuss and demonstrate sowing by hand into cell type trays
  - d) Discuss and demonstrate sowing into cell trays with a sliding plate seeder or other mechanisms
4. Discuss labeling and record keeping and their importance in maintaining variety distinctions, trouble shooting, and future crop planning (see appendix 10)
5. Discuss and demonstrate watering-in techniques
6. Discuss and demonstrate optimal min/max germination temperatures (see appendix 2)
7. Discuss days to germination at varying temperatures (see appendix 4)
8. Discuss and demonstrate optimal post-germination growing temperatures for seedlings (see appendix 5)



# Demonstration 4: Transplanting or “Pricking Out” *for the instructor*

## OVERVIEW

*This demonstration illustrates the technique of transplanting immature seedlings from a high-density flat format to a lower-density format. The importance of doing this work under appropriate environmental conditions (low light levels, low temperatures, high relative humidity, and still air/low wind velocity) cannot be overemphasized. Students will have the chance to look at plant development and its relevance to successful transplanting or “pricking out” in the greenhouse setting. Be sure to emphasize the significance of seedling density and proper timing of pricking out to prevent undue competition for resources and to prevent diseases.*

## PREPARATION AND MATERIALS

1. Have plants available for visual inspection that only show taproot development.
2. Gather plants that have initiated a branched root system suitable for pricking out.
3. Have plants showing signs of overdevelopment that would make pricking out more difficult.
4. Have undersown (very low-density) flats to illustrate inefficient use of space as well as the wider window of opportunity possible when young plants are not competing for resources.
5. Have oversown flats illustrating the effects of competition and the imperative of moving swiftly to prevent disease and alleviate the effects of nutrient stress.
6. Have flats sown at appropriate density to demonstrate best use of space and proper timing for movement.
7. Have plants of basal rosette nature (e.g., statice, *Limonium sinuatum*) and upright nature (e.g., snapdragons, *Antirrhinum majus*) to discuss and demonstrate appropriate planting depth relative to seedling architecture and physiological adaptations such as adventitious rooting.

## PREPARATION TIME

1 hour

## DEMONSTRATION TIME

1.5 hours

## **DEMONSTRATION OUTLINE**

### **A. Transplanting and Pricking Out Techniques (see appendix 8)**

1. Review/discuss environmental conditions appropriate to plant handling
2. Discuss and demonstrate stages of plant development appropriate for pricking out
3. Discuss and demonstrate plant root systems appropriate for pricking out
4. Discuss and demonstrate the significance of seedling density relative to timing of pricking out
5. Discuss and demonstrate proper/gentle handling techniques when dealing with young/easily injured seedlings
6. Discuss and demonstrate techniques for watering-in transplants
7. Discuss labeling and record keeping and their importance in maintaining variety distinction, trouble shooting, and future crop planning (see appendix 10)
8. Discuss considerations for post-transplant care

# Demonstration 5: Greenhouse Irrigation

## *for the instructor*

### **OVERVIEW**

*In this demonstration, students will learn about the various tools and techniques used to deliver water to pre-emergent seeds and seedlings in a given propagation facility. Emphasis should be placed on creating optimal soil moisture conditions to facilitate healthy plant growth through proper irrigation frequencies and volumes of water applied. You should also discuss the advantages and disadvantages of the systems and tools used.*

### **PREPARATION AND MATERIALS**

- All irrigation equipment commonly used in the propagation facility (e.g., hoses, watering cans, fixed spray nozzles, irrigation timers and solenoid control valves, mist systems, etc.)
- Recently sown seeds in flat and cell tray format
- Seedlings in flat and cell tray format

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

1 hour

### **DEMONSTRATION OUTLINE**

#### **A. Irrigating Seeds and Seedlings**

1. Discuss and demonstrate irrigation techniques prior to seedling emergence with attention to the differences in wet-to-dry swing for large- and small-seeded crops
2. Discuss and demonstrate irrigation techniques used for post-seedling emergence and early seedling development
3. Discuss the typical changes in frequency and volume of water delivered during seedling development (i.e., from pre-germination—frequent, shallow applications—to lower frequency, greater volume of water supplied as seedlings mature)
4. Discuss and demonstrate any necessary adjustments needed based on germination, disease or pest problems, and/or plant growth observations
5. Emphasize the importance of paying extra attention to corners and edges of greenhouse; these are often overlooked





# Demonstration 6: Seedling Development and the “Hardening Off” Process

## *for the instructor*

### **OVERVIEW**

*This demonstration shows students how to prepare seedlings for field transplanting.*

### **PREPARATION AND MATERIALS**

- Seedlings at varying stages of maturity

### **PREPARATION TIME**

0.5 hour

### **DEMONSTRATION TIME**

0.5 hour

### **DEMONSTRATION OUTLINE**

#### **A. The Hardening Off Process**

1. Define the hardening off process and its role in seedling maturation and survival
2. Discuss characteristics of seedling maturity (see appendix 9)
3. Discuss regional importance and influence on duration of hardening off process. Greater temperature differences between greenhouse and field conditions will require a longer hardening off period.
4. Discuss and demonstrate the various propagation structures and techniques used in the hardening-off progression
  - a) Highly controlled environment of greenhouse settings
  - b) Partially moderated conditions: Hoophouses
  - c) Outdoor benches approximating field conditions
5. Provide examples of seedlings prepared for transplanting







# Assessment Questions Key

- 1) List two pre-conditions that must be met for seed germination and four environmental conditions that must be achieved for optimal seed germination.

*Pre-conditions:*

- *Viable seed*
- *Dormancy factor released*

*Necessary environmental conditions for seed germination and role of each:*

- *Optimal temperature range: To increase the rate of respiration*
- *Optimal moisture range: To soften seed coat and increase the rate of respiration*
- *Aeration: To provide adequate air circulation for supplying oxygen used in respiration and remove carbon dioxide produced during respiration*
- *Light: Though not needed for germination of all seeds, light stimulates increased respiration in some plants*

- 2) What is the optimal average daytime temperature range that should be maintained in the greenhouse for the germination and early growth of most annual vegetables and cut flowers? What would be the minimum nighttime temperature?

- *Optimal average temperature range is between 65-85°F. (The average optimal germination temperature for most vegetables and cut flowers is 82°F. Please see appendix 2 for specific minimum, maximum, and optimal germination temperatures.)*
- *Minimum nighttime temperature should not dip below 55°F*

- 3) List four advantages of the use of greenhouse-raised transplants over direct seeding of crop plants. Describe two disadvantages.

*Advantages of transplants:*

- *Season extension*
- *Ability to manage environmental conditions: Temperature, moisture, air circulation and growing media*
- *Crop selection*
- *Ability to intensively manage large numbers of plants in a small area*
- *Efficient use of seed, water and space*

*Disadvantages of transplants:*

- *Additional infrastructure costs*
- *Additional skill and labor required*
- *Not all crops grow or transplant well from containers*
- *Additional non-renewable resource use*
- *Often results in more total days of growth*

- 4) Why is the careful selection of crop varieties important?

- *To help assure disease resistance*
- *To help assure good crop performance in different climates or micro-climates*
- *To help assure other crop qualities such as storage, visual aesthetics, flavor, etc.*

- 5) What are four important qualities of a propagation mix? List two propagation mix constituents that may be used to assure each of the previously listed qualities.

- *Drainage. Constituents that impart this quality: Perlite, sand, soil, leaf mould, gravels and lava rock, and to a lesser extent, vermiculite, compost, peat moss, and coir fiber*

- *Aeration. Constituents that impart this quality: Perlite, sand, soil, leaf mould, gravels and lava rock, and to a lesser extent, vermiculite compost, peat moss and coir fiber*
- *Density. Constituents that impart this quality: Sand, soil, gravel, compost, and leaf mould*
- *Nutrient availability. Constituents that impart this quality: Compost, soil, mineral and organic matter amendments, and leaf mould*
- *Water-holding capacity. Constituents that impart this quality: Compost, peat moss and coir fiber, vermiculite*

6) What pieces of information are commonly documented in the propagation process and why?

- *Genus and species of crop*
- *Variety of crop*
- *Date sown*
- *Date pricked out (if applicable)*
- *Seed company name*
- *Seed lot (year seed was produced for)*

*Why: The above would provide adequate information for future trouble shooting and the selection of crops during variety trials*

7) What is the "hardening off" process?

*The gradual exposure and acclimation of greenhouse-raised transplants to the environmental conditions of the field.*

8) List two characteristics of cell-tray-grown seedlings at transplanting maturity.

- *Second set of true leaves initiated*
- *Root knit*

9) List two necessary steps for preparing seedlings before transplanting them to the field or garden.

- *Pre-moistened to 75% field capacity*
- *Hardened-off for 3–21 days*

10) List the environmental conditions most favorable for the successful bare-root transplanting/ pricking out seedlings grown in a flat format.

- *Low light levels*
- *Low temperatures*
- *Low wind velocity*

11) Describe four preventive measures and two active measures used to control fungal plant pathogens in greenhouse facilities.

*Preventive measures:*

- *Proper sanitation of propagation media, facilities, and containers*
- *The selection and use of disease-resistant varieties*
- *The selection and use of climate-appropriate varieties*
- *The use of disease-free seed stock*
- *Management of environmental conditions of greenhouse (air circulation, temperature, light) and propagation media (moisture, aeration, nutrients) within the optimal range. Good cultural practices.*
- *Monitoring*

*Active measures:*

- *Roguing affected crops*
- *Biological control*
- *The use of acceptable chemical controls*

# Resources

## PRINT RESOURCES

Bunt, A. C. 1988. *Media and Mixes for Container Grown Plants*. Boston, MA: Unwin Hyman.

*Extensive information on the creation of container mixes and managing fertility, principally by conventional means.*

Deno, Norman. 1994. *Seed Germination Theory and Practices*. Self published, State College, PA.

*Important reference on principles of seed germination and the utilization of specific techniques for a wide array of cultivated crops.*

Dreistadt, Steve, and Mary Louise Flint. 2001. *Integrated Pest Management for Floriculture and Nurseries*. Publication 3402. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Outstanding new resource for developing a pest management program.*

Flint, Mary Louise. 1998. *Pests of the Garden and Small Farm and Garden: A Grower's Guide to Using Less Pesticide, Second Edition*. Publication 3332. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Excellent tool for the identification of common greenhouse pests and pathogens.*

Flint, Mary Louise, and Steve Dreistadt. 1998. *Natural Enemies Handbook: The Illustrated Guide to Biological Pest Control*. Publication 3386. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A valuable resource for biological control of pests and pathogens.*

Hanan, Joe. 1998. *Greenhouses: Advanced Technology for Protected Horticulture*. Boston, MA: CRC Press.

*Exhaustive reference on all aspects of greenhouse design and management, written principally from a conventional perspective, but with much valuable information for the organic grower.*

Hartmann, Hudson, Dale Kester, Fred Davies, Jr. and Robert Geneve. 1997. *Plant Propagation: Principles and Practices, Sixth Edition*. Upper Saddle River, NJ: Prentice Hall.

*The standard reference tool for propagators, covering all aspects of sexual and asexual propagation, principally from a large-scale, conventional focus.*

Johnston, Robert Jr. 1983. *Growing Garden Seeds*. Albion, ME: Johnny's Selected Seeds.

*Brief but valuable reference on seed viability and seed production strategies.*

Jozwik, Francis. 1992. *The Greenhouse and Nursery Handbook*. Mills, WY: Andmar Press.

*Good general information for small- to medium-scale growers.*

Maynard, Donald and George Hochmuth. 1997. *Knott's Handbook for Vegetable Growers*. New York: John Wiley & Sons.

*The standard reference for field -scale vegetable production, but also provides many valuable charts on seed viability, germination temperatures, days to germination, etc.*

Milne, Lorus and Margery. 1980. *National Audubon Society Field Guide to North American Insects and Spiders*. New York: Alfred A. Knopf.

*Great visual reference for identifying both beneficial and pest species.*

Olkowski, William, Sheila Daar, and Helga Olkowski. 1991. *Common Sense Pest Control*. Newtown CT: Taunton Press.

*Excellent reference for non-toxic pest control strategies geared both for homeowners and production-oriented growers.*

Styer, Roger, and David Koranski. 1997. *Plug and Transplant Production*. Batavia, IL: Ball Publishing.

*Excellent discussion on soils and containers and detailed information on managing environmental conditions for vegetable and cut flower transplants.*



Thompson, Peter. 1992. *Creative Propagation*. Portland, OR: Timber Press.

*Very user-friendly guide to growing plants from seed, cuttings, and divisions.*

Walls, Ian. 1996. *The Complete Book of the Greenhouse*. London: Ward Lock.

*Geared toward small-scale and backyard growers, this book provides good information on greenhouse design and management tools.*

Yamaguchi, Mas. 1983. *World Vegetables*. New York: Van Nostrand Reinhold.

*Invaluable resource on the history and origins of major world vegetable crops and their cultural requirements.*

#### WEB RESOURCES

Appropriate Technology Transfer for Rural Areas

[www.attra.org](http://www.attra.org)

*ATTRA provides excellent information on soil mixes for containers, transplant production, amendments, supplemental fertilizers, compost tea and much more.*

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil,*

*crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

Integrated Pest Management, UC Davis

[www.ipm.ucdavis.edu](http://www.ipm.ucdavis.edu)

*Excellent resource for insect identification and non-chemical control strategies, as well as links to other sites concerned with pests and pathogens.*

Soil Foodweb

[www.soilfoodweb.com](http://www.soilfoodweb.com)

*Initiated by Dr. Elaine Ingham, Soil Foodweb Inc. is a clearinghouse for information and research summaries on soil ecosystem process and a product, services and resource for how to grow crop plants without the use of pesticides or inorganic fertilizers. Includes how-to manuals on the production of compost teas.*

#### SUPPLIERS

Johnny's Selected Seeds

(207) 437-4395, [www.johnnyseeds.com](http://www.johnnyseeds.com)

*Good selection of vegetable and flower seed, with excellent cultural information.*

MC Development Sales

(800) 511-6151, [www.developmentsales.com](http://www.developmentsales.com)

*Large distributor of greenhouse and propagation supplies.*

Peaceful Valley Farm Supply

PO Box 2209, Grass Valley, CA

(888) 784-1722, [www.groworganic.com](http://www.groworganic.com)

*Suppliers of Plantel and Speedling trays, and fertility amendments.*

Speedling

PO Box 7238, Sun City, FL 33586

(800) 426-4400

*Source of Speedling trays.*

Stuppy Greenhouse Manufacturing

1212 Clay Road, North Kansas City, MO 64116

(800) 733-5025, [www.stuppy.com](http://www.stuppy.com)

*Source of greenhouses and greenhouse supplies.*

# Glossary

## Aeration

*To add oxygen*

## Annual

*A plant that completes its life cycle (germination through death) in one year or growing season, essentially non-woody*

## Asexual propagation

*Propagation by vegetative means, rather than by seed. Not sexual, i.e., not involving the fusion of male and female sex cells.*

## Biennial

*A plant completing its life cycle (germination through death) in two years or growing seasons (generally flowering only in the second) and non-woody (at least above ground), often with a rosette the first growing season)*

## Cell Tray

*Multi-cell propagation container, also known as “plug tray”*

## Cotyledon

*Seed-leaf; a modified leaf present in the seed, often functioning for food storage. Persistent in some annuals and helpful in their identification.*

## Cross pollination

*The transfer of pollen from one plant to another*

## Dicot

*Flowering plant having two cotyledons (e.g., poppy, cactus, rose, sunflower)*

## Damping Off

*A fungal pathogen whose populations are encouraged by consistently high moisture levels in the propagation media and high humidity. Negatively affect developing seedlings, often leading to lodging. Presence indicated by brown ring of compromised tissue around stem of plant. Often leads to losses.*

## Embryo

*An immature plant within a seed*

## Endosperm

*The starch- and oil-containing tissue of many seeds used by the seedling in the initial stages of development prior to the beginning of photosynthesis*

## F-1 Hybrid

*A plant resulting from a cross between two genetically distinct individuals, which allows for the combination and expression of desirable traits in the F-1 generation*

## Fertigation

*Fertilizer delivered through irrigation equipment*

## Fertilization

*The use of concentrated forms of nutrients (e.g., fish emulsion to deliver soluble sources of nitrogen)*

## Hardening Off

*The process of gradually exposing greenhouse-raised transplants to field conditions resulting in the development of more resistant and resilient seedlings*

## Imbibition

*The process of water absorption by a dry substance or structure, causing it to swell*

## Monocot

*Flowering plant having one cotyledon (e.g., lily, orchid, grass, cat-tail, palm)*

## Open pollination

*The placing of pollen on a stigma or stigmatic surface by natural means, e.g., insect, wind, etc.*

## Perennial

*A plant with a life cycle of more than two years*

## Photoperiodism

*The response of a plant to the relative duration of day and night, especially in regard to flowering*

## Plumule

*The young shoot as it emerges from the seed on germination, usually after the appearance of the radicle*

## Pricking Out

*A traditional French-intensive method of raising seedlings in wooden flats, where seedlings are transplanted from a sowing flat at high density to a second propagation flat at lower density*

## Propagation Media

*The growing media in which seeds are germinated and seedlings are grown*

**Radicle**

*The young root as it emerges from the seed, normally the first organ to appear on germination*

**Roguing**

*The selective removal of seedlings affected by pests or pathogens*

**Scarification**

*Scratching or etching a thick seed coat to improve water uptake*

**Sexual Propagation**

*The intentional reproduction of a new generation of plants by the germination and growth of seeds that were created in the previous generation through the fertilization of a plant ovary via the union of male and female sex cells. Results in a genetically unique plant generation.*

**Stratification**

*The exposure of ungerminated seeds to either warm or cold temperature extremes to release chemical dormancy factors*

**Transpiration**

*The loss of water vapor from a plant, mostly from the stomata of leaves*

**Viability**

*Capability of germination*

# Appendix 1: Seed Viability Chart

SEED TYPE	WITH NO SPECIAL STORAGE CONDITIONS (YEARS)	IN CONSISTENTLY COOL/DRY CONDITIONS (YEARS)
Beans, all	2–3	4–6
Beets	2	3–4
Broccoli	2	4–5
Brussels Sprouts	2	4–5
Burdock	2	4–5
Cabbage, regular	2	4–5
Cabbage, Chinese	3	5–8
Cantaloupe	3–4	6–10
Carrot	1–2	3–5
Cauliflower	2	4–5
Celery	1–2	3–5
Collard	2	4–5
Corn, all	1–2	4–6
Cucumber	3	5–7
Eggplant	1–2	3–5
Endive/Escarole	2	3–4
Kale	2	4–5
Kohlrabi	2	4–5
Leeks	up to 1	2–4
Lettuce	1–2	3–4
Mustard	2–3	5–8
Onion	up to 1	2–4
Parsley	1–2	3–5
Parsnip	up to 1	1–3
Peas	1–2	4–6
Pepper	1–2	3–5
Potato (true seed)	2–3	5–7
Pumpkin	1–2	3–5
Radish	2	3–5
Rutabaga	2	3–5
Salsify	2	3–4
Scorzonera	2	3–4
Spinach	1–2	3–4
Squash	1–2	3–5
Strawberry	2–3	3–6
Sunflower	2	4–6
Swiss Chard	2	3–4
Tomato	2–3	4–7
Turnip	2–3	5–8
Watermelon	2–3	4–6

## Appendix 2: Soil Temperature Conditions for Vegetable Seed Germination

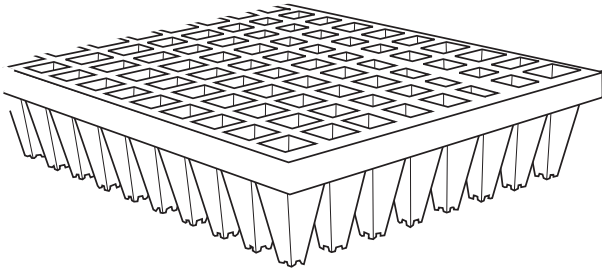
VEGETABLE	MINIMUM (°F)	OPTIMUM RANGE (°F)	OPTIMUM (°F)	MAXIMUM( °F)
Asparagus	50	60 – 85	75	95
Bean	60	60 – 85	80	95
Bean, lima	60	65 – 85	85	85
Beet	40	50 – 85	85	95
Cabbage	40	45 – 95	85	100
Carrot	40	45 – 85	80	95
Cauliflower	40	45 – 85	80	100
Celery	40	60 – 70	70 <sup>1</sup>	85 <sup>1</sup>
Chard, Swiss	40	50 – 85	85	95
Corn	50	60 – 95	95	105
Cucumber	60	60 – 95	95	105
Eggplant	60	75 – 90	85	95
Lettuce	35	40 – 80	75	85
Muskmelon	60	75 – 95	90	100
Okra	60	70 – 95	95	105
Onion	35	50 – 95	75	95
Parsley	40	50 – 85	75	90
Parsnip	35	50 – 70	65	85
Pea	40	40 – 75	75	85
Pepper	60	65 – 95	85	95
Pumpkin	60	70 – 90	90	100
Radish	40	45 – 90	85	95
Spinach	35	45 – 75	70	85
Squash	60	70 – 95	95	100
Tomato	50	60 – 85	85	95
Turnip	40	60 – 105	85	105
Watermelon	60	70 – 95	95	105

<sup>1</sup>Daily fluctuation to 60° F or lower at night is essential.

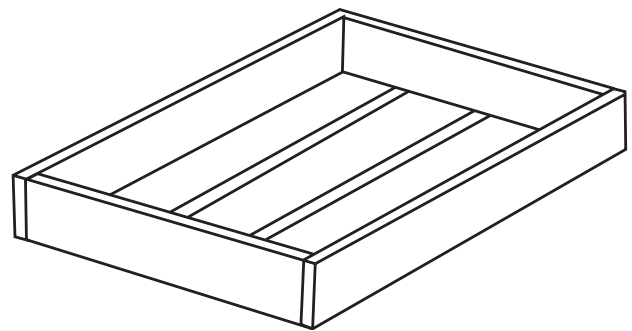
Compiled by J.F. Harrington, Dept. of Vegetable Crops, University of California, Davis.

Source: *Knott's Handbook for Vegetable Growers*, by Donald Maynard and George Hochmuth, Wiley & Sons, Inc., 1997. Used by permission of Wiley & Sons, Inc.

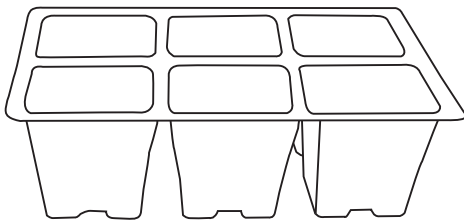
# Appendix 3: Examples of Propagation Containers



Cell Tray or Plug Tray



Wooden Flat



Six-Pack

*illustrations by Cathy Genetti Reinhard; not to scale*

## Appendix 4: Days Required for Seedling Emergence at Various Soil Temperatures from Seed Planted 1/2 inch Deep

VEGETABLE	32°	41°	50°	59°	68°	77°	86°	95°	104°
Asparagus	NG	NG	53	24	15	10	12	20	28
Bean, lima	—	—	NG	31	18	7	7	NG	—
Bean snap	NG	NG	NG	16	11	8	6	6	NG
Beet	—	42	17	10	6	5	5	5	—
Cabbage	—	—	15	9	6	5	4	—	—
Carrot	NG	51	17	10	7	6	6	9	NG
Cauliflower	—	—	20	10	6	5	5	—	—
Celery	NG	41	16	12	7	NG	NG	NG	—
Corn, sweet	NG	NG	22	12	7	4	4	3	NG
Cucumber	NG	NG	NG	13	6	4	3	3	—
Eggplant	—	—	—	—	13	8	5	—	—
Lettuce	49	15	7	4	3	2	3	NG	NG
Muskmelon	—	—	—	—	8	4	3	—	—
Okra	NG	NG	NG	27	17	13	7	6	7
Onion	136	31	13	7	5	4	4	13	NG
Parsley	—	—	29	17	14	13	12	—	—
Parsnip	172	57	27	19	14	15	32	NG	NG
Pea	—	36	14	9	8	6	6	—	—
Pepper	NG	NG	NG	25	13	8	8	9	NG
Radish	NG	29	11	6	4	4	3	—	—
Spinach	63	23	12	7	6	5	6	NG	NG
Tomato	NG	NG	43	14	8	6	6	9	NG
Turnip	NG	NG	5	3	2	1	1	1	3
Watermelon	—	NG	—	—	12	5	4	3	—

NG = No germination, — = not tested

Adapted from J.F. Harrington and P.A. Minges, Vegetable Seed Germination, California Agricultural Extension Mimeo Leaflet (1954).

Source: *Knott's Handbook for Vegetable Growers*, 1997, John Wiley & Sons, Inc. Used by permission of John Wiley & Sons, Inc.

# Appendix 5: Approximate Monthly Temperatures for Best Growth and Quality of Vegetable Crops

Some crops can be planted as temperatures approach the proper range. Cool season crops grown in the spring must have time to mature before warm weather. Fall crops can be started in hot weather to ensure a sufficient period of cool temperature to reach maturity. Within a crop, varieties may differ in temperature requirements; hence this listing provides general rather than specific guidelines.

OPTIMUM °F	MINIMUM °F	MAXIMUM °F	VEGETABLE
55°–75°	45°	85°	Chicory, chive, garlic, leek, onion, salsify, scolymus, scorzonera, shallot
60°–65°	40°	75°	Beet, broad bean, broccoli, Brussels sprouts, cabbage, chard, collards, horseradish, kale, kohlrabi, parsnip, radish, rutabaga, sorrel, spinach, turnip
60°–65°	45°	75°	Artichoke, cardoon, carrot, cauliflower, celeriac, celery, Chinese cabbage, endive, Florence fennel, lettuce, mustard, parsley, pea, potato
60°–70°	50°	80°	Lima bean, snap bean
60°–75°	50°	95°	Sweet corn, Southern pea, New Zealand spinach
65°–75°	50°	90°	Chayote, pumpkin, squash
65°–75°	60°	90°	Cucumber, muskmelon
70°–75°	65°	80°	Sweet pepper, tomato
70°–85°	65°	95°	Eggplant, hot pepper, martynia, okra, roselle, sweet potato, watermelon

Source: *Knott's Handbook for Vegetable Growers*, by Donald Maynard and George Hochmuth, Wiley & Sons, Inc., 1997. Used by permission of John Wiley & Sons, Inc.



# Appendix 6: Propagation Media — Ingredients and Properties Imparted

INGREDIENT	FUNCTION/QUALITIES IMPARTED	SOURCE	COMMENTS/SUSTAINABILITY COSTS
Peat Moss	Fungistatic/acidic, H <sub>2</sub> O-holding capacity 10 times dry wt.		\$\$\$, pH 3.5-5.0 Non-renewable
Perlite 5–8 lbs/cu ft	H <sub>2</sub> O holding capacity 3–4 times wt., aeration, drainage	Mined silica, volcanic origin	\$\$\$, no CEC <sup>1</sup> , no nutrients
Vermiculite 6–10 lbs/cu ft	Drainage, High CEC, H <sub>2</sub> O-holding capacity 6–8 times wt., has Mg/K	Mica from MT & NC	\$\$\$, Heated @2000°F to expand water-holding capacity
Compost	Moisture retention, drainage, nutrients, pathogen suppression	Produce	Requires labor to produce, weed seed
Soil	Minerals, minor NPK, bulk density	On-site	Free, weed seed
Sand	Drainage, aeration,	Quarried/Sharp	\$, 0.05-2.0mm diameter, no CEC or nutrients
Leaf Mold (decomposed leaf litter)	Serves as peat substitute, acidic/fungistatic, drainage, H <sub>2</sub> O-holding	On-site	Free, labor to harvest
Coir Fiber	H <sub>2</sub> O-holding, drainage	From Sri Lanka, Madagascar, coconut byproduct	\$\$, hard to handle/break up, non fungistatic
Grape Seed Pomace	Drainage, aeration	Winery byproduct	Time/labor, perlite substitute for mixes, could have high potas- sium

<sup>1</sup>CEC=Cation Exchange Capacity (see Unit 2.2, Soil Chemistry and Fertility)

\$\$\$ = expensive input

\$\$ = moderately expensive input

\$ = low-cost input

# Appendix 7: Sample Soil Mix Recipes

## FLAT/SOWING MIX

---

3 parts compost (sifted .5 inch screen)  
2 parts soil  
1 part sand  
2 parts coir fiber (premoistened) or 1 part coir fiber  
+ 1 part leaf mold (sifted .5 inch screen)

## GARDEN SPEEDLING MIX

---

2-1/2 compost (sifted .5 inch screen)  
1 soil  
2 coir fiber (premoistened) or 1 coir fiber + 1 leaf  
mold (sifted .5 inch screen)  
1/4 gallon kelp meal (\*1 tablespoon)  
\*Use 1/4 gallon when one part is equal to one  
wheelbarrow. Use 1 tablespoon when the measure is  
a shovelful.

## POTTING MIX

---

1-1/2 compost  
1-1/2 partially decomposed duff  
1 used mix  
1 sand  
1 perlite (or used mistbox mix) or 1/2 perlite (or  
used mistbox mix and 1/2 grape seed  
1/2 soil

## DRYLAND POTTING MIX

---

3 potting mix  
1 sand  
1 perlite (or used mistbox mix)  
or  
1 grape seed

## UCSC FIELD SPEEDLING MIX

---

2 compost (sifted .5 inch screen)  
1 coir fiber (premoistened)  
1 vermiculite (medium/fine)  
3 cups blood meal\*  
\*This amount of blood meal is based on when the  
measure of one part is equal to a wheelbarrow.

## 6-PACK MIX

---

2 compost  
2 used flat mix  
1 coir fiber  
1 sand

## LIQUID SUPPLEMENTAL FERTILIZER

---

*Using watering can, per gallon of water:*

1/4 cup liquid fish emulsion  
1/2 tsp. Kelp powder

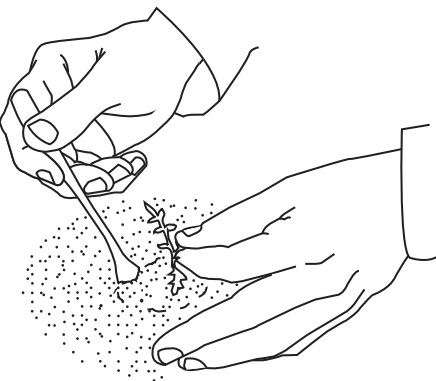
*Using foliar sprayer:*

Also add 1/4 tsp. sticker-spreader (surfactant),  
added last into the tank to avoid excess foaming (see  
Resources section)

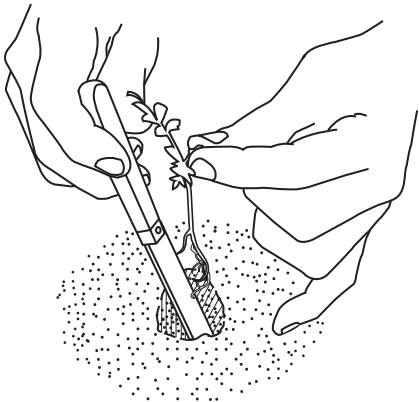
Mix ingredients in a little water in a bucket, then  
pour into a 3-gallon backpack sprayer and fill to the  
line with more water. For basal applications, remove  
spray nozzle.

Fertigation is best done in the early morning or in  
the evening.

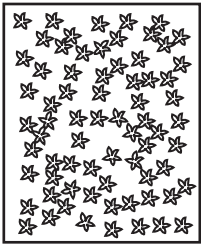
# Appendix 8: Pricking Out Technique and Depth of Transplanting



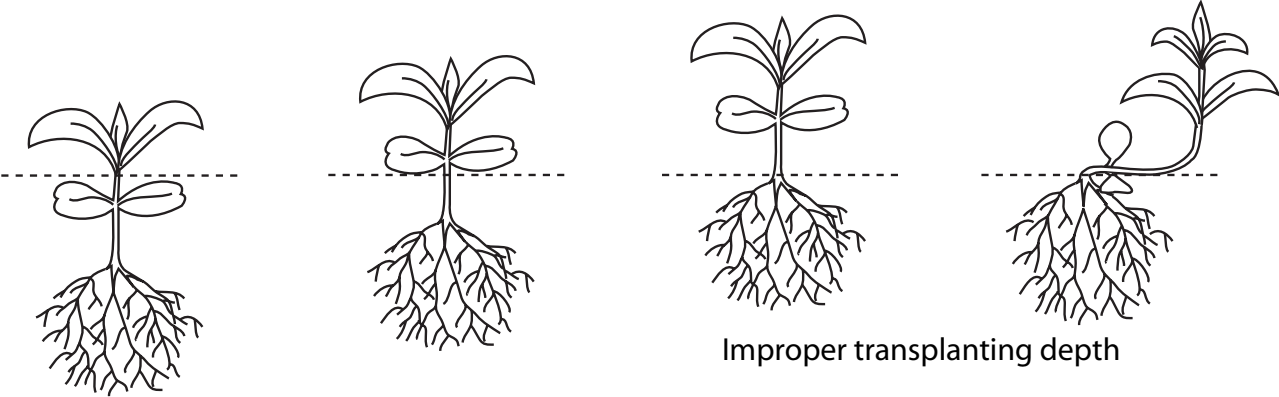
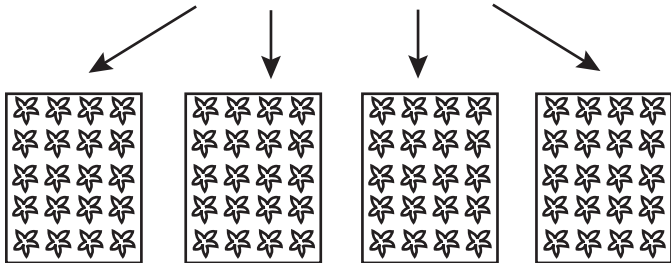
Gently prick out seedling from densely planted flat



Place seedling in a new flat planted at lower density



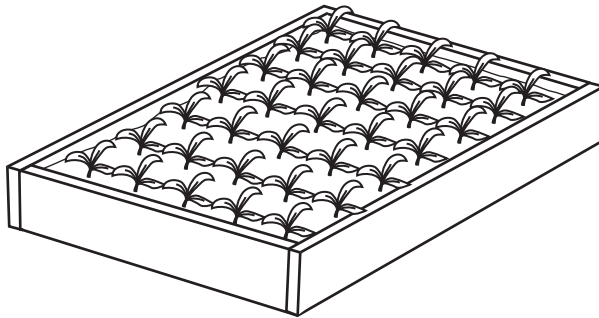
Plants sown at a high density (e.g., 200/flat) are pricked out into several flats at a lower density (e.g., 50/flat) to mature



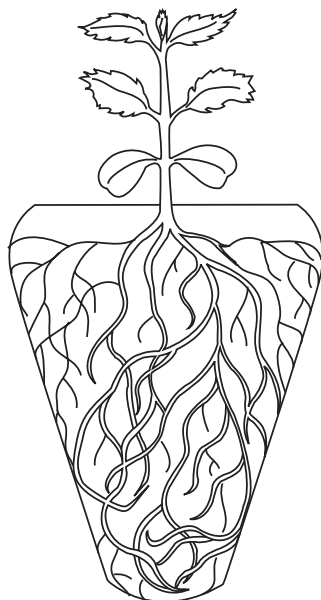
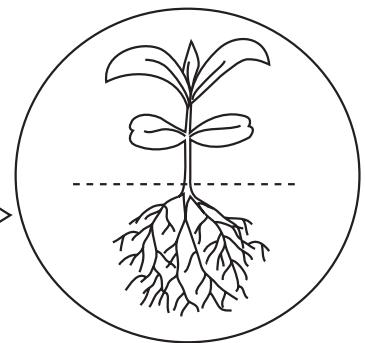
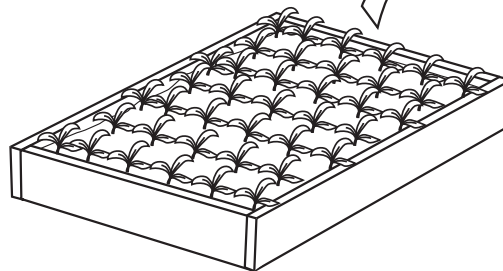
Proper transplanting depth

Improper transplanting depth

# Appendix 9: Flat-Grown and Cell-Grown Seed-



Flat-grown seedlings at transplant maturity —note balance of roots and shoots



Cell-grown seedling at transplant maturity —note balance of roots and shoots

*illustrations by Cathy Genetti Reinhard; not to scale*







# 1.4 Transplanting and Direct Seeding

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# Introduction: Transplanting and Direct Seeding

## UNIT OVERVIEW

*In this unit, two field demonstrations introduce students to the basic skills and concepts associated with direct seeding and transplanting techniques used in traditional French-intensive gardening, and small- to medium-scale field production. Note that there is no lecture outline associated with this unit; it uses garden and field demonstrations and a set of step-by-step instructions to convey the material. Refer to Unit 1.3, Propagating Crops from Seed and Greenhouse Management, for additional information relevant to the material presented here.*

## MODES OF INSTRUCTION

- > GARDEN-SCALE TRANSPLANTING DEMONSTRATION (1–1.5 HOURS)  
The garden-scale demonstration outline details the basic skills and concepts for direct seeding annual crops and transplanting both annual and perennial container-grown plants. Following the outline is a set of step-by-step instructions for students on seedling and soil preparation, direct seeding, and transplanting techniques.
- > TRACTOR-MOUNTED SEEDING AND TRANSPLANTING EQUIPMENT DEMONSTRATION (1 HOUR)  
The demonstration outline for field-scale transplanting and direct seeding details how to use tractor-mounted equipment for planting on a larger scale.
- > ASSESSMENT QUESTIONS (0.5 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The optimal physical environment conditions favorable for successful transplanting
- The optimal soil moisture conditions favorable for successful transplanting
- The optimal seedling development and pre-treatments necessary for successful transplanting

### SKILLS

- How to sow small- and large-seeded crops using hand methods and push seeders
- How to transplant from a cell tray and flat format
- How to water-in/irrigate recently transplanted seedlings
- How to irrigate seed beds for optimal germination



# Demonstration 1: Garden-Scale Transplanting and Direct Sowing

*for the instructor*

## OVERVIEW

*The following field demonstration outline covers the basic skills and concepts used to direct seed and transplant crops for garden-scale production. Following the outline below, discuss and demonstrate the tools and techniques used in garden-scale transplanting and direct seeding.*

## PREPARATIONS AND MATERIALS

- Recently prepared garden bed at 50%–75% of field capacity, including a 4-foot section prepared as a seed bed and a 4-foot section prepared using coarse secondary tillage
- Flat of plants at seedling maturity (allium and broad-leaf crops)
- Cell tray at seedling maturity and immaturity
- Hand trowel and hand fork
- Watering wand
- Dibble
- Measuring tape
- Ross and hose
- Mist system/micro-sprinklers
- String and stakes
- Large and small seed (e.g., squash and carrots)
- Push seeder
- Bed end markers and indelible marker
- Appendix 10, Propagation and Crop Performance Record Sheet, from Unit 1.3, Propagating Crops from Seed and Greenhouse Management

## PREPARATION TIME

1.5 hours

## DEMONSTRATION TIME

1.5 hours

## **DEMONSTRATION OUTLINE**

### **A. Discuss Transplanting versus Direct Sowing**

Ask students to explain why certain crops are transplanted and others directly sown

1. Transplanted crops
  - a) Greenhouse advantages
    - i. Greater climate control
    - ii. Greater season extension
    - iii. Intensive rather than extensive management of seedlings
    - iv. Rapid crop successions (e.g., from cover crops to cropping and from one crop to another)
  - b) Root nature of transplanted crops: Fibrous
  - c) May allow for greater control over specific density of crops
2. Direct-sown crops
  - a) Root nature of direct-sown crops: Often tap rooted
  - b) Intended density of crop: Direct-seeded crops require sowing at high density and eventual thinning
  - c) Scale of production: Many crops are direct seeded on a large scale to avoid additional production costs
  - d) Exceptions: Most crops, including tap-rooted crops, may be transplanted if sown and transplanted in clusters

### **B. Review Assessments of Plant, Soil, and Environmental Conditions Prior to Transplanting**

Ask students to assess the compatibility of the following environmental conditions and seedling maturity with the planned tasks, then discuss and demonstrate the following:

1. Seedling development necessary for successful transplanting
  - a) Shoot development
  - b) Root development
2. Seedling pre-treatments necessary for successful transplanting
  - a) Soil/media moisture
    - i. Cell-grown seedlings with media at field capacity
    - ii. Flat-grown seedlings with media at 50%–75% of field capacity
  - b) Hardening-off period: A minimum of three days of full exposure to field conditions
3. Soil conditions favorable for successful transplanting or direct sowing

Ask students to determine soil moisture

  - a) Soil moisture (see appendix 1, Estimating Soil Moisture By Feel): 50%–75% of field capacity
  - b) Degree of secondary cultivation: Smaller seeds require greater secondary cultivation
4. Optimal physical environment conditions favorable for successful transplanting of flat-grown seedlings
  - a) Low light levels
  - b) Low temperature
  - c) Low wind speed
  - d) High humidity
  - e) Steps to take if environmental conditions are not optimal

### C. Discuss and Demonstrate Transplanting

1. Plant spacing considerations: Ask students to consider how the following factors influence crop spacing
  - a) Irrigation and cultivation considerations
  - b) Soil fertility/soil development considerations: Low fertility may require reduced density or supplemental fertility
  - c) Root and shoot size at maturity
  - d) Disease prevention/air circulation
  - e) Stem length or stem number for cut flowers
  - f) References: Crop-spacing chart in *Knott's Handbook for Vegetable Growers*, and in *How to Grow More Vegetables*, by John Jeavons; seed catalogues (see Resources section of Unit 1.3, Propagating Crops from Seed and Greenhouse Management)
2. Tools used to assure uniform plant spacing: Discuss and demonstrate tools used to guide planting
  - a) Parallel lines of string between stakes
  - b) Transplant marker, e.g., dibble
  - c) Triangulation
  - d) One's hand
3. How to plant: Discuss and demonstrate the following
  - a) The importance of a knowledge of crop being planted
  - b) Plant selection criteria (development and vigor of seedling)
  - c) Plant handling technique
  - d) Depth of planting
4. Watering in: Discuss and demonstrate why, how, and irrigation options
  - a) Why? To assure even soil moisture between transplant and surrounding soil in order to assure uninterrupted regrowth
  - b) Options on how to irrigate after transplanting (water in)
    - i. Basal application with watering wand
    - ii. Overhead sprinkler and considerations of scale
    - iii. Overhead sprinkler, transition to drip irrigation
5. Documenting
  - a) Discuss documenting as learning tool
  - b) Where to document?
    - i. Field or bed marker
    - ii. Garden log book with crop seeding dates and seed company (see appendix 10 in Unit 1.3)
6. Post-transplant follow up
  - a) Irrigation
    - i. Method of irrigation
    - ii. Monitoring root zone for 50% of field capacity (see appendix 1 in this unit, and Unit 1.5, Irrigation, for discussion of field capacity)
  - b) Observations of subsequent growth
    - i. Predation: Watch seedlings for insect or pest damage. Replace as needed.
    - ii. Nutrient needs: In spring, heat-loving crops growing in poorly developed soils may require supplemental fertility
    - iii. Root development: Carefully digging up seedlings to observe root development provides information for depth of irrigation requirements

- c) Excess/replacement seedlings
  - i. Management of excess seedlings in propagation area
  - ii. Treatment: Supplemental fertility may be required to sustain replacement seedlings

#### **D. Discuss and Demonstrate Direct-Sowing Techniques**

1. Briefly review optimal environmental considerations for seed germination. Ask students to consider the optimal environmental conditions for seed germination in terms of:
  - a) Soil moisture
  - b) Degree of secondary cultivation
  - c) Soil temperature
  - d) Depth of planting
2. Demonstrate and discuss the pros/cons of the various direct-sowing techniques
  - a) Drills/sowing into furrows by hand
  - b) Push seeder
  - c) Broadcast sowing
3. Irrigation
  - a) Objective
  - b) Techniques and frequency used
    - i. Mist systems
    - ii. Overhead
    - iii. Drip
4. Thinning established stand
  - a) Stage of development
  - b) Density: see crop-spacing charts in Resources section in Unit 1.3
5. Questions and answers

# Demonstration 1: Garden-Scale Transplanting and Direct Sowing

## *step-by-step instructions for students*

### **A. Assess Plant, Soil, and Environmental Conditions *Prior* to Sowing or Transplanting**

1. Seedling development
  - a) Shoot development
    - i. Second set of true leaves (cell format)
    - ii. Filling out allotted space and second set of true leaves established (flat format)
  - b) Root development
    - i. Root knit (cell format)
    - ii. Filling out allotted space (flat format)
2. Seedling pre-treatments
  - a) Soil/mix moisture
    - i. Field capacity (cell format)
    - ii. 50%–75% of field capacity (flat format)
  - b) Hardened-off
    - i. 3–21 day range (minimum of 3 days with 24 hours at field conditions)
    - ii. Hardening-off period should increase in duration with increased differential between field and greenhouse conditions
3. Field or garden soil conditions
  - a) Soil moisture
    - i. 50%–75% of field capacity
  - b) Degree of secondary cultivation
    - i. Extensive secondary cultivation for small-seeded, direct-sown crops and transplants with small, weak, or inefficient root systems (e.g., carrots)
    - ii. Course secondary tillage for large, vigorous, and resilient transplants (e.g., tomatoes)
4. Optimal environmental conditions favorable to successful transplanting from flat format
  - a) Low light levels
  - b) Low temperature
  - c) Calm winds
  - d) High relative humidity
  - e) Late afternoon and early evening

### **B. Transplanting**

1. Gather necessary tools and materials
  - a) Seedlings at transplant maturity
  - b) Hand trowel and hand fork
  - c) Watering wand
  - d) Dibble
  - e) Measuring tape
  - f) Ross and hose



- g) Mist system/micro-sprinklers
  - h) String and stakes
  - i) Seed
  - j) Push seeder
2. Plant spacing considerations: Consider how the following factors influence crop spacing
- a) Irrigation and cultivation considerations
    - i. Rows should be straight and between-row crop spacing should be large enough to accommodate drip irrigation ribbon and cultivation tools
  - b) Soil fertility/soil development considerations
    - i. In infertile or degraded soil, plant densities should be low and increased as soil fertility develops over time
  - c) Root and shoot size
    - i. How large is the root system and vegetative portion of the plant at maturity?
  - d) Disease prevention considerations
    - i. Is the crop susceptible to certain plant pathogens?
    - ii. Increasing the plant spacing may help to assure adequate air circulation and prevent the development and spread of fungal plant pathogens in certain climates
  - e) Stem length and stem number in cut flowers
    - i. By increasing crop density in certain cut flowers, the bloom shaft length may be increased. Decreasing plant densities often results in greater numbers of shorter bloom shafts.
  - f) References: Crop-spacing chart in *Knott's Handbook for Vegetable Growers*, and *How to Grow More Vegetables*, by John Jeavons; seed packages and catalogues
3. How to plant
- a) Know the crop being planted
    - i. Review the crop culture information on the back of the seed package, in seed catalogues, or books on crop culture
  - b) Plant selection criteria (seedling vigor): Select for vigor and color
  - c) Plant handling
    - i. Crops grown in a flat format should be handled carefully by the rootball, attempting to disturb the root system as little as possible during the transplanting process. Crops grown in a flat format should only be transplanted during the early evening.
    - ii. Crops grown in a cell tray format may be planted throughout the day and with less concern for disturbance of the root system during planting
  - d) Depth of planting
    - i. Most crops should be planted to the depth of the cotyledons
    - ii. Crops in the Solanaceae family (tomatoes, peppers, eggplants, etc.) and Brassicaceae family (broccoli, cabbage, cauliflower, etc.) are adventitious rooters and may be buried to the bottom of the first set of true leaves (see appendix 2, Seedlings at Transplant Maturity, Planting Depths)
4. Watering in
- a) Seedlings should be immediately irrigated following transplanting
  - b) Bring the root zone of the crop to field capacity using drip irrigation, overhead sprinkler, or basal soaking
5. Documenting
- a) Transcribe the information on the horticultural label (including the transplanting date) to a bed-end stake *and* the garden record log book (see appendix 10, Unit 1.3)

6. Follow-up
  - a) Determine the type of irrigation to be used and set up any necessary irrigation equipment at this time
  - b) Return remaining seedlings to the propagation area. Refill flats with propagation mix and water thoroughly.
  - c) Over the following approximately 2–5 days, monitor soil moisture in the root zone of the recently transplanted crop. Irrigate once the soil in the root zone has reached 50% of field capacity.
  - d) Periodic, light overhead irrigation will raise the relative humidity around the seedlings, reduce the rate of evapotranspiration, and help minimize transplant shock
  - e) Observe the growth and development of the roots and shoots of the seedlings, noting the following: Rates of growth, changes in color, and damage due to predation
  - f) Replace seedlings lost to predation

### C. Direct Sowing

1. Consider the optimal environmental conditions for seed germination in terms of:
  - a) Soil moisture
    - i. 50%–75% of field capacity
  - b) Degree of secondary cultivation
    - i. Extensive secondary cultivation is necessary for small-seeded direct-sown crops and transplants with small, weak, or inefficient root systems
  - c) Soil temperature
    - i. Compare the existing soil temperatures with the optimal germination temperatures found on the back of the seed package, in *Knott's Handbook for Vegetable Growers*, or in appendix 2, Unit 1.3, Propagating Crops from Seed and Greenhouse Management
2. Direct-sowing techniques
  - a) Sowing into furrows with hands
    - i. Open furrow with fingers or hand tool to a depth of approximately 2 times the diameter of the seed to be sown
    - ii. Sow seed at 2–3 times the density desired at maturity (seedlings are later thinned to desired spacing when the first set of true leaves have developed)
    - iii. Cover seed by pinching furrow together
    - iv. Gently tamp soil with head of rake to assure soil-to-seed contact
  - b) Sowing into furrows with push seeder
    - i. Consult the seed plate chart for use of push seeder
    - ii. Test seeder output on hard, flat surface to confirm desired seed rate/spacing
    - iii. Periodically check to assure seed output and seed supply in hopper
  - c) Broadcast sowing
    - i. Determine application rate using references such as crop-spacing chart in *Knott's Handbook for Vegetable Growers*, and in *How to Grow More Vegetables*, by John Jeavons; seed packages and catalogues
    - ii. Broadcast evenly over surface of soil
    - iii. Cover lightly with a mixture of 50% garden soil and 50% mature compost
3. Irrigating seed beds
  - a) Using Ross, oscillator, or mist/micro-sprinklers, maintain surface soil moisture with light, frequent applications of water each time 50% of the surface of the soil has dried and discolored (see appendix 4, Garden-Scale Seed Bed Irrigation)

4. Thinning direct-sown crops

- a) Thin directly seeded crops to desired spacing, if necessary, once the first set of true leaves has developed (see crop-spacing chart in *Knott's Handbook for Vegetable Growers*, and *How to Grow More Vegetables*, by John Jeavons; seed packages and catalogues)

# Demonstration 2: Tractor-Mounted Seeding and Transplanting Equipment

## *for the instructor*

### **INSTRUCTOR OVERVIEW**

*This field demonstration outline introduces the tractor-mounted equipment and skills used to transplant and direct seed crops. It first covers the sequence of techniques and equipment used to prepare the soil for both transplanting and direct seeding. The outline then introduces the range of equipment and techniques used to transplant and direct seed crops, followed by irrigation techniques.*

### **PREPARATION AND MATERIALS**

- Bed shaper/marker
- Tractor-mounted seeder
- Push seeder
- Plate planter
- Tractor-mounted transplanting equipment
- Hand trowels
- Irrigation equipment: drip and sprinkler
- Record book for recording crops planted, sown (see appendix 10 in Unit 1.3)
- Labels for marking bed
- Shovels for single row plantings

### **GROUND PREPARATION**

This demonstration requires access to an area of ground that has received primary and secondary tillage, pre-irrigation, and weed cultivation. These techniques should be included in the demonstration if not covered previously in Unit 1.2, Garden and Field Tillage and Cultivation.

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

1 hour

## **DEMONSTRATION OUTLINE**

### **A. Review and Discuss Tools and Sequence Used to Prepare Ground**

1. Review field soil conditions prior to tillage
  - a) Soil moisture range: 50%–75% of field capacity (see appendix 1 in this unit, and Unit 1.5, Irrigation, for discussion of field capacity)
2. Incorporation of cover crop residue through primary tillage
  - a) Mowing (flail or rotary)
  - b) Apply compost prior to residue incorporation, if necessary
  - c) Incorporate cover crop residue with spader or off-set wheel disc
3. Establishment of seedbed through secondary tillage techniques
  - a) Rototill or disc field to improve surface uniformity following residue breakdown
4. Planting bed formation
  - a) Form beds with lister bar and shovels or rolling cultivator
  - b) Shape bed with bed shaper
  - c) Pre-irrigate to germinate weed seed
  - d) Cultivate unplanted beds with sweeps, knives, or rolling cultivator to minimize weed pressure and exhaust seed bank
  - e) Plant beds with seeder, transplanter, or by hand

### **B. Demonstrate Bed Shaper/Seeder for Direct-Sown Crops**

1. Review attachment of implement(s)
2. Demonstrate adjustment of bed shaper height
3. Demonstrate adjustment of seeder shovels' height for seeding various crops
4. Review examples of crops that are directly sown and why

### **C. Demonstrate Implements Used to Prepare Beds for Single-Line Plantings**

1. Review attachment and adjustment of implement(s) used
2. Review examples of single-line crops

### **D. Demonstrate the Use of Mechanical Transplanter**

1. Review attachment of implement(s)
2. Demonstrate adjustment of transplanter
3. Transplant preparations: Irrigation and hardening off (see Unit 1.3, Propagating Crops from Seed and Greenhouse Management)
4. Handling and placement of transplants
5. Review examples of crops that are mechanically transplanted and why

### **E. Review Hand Transplanting Techniques**

1. Transplant preparations: Irrigation and hardening off (see Unit 1.5, Irrigation)
2. Handling and placement
3. Review of transplanted crops
  - a) Single line crops
  - b) Double line crops

### **F. Review Irrigation Techniques Used Immediately Following Transplanting and Direct Seeding**

1. Drip irrigation
2. Sprinkler irrigation



# Assessment Questions Key

- 1) List three physical environmental conditions favorable for successful transplanting of flat-grown seedlings
  - *Low light levels*
  - *Low temperature*
  - *High relative humidity*
  - *Calm winds*
- 2) What is the optimal range of soil moisture for transplanting or direct seeding of crops?
  - *Between 50%–75% of field capacity*
- 3) Describe how the size, root nature, and vigor of transplants and the size of seeds influence the degree of secondary cultivation needed
  - *Directly sown crops (especially small-seeded crops) require extensive secondary cultivation in order to reduce the surface soil particle size and produce a quality seed bed. Small, inefficient, weak, or shallow-rooted crops (e.g., onions, leeks, lettuce) also respond favorably to being transplanted into soils having received extensive secondary cultivation.*
  - *Large, vigorous transplants may be transplanted into more coarsely tilled soils*
- 4) List two characteristics of seedlings at transplanting maturity.
  - *Second set of true leaves initiated*
  - *Root knit*
- 5) List two necessary steps in preparing seedlings for transplanting.
  - *Pre-moistened to 50–75% and 100% of field capacity (flats and cell tray transplants respectively)*
  - *Hardened-off for 3–21 days*

# Appendix 1: Estimating Soil Moisture by Feel

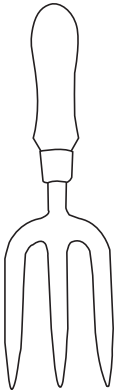
SOIL MOISTURE LEVEL (% OF FIELD CAPACITY)	COARSE (SAND)	LIGHT (LOAMY SAND, SANDY LOAM)	MEDIUM (FINE, SANDY LOAM, SILT LOAM)	HEAVY (CLAY LOAM, CLAY)
<b>0–25%</b> No available soil moisture. Plants wilt. Irrigation required. (1 <sup>st</sup> range)	Dry, loose, single grained, flows through fingers. No stain or smear on fingers.	Dry, loose, clods easily crushed and will flow through fingers. No stain or smear on fingers.	Crumbly, dry, powdery, will barely maintain shape. Clods, breaks down easily. May leave slight smear or stain when worked with hands or fingers.	Hard, firm baked, cracked. Usually too stiff or tough to work or ribbon <sup>1</sup> by squeezing between thumb or forefinger. May leave slight smear or stain.
<b>25–50%</b> Moisture is available, but level is low. Irrigation needed. (2 <sup>nd</sup> range)	Appears dry; will not retain shape when squeezed in hand.	Appears dry; may tend to make a cast <sup>2</sup> when squeezed in hand, but seldom will hold together.	May form a weak ball <sup>2</sup> under pressure but will still be crumbly. Color is pale with no obvious moisture.	Pliable, forms a ball; will ribbon but usually breaks or is crumbly. May leave slight stain or smear.
<b>50–75%</b> Moisture is available. Level is high. Irrigation not yet needed. (3 <sup>rd</sup> range)	Color is darkened with obvious moisture. Soil may stick together in very weak cast or ball.	Color is darkened with obvious moisture. Soil forms weak ball or cast under pressure. Slight finger stain, but no ribbon when squeezed between thumb and forefinger.	Color is darkened from obvious moisture. Forms a ball. Works easily, clods are soft with mellow feel. Will stain finger and have slick feel when squeezed.	Color is darkened with obvious moisture. Forms good ball. Ribbons easily, has slick feel. Leaves stain on fingers.
<b>75% to field capacity (100%)</b> Soil moisture level following an irrigation. (4 <sup>th</sup> range)	Appears and feels moist. Color is darkened. May form weak cast or ball. Will leave wet outline or slight smear on hand.	Appears and feels moist. Color is darkened. Forms cast or ball. Will not ribbon, but will show smear or stain and leave wet outline on hand.	Appears and feels moist. Color is darkened. Has a smooth, mellow feel. Forms ball and will ribbon when squeezed. Stains and smears. Leaves wet outline on hand.	Color is darkened. Appears moist; may feel sticky. Ribbons out easily, smears and stains hand, leaves wet outline. Forms good ball.

<sup>1</sup> Ribbon is formed by squeezing and working soil between thumb and forefinger

<sup>2</sup> Cast or ball is formed by squeezing soil in hand



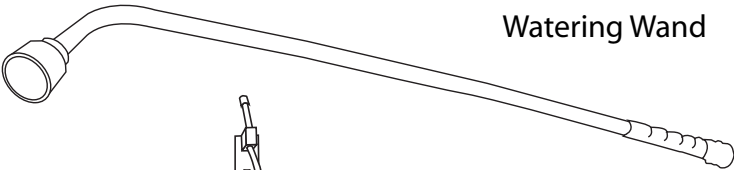
# Appendix 2: Transplanting and Irrigation Equipment



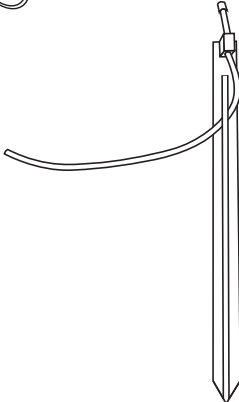
Hand Fork



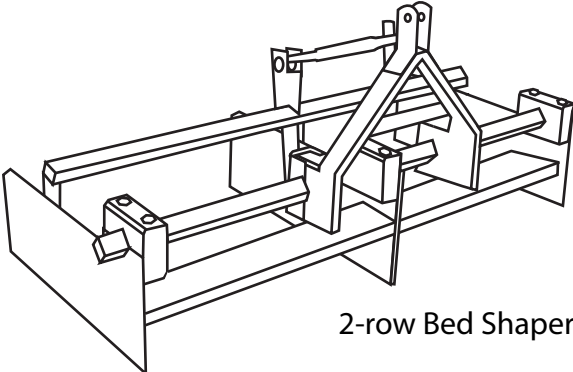
Hand Trowel



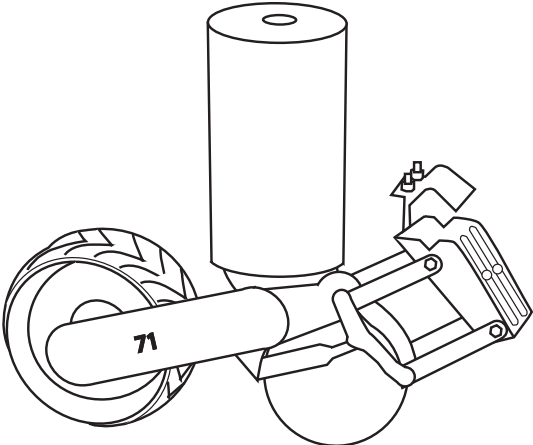
Watering Wand



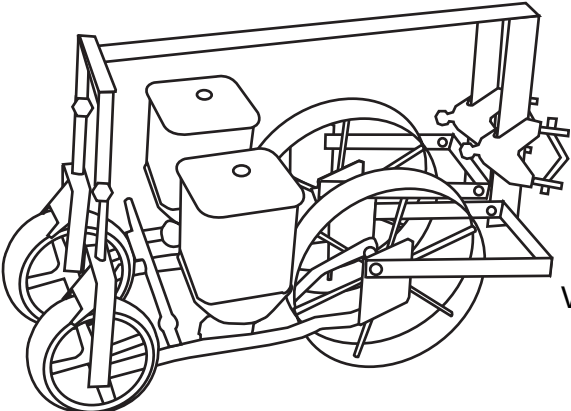
Micro-sprinkler



2-row Bed Shaper



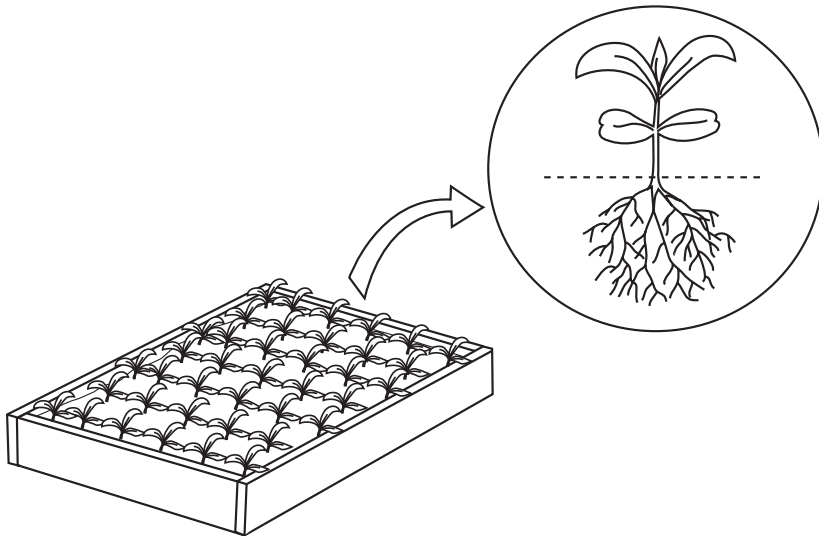
John Deere Model 71 Plate Planter



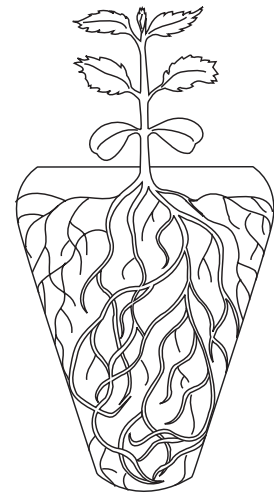
Planet Jr. Vegetable Planter

*illustrations by Cathy Genetti Reinhard; not to scale*

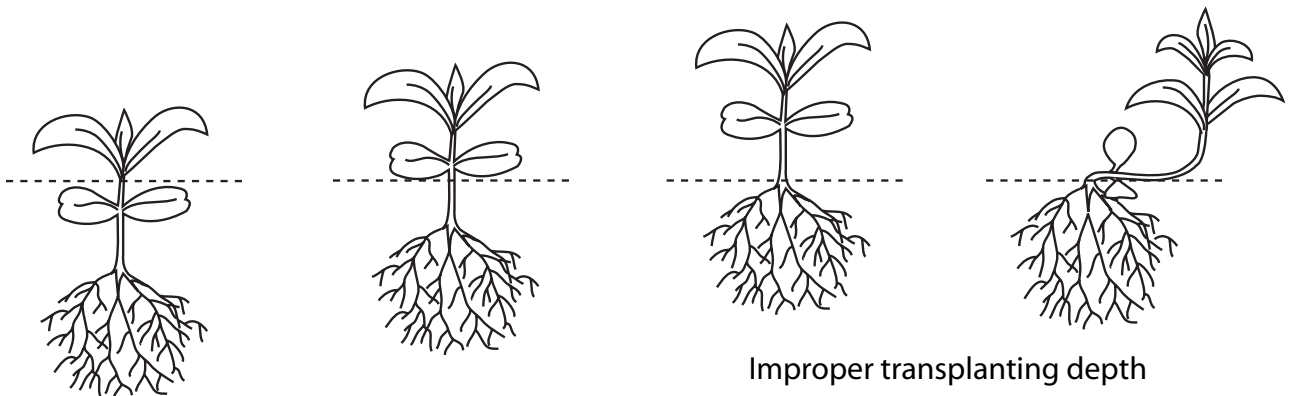
# Appendix 3: Seedlings at Transplant Maturity, Planting Depths



Flat-grown seedling at transplant maturity—note balance of roots and shoots



Cell-grown seedling at transplant maturity—note balance of roots and shoots

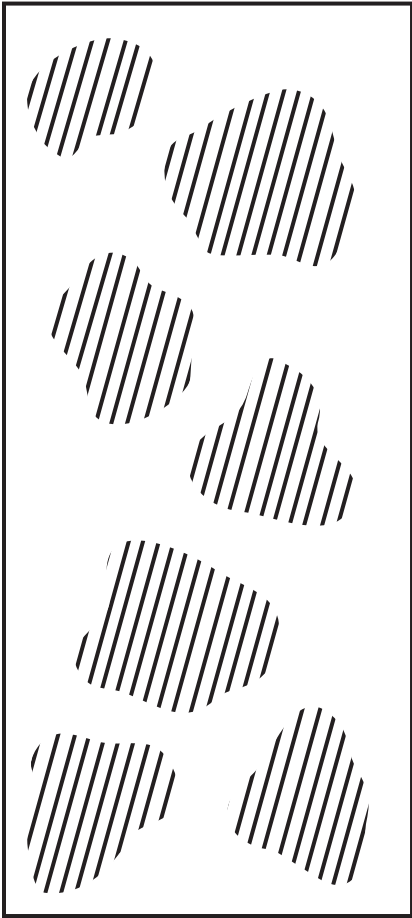
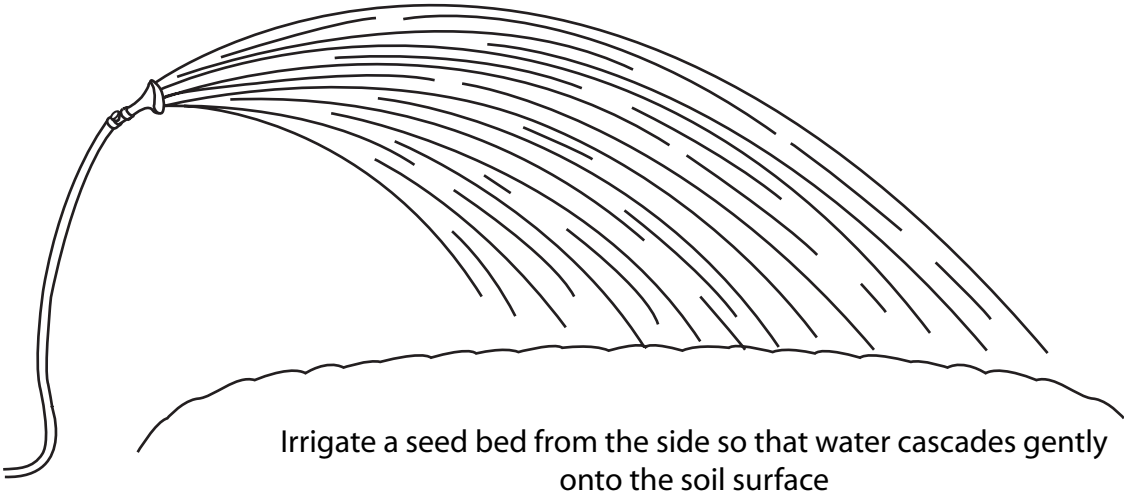


Proper transplanting depth

Improper transplanting depth

*illustrations by Cathy Genetti Reinhard; not to scale*

# Appendix 4: Garden-Scale Seed Bed Irrigation



Irrigate a seed bed each time 50% of the bed's surface area has dried

*illustrations by Cathy Genetti Reinhard*

# 1.5 Irrigation— Principles and Practices

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# Introduction: Irrigation

## UNIT OVERVIEW

*Effective irrigation practices can improve yields and quality, minimize water use, and protect natural resources. This unit introduces students to the basic concepts, tools, and skills used to deliver water efficiently and effectively on both a field and garden scale. Students will learn about the role of irrigation water in agriculture, the movement and cycling of water in agricultural systems, and the environmental factors that influence the type, frequency, and duration of irrigation. A lecture and demonstrations introduce the resources and essential skills needed to determine the proper timing and volume of irrigation, using both qualitative and quantitative methods. Through exercises and problem solving, students will practice calculating water budgets used to develop irrigation schedules and determine total water volume needs per unit of time. The latter calculations will help the student define needed irrigation delivery systems.*

## MODES OF INSTRUCTION

- > LECTURE (1 LECTURE, 2 HOURS)  
The class lecture outline introduces to the basic concepts and terms used in irrigation as well as two of the commonly used approaches to garden- and field-scale irrigation. Note: The instructor may want to present this lecture in two parts.
- > DEMONSTRATION 1: FIELD-SCALE IRRIGATION (2 HOURS)  
This field-scale demonstration illustrates how to gauge soil moisture by feel and how to establish, use, and maintain field-scale irrigation equipment.
- > DEMONSTRATION 2: GARDEN-SCALE IRRIGATION (2 HOURS)  
This garden-scale demonstration illustrates how to gauge soil moisture by feel and how to establish, use, and maintain garden-scale irrigation equipment.
- > EXERCISES 1–3: FIELD- AND GARDEN-SCALE IRRIGATION SAMPLE CALCULATIONS (0.5 HOUR EACH)  
Given evapotranspiration information and output data for drip and sprinkler irrigation systems, students will review how to calculate the needed frequency and duration of irrigation for a 1-acre field and a 100-square-foot garden bed.
- > EXERCISE 4: CALCULATING A WATER BUDGET FOR A ONE-ACRE BLOCK OF VEGETABLES (0.5 HOUR)  
Students will use their region's evapotranspiration information to calculate the needed frequency and duration of irrigation for a 1-acre field.
- > EXERCISES 5–6: HOW MUCH WATER DO I NEED? HOW MANY ACRES CAN I IRRIGATE? SAMPLE CALCULATIONS (0.5 HOUR EACH)  
Students will practice calculating total water volume needs per unit of time to determine the need for irrigation infrastructure.
- > ASSESSMENT QUESTIONS (0.5 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The role of irrigation water in agricultural systems
- The movement and cycling of water in agricultural systems: E.g., transpiration, capillary action, evaporation, evapotranspiration, evapotranspiration rate, percolation
- Water quantity measurements: E.g., acre/feet, acre/inch, and gallons/minute (GPM)
- Relevant measurements of soil moisture: Soil saturation, gravitational water, field capacity, permanent wilting point
- Environmental factors that influence the type, frequency, and duration of irrigation

### SKILLS

- How to determine the timing and volume of irrigation using qualitative approaches: Gauging relative measures of field capacity using the feel method
- How to determine the timing and volume of irrigation using quantitative approaches: Water budgeting calculations using evapotranspiration rates and calibrated water delivery systems
- How to calculate total water volume needs per unit of time to determine the need for irrigation infrastructure
- How to access Web-based irrigation information

# Lecture Outline: Irrigation

## *for the instructor*

### **A. Pre-Assessment Questions**

1. How do you determine when it is time to irrigate, and how frequently?
2. How do you determine how much water to apply?
3. What are some of the environmental factors that may influence the frequency or duration of irrigation?
4. What are some of the environmental factors that may influence the type of irrigation used?

### **B. The Role of Irrigation Water in Agricultural Systems**

1. Sustains soil biological and chemical activity, extending mineralization and plant growth during dry periods
2. Creates soil solution for nutrient uptake and transfer
3. Provides necessary building blocks for the formation of carbohydrates
4. Provides physical support/structure for plant
5. Maintains optimal temperatures within the plant
6. Protects crops, e.g., during threats of freezing temperatures

### **C. Water Cycling in Agricultural Systems**

1. Definition of terms
  - a) Transpiration
  - b) Capillary action
  - c) Evaporation
  - d) Evapotranspiration (ET)
  - e) Evapotranspiration rate (ETo)
  - f) Infiltration
  - g) Percolation

### **D. Units of Water Measurement**

1. Definition of terms
  - a) Acre inch
  - b) Acre foot
  - c) Gallons per minute (GPM)

### **E. Soil Moisture, Plant Stress, and Crop Productivity**

1. Reduction of yield due to water stress
  - a) Water-stress-sensitive stages of crop development (prioritized)
    - Flowering
    - Yield formation/fruit set
    - Early vegetative growth/seedling stage
    - Fruit ripening
2. Water stress and an increased susceptibility to pests and pathogens
3. Permanent wilting point and crop loss



## **F. Determining When to Irrigate and How Much Water to Apply**

1. Water budgeting (quantitative) approach
  - a) When evapotranspiration exceeds precipitation, irrigation is required
  - b) Resources for determining regional average evapotranspiration rates: California Irrigation Management Information Systems (CIMIS) data (see Resources section)
  - c) Techniques for determining site-specific evapotranspiration
    - i. Evaporation pans
  - d) Calculations used to determine quantities of water delivered through calibrated irrigation systems (see Hands-on Exercises 1–3)
  - e) Irrigation scheduling in different systems based on water budgeting approach
    - i. Annual crops
    - ii. Perennial crops
    - iii. Orchard systems
    - iv. Disadvantages of water budgeting approach
    - v. Advantages of water budgeting approach
2. Monitoring soil moisture by feel: a qualitative approach (see appendix 1)
  - a) Definition of terms
    - i. Soil saturation
    - ii. Gravitational water
    - iii. 100% of field capacity
    - iv. 50% of field capacity as critical soil moisture level
    - v. 25% of field capacity
    - vi. Permanent wilting point
    - vii. Soil water potential
  - b) Exceptions to and variations on the above general rule (see appendix 2)
    - i. Vegetables
    - ii. Perennials
    - iii. Orchards
  - c) Tools for determining soil moisture
    - i. Soil auger
3. Automated tools for determining soil moisture in root zone of crop
  - a) Tensiometers
  - b) Gypsum blocks
  - c) Advantages and disadvantages of method

## **G. Environmental Factors Influencing Frequency and Volume of Irrigation**

1. Climate
  - a) Air temperature
  - b) Precipitation
  - c) Humidity
  - d) Wind
2. Soils
  - a) Sandy soils
  - b) Silty soils
  - c) Clay soils
  - d) Loam soils
  - e) Well-improved agricultural soils

3. Stage of development and crop natural history
  - a) “Water-loving” crops (e.g., celery)
  - b) Drought tolerant crops (e.g., tomato varieties, winter squash varieties, Amaranth, etc.)
  - c) Maturation period (e.g., onions and garlic)

## **H. Environmental Factors Influencing the Type of Irrigation Used**

1. Climate and incidence of disease
  - a. Drip-irrigated crops
  - b. Overhead-irrigated crops

## **I. Irrigation Delivery Systems**

1. Sprinklers
  - a) Micro-sprinklers
    - i. Cost
    - ii. Efficiency
    - iii. Application uniformity
    - iv. Design considerations and infrastructure requirements
  - b) Hand-moved aluminum pipe with impact heads
    - i. Cost
    - ii. Efficiency
    - iii. Application uniformity
    - iv. Design considerations and infrastructure requirements
2. Drip irrigation
  - a) In-line emitters
  - b) T-tape
  - c) Header design
  - d) Management
    - i. Filtration
    - ii. Pressure regulation
    - iii. Flushing
    - iv. Fertigation



# Detailed Lecture Outline: Irrigation

## *for the student*

### **A. Pre-Assessment Questions:**

1. How do you determine when it is time to irrigate?
2. How do you determine how much water to apply?
3. What are some of the environmental factors that may influence the frequency or duration of irrigation?
4. What are some of the environmental factors that may influence the type of irrigation used?

### **B. The Role of Irrigation Water in Agriculture Systems**

1. Sustains soil biological and chemical activity and mineralization during dry periods  
In seasonally dry areas, irrigation water artificially extends the time period in which soil biological activity and nutrient release are elevated, creating more optimal growing conditions for cultivated crops
2. Promotes soil solution and nutrient uptake  
Irrigation water becomes the medium into which soil nutrients are dissolved (soil solution) and through which nutrients are made available for plant uptake
3. Provides carbohydrate building block:  $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$   
Through the process of photosynthesis, water molecules taken up by plants are broken down and their constituent atoms rearranged to form new molecules: Carbohydrates and oxygen
4. Provides plant structure/support  
Water molecules contained within the water-conducting vascular bundles and other tissues of plants serve to provide physical support for the plant itself
5. Promotes the maintenance of optimal temperatures within the plant  
The loss of water through the process of evapotranspiration liberates heat from the plant, thereby regulating plant temperature
6. Crop protection  
Irrigation water is commonly used to lower the freezing temperature in orchard systems during threats of damaging frost

### **C. Water Cycling in Agricultural Systems**

1. Definition of terms
  - a) Transpiration: The loss of water through the stomata of plants as it changes from a liquid to a gas form
  - b) Capillary action: The movement of water through very small pores in the soil from wetter areas to drier areas. Water may move vertically and horizontally.
  - c) Evaporation: The loss of water from the soil to the atmosphere as it changes from a liquid to a gas form and is no longer available to crop plants
  - d) Evapotranspiration (ET): The combination of water being lost from a soil through the combined processes of evaporation and transpiration
  - e) Evapotranspiration rate (ET<sub>o</sub>): The volume of water lost through evapo-transpiration in a given time period
  - f) Percolation: The gravitational process of water moving downward and through the soil horizons

## D. Units of Water Measurement

1. Definition of terms
  - a) Acre inch: The equivalent volume of water application that would cover one acre of land one inch deep in water. Example: On average, approximately one inch of water is lost through evaporation and plant transpiration each week from May 15th–October 15 along the central coast of California.
  - b) Acre foot: The equivalent volume of water application that would cover one acre of land one foot deep in water
  - c) Gallons per minute (GPM): The number of gallons being delivered through an irrigation system in one minute

## E. Soil Moisture, Plant Stress, and Crop Productivity

1. Reduction of yield due to water stress
  - a) Water-stress-sensitive stages of crop development (prioritized)
    - i. Flowering
    - ii. Yield formation/fruit set
    - iii. Early vegetative growth/seedling stage
    - iv. Fruit ripening
2. Increased susceptibility to pests and pathogens with water stress  
Crops repeatedly subjected to water stress will be less resistant and resilient to both pest and pathogens
3. Permanent wilting point  
Crop plants reaching permanent wilting point often die, do not grow well thereafter, or are non-productive

## F. Determining When to Irrigate and How Much Water to Apply

1. Water budgeting approach
  - a) When seasonal ET > precipitation, irrigation is required
  - b) Resources for determining regional average ET (e.g., CIMIS; see Resources section)
  - c) Determining site specific ETo  
The evapotranspiration rate for your garden or farm may be determined by averaging the time period required for the evaporation of 1 inch of water from a given vessel
  - d) Replacing ET with calibrated irrigation systems (see Hands-on Exercises)  
Once the Et rate of your site is determined, this known volume of water may be replaced through the use of calibrated irrigation systems that deliver water at a known rate and volume
  - e) Irrigation scheduling in different systems based on water budgeting approach (see Hands-on Exercises)  
Once the evapotranspiration rate (in gallons/week) and the water delivery rates (in gallons/hour) of the irrigation system are known, the amount of time required to replace water lost may be calculated by dividing ET by the water delivery rate. This will provide the total number of hours required to replace the water lost through evapotranspiration. (An additional 10% should be calculated in to compensate for water loss inefficiencies.)  
The frequency of irrigation should correspond to the time period required for the soil in the root zone of the crop to dry to approximately 50% of field capacity. Due to shallow root systems and greater susceptibility to water stress, annual crop culture often requires a higher frequency of irrigation (2–3 times/week for many crops). Established orchards, which have deep root systems and are less susceptible to water stress, often require less frequent but larger volumes of water to be delivered in each irrigation. In both situations the amount of water lost through ET is replaced. It is only the frequency of irrigation that is different.
    - i. Annual crops

- ii. Perennial crops
  - iii. Orchard systems
- f) Disadvantages: Root restriction and drought susceptibility
- g) Advantages of water budgeting approach: Efficiency in time and water resources
- 2. Measuring soil moisture by feel approach (see appendix 1)
  - a) Definition of terms
    - i. Soil saturation: When all the pores of a given soil are filled with water
    - ii. Gravitational water: The water that will drain from a saturated soil if no additional water is added. This water is not available for plant growth.
    - iii. 100% of field capacity: The point reached when no additional gravitational water drains from a previously saturated soil
    - iv. 50% of field capacity: The amount of water remaining in the soil when 1/2 of the water held in the soil at field capacity has evaporated, drained, and/or has been transpired by growing plants. 50% of field capacity in the root zone of the crop is the soil moisture level at which most crops should be irrigated.
    - v. Permanent wilting point: The point at which soil moisture has been reduced to where the plant cannot absorb it fast enough to grow or stay alive
    - vi. Plant available water: The water content held in the soil between field capacity and permanent wilting point that is available for uptake by plants
    - vii. Soil water potential: The amount of energy required to remove water from the soil. This measurement increases as soils dry, which then increases the possibility of transpiration rates exceeding the rate of uptake, leading to plant stress.
  - b) Exceptions to the above general rule (see appendix 2)
    - i. Vegetable crops
    - ii. Perennial crops
    - iii. Orchard systems
  - c) Hand tools for determining soil moisture in root zone of crop
    - i. Soil auger
  - d) Advantages and disadvantages of measuring soil moisture by feel approach: Additional labor time and inefficiencies of water use
- 3. Automated tools for determining soil moisture in root zone of crop
  - a) Tensiometers
  - b) Gypsum blocks

## **G. Environmental Factors Influencing Frequency and Volume of Irrigation**

- 1. Climate
  - a) Air temperature: Increased air temperatures will increase the rate of ET
  - b) Precipitation: In areas of regular summer rainfall, where precipitation exceeds ET, irrigation is seldom required. Irrigation demands are based on ET rates. Where ET exceeds precipitation, irrigation is required.
  - c) Humidity: Increased humidity will decrease the rate of ET
  - d) Wind: High wind speeds increase ETo
- 2. Soils
  - a) Sandy soils drain rapidly and do not hold water well
  - b) Silty soils drain slowly and hold water well
  - c) Clay soils drain very slowly and hold water tightly
  - d) Loam soils both drain well and hold water well
  - e) Well-improved agricultural soils maintain good drainage and moisture retention properties

3. Stage of development and crop natural history
  - a) "Water-loving" crops (e.g., celery) demand less fluctuation in soil moisture levels
  - b) Drought-tolerant crops (e.g., tomato varieties, winter squash varieties, Amaranth, etc.) may require little or no irrigation
  - c) Maturation period: Prior to harvest, many crops (e.g., onions and garlic) require a gradual reduction in irrigation to encourage maturation.

## **H. Environmental Factors Influencing the Type of Irrigation Used**

1. Climate and incidence of plant pathogens

Overhead irrigation may encourage the growth and spread of certain plant pathogens on crops in certain climates (e.g., *Phytophthora* spp. on melons, cucumber, onions, peppers, and tomatoes along coastal California).

## **I. Irrigation Delivery Systems**

1. Sprinklers
  - a) Micro-sprinklers
    - i. Cost
    - ii. Efficiency
    - iii. Application uniformity
    - iv. Design considerations and infrastructure requirements
  - b) Hand-moved aluminum pipe with impact heads
    - i. Cost
    - ii. Efficiency
    - iii. Application uniformity
    - iv. Design considerations and infrastructure requirements
2. Drip irrigation
  - a) In-line emitters
  - b) T-tape
  - c) Header design
  - d) Management
    - i. Filtration
    - ii. Pressure regulation
    - iii. Flushing
    - iv. Fertigation

# Demonstration 1: Field-Scale Irrigation

## *for the instructor*

### **OVERVIEW**

*This demonstration offers students an in-field look at the tools and techniques used to deliver irrigation water efficiently from the mainline irrigation infrastructure through the specific irrigation delivery system used on your farm. The instructor should begin with an explanation of the irrigation infrastructure used to deliver water to and through the farm, then explain how to set up, adjust, and maintain the specific irrigation system(s) currently in use.*

### **PREPARATION AND MATERIALS**

- Map of farm irrigation system

Irrigation equipment:

- Established set of aluminum pipe with sprinklers
- Component pieces of sprinklers
- Established set of drip irrigation
- Component pieces of drip irrigation equipment
- Tools for setting up and adjusting irrigation equipment
- Irrigation schedules (see appendix 3)

### **PREPARATION TIME**

1.5 hours

### **DEMONSTRATION TIME**

2 hours



## **DEMONSTRATION OUTLINE**

### **A. Irrigation Infrastructure**

1. Explain the layout and identify major components of the farm irrigation water delivery system from source to crop

### **B. Measuring Flow Rate**

1. Demonstrate how to determine flow rate using a garden hose and a 5-gallon bucket

### **C. Sprinkler Irrigation Systems**

1. Demonstrate a typical field layout and a typical orchard layout of a hand-moved aluminum sprinkler system. Include the following demonstrations:
  - a) The proper technique for moving and laying out sprinkler pipes
  - b) Flushing the system clean
  - c) Sprinkler head adjustment
  - d) Layout design and pipe hook-up
2. Demonstrate and explain the importance of proper head adjustment and timing as it relates to application uniformity
3. Demonstrate and explain how to determine optimum operating pressure
4. Students are given the opportunity to unhook, move, and hook up a sprinkler set. The sprinkler set is then turned on and adjusted.

### **D. Drip Irrigation Systems**

1. Demonstrate and explain several examples of drip irrigation header set-ups
2. Demonstrate and explain how to turn on a drip system and set pressure and check for leaks
3. Demonstrate the following:
  - a) How a gate-valve and ball-valve work
  - b) How to set up a drip irrigation header
    - i. How to properly punch holes in the 2" oval tube
    - ii. How to install the barbed connectors into the oval tube
    - iii. How to connect the T-tape to the various types of connectors
    - iv. How to splice T-tape for repairs
    - v. How to cap ends of T-tape
    - vi. How to determine proper system pressure
    - vii. How to properly roll out and roll up T-tape for placement and storage
- 4) Have students cut and splice T-tape

### **E. Review and Discuss Irrigation Scheduling**

1. Review the calculations in Hands-on Exercises 1–3 to determine the volume of water and the frequency of irrigation necessary to replace the water lost through regional evapotranspiration
2. Assign Exercise 4: Calculating irrigation requirements using regional evapotranspiration data
3. Describe and demonstrate the use of an irrigation schedule for tracking and planning irrigation (see appendix 3)

### **F. Review and Discuss Exercises 5 and 6**

1. Exercise 5: How much water is needed to irrigate a given area of land?
2. Exercise 6: How much area can one irrigate with a given flow rate?

# Demonstration 2: Garden-Scale Irrigation

## *for the instructor*

### **OVERVIEW**

*Students must be able to accurately gauge soil moisture and use scale-appropriate irrigation tools and techniques in order to irrigate garden crops efficiently and effectively. The following demonstration provides an overview of the basic skills, concepts, and tools used in garden-scale irrigation. During this demonstration, the instructor should discuss the different approaches to irrigation (qualitative and quantitative) as well as demonstrate the tools and techniques used to monitor soil moisture and schedule irrigation.*

### **PREPARATION AND MATERIALS**

- Oscillators
- Fan
- Drip irrigation system
- Rose
- Micro-sprinklers
- Rain gauge
- Ross
- Soil moisture chart (see appendix 1)
- Blank irrigation schedule (see appendix 4)
- Soil samples or pre-irrigated soils at varying percentages of field capacity

### **PREPARATION TIME**

1.5 hours

### **DEMONSTRATION TIME**

2 hours

## **DEMONSTRATION OUTLINE**

### **A. Irrigation Management by Percent Field Capacity**

1. Review terms
  - a) Soil saturation
  - b) Gravitational water
  - c) 100% of field capacity
  - d) 50% of field capacity
    - i. Review 50% of field capacity as critical moisture level for most cultivated annual crops
  - e) 25% of field capacity
  - f) Permanent wilting point
2. Review exceptions to the to the 50% field capacity general rule (see appendix 2)
3. Review the stages of crop development at which plants are most sensitive to drought/water stress
  - a) Flowering
  - b) Yield formation/fruit set
  - c) Early vegetative growth/seedling stage
  - d) Fruit ripening
4. Have students gauge soil moisture (in percent field capacity) by feel and appearance using appendix 1, Estimating Soil Moisture by Feel
5. Review how to develop an irrigation schedule based on an estimated frequency of dry down to 50% of field capacity (see appendices 3 and 4)
6. Discuss and demonstrate how to properly maintain seedbed soil moisture for small- and large-seeded direct-sown crops
7. Discuss and demonstrate how to assemble, use, and repair garden-scale irrigation equipment (t-tape, oscillators, micro sprinklers, etc.) in delivering water effectively and efficiently
8. Discuss and demonstrate how to assemble and repair the PVC portions of a garden-scale irrigation system

### **B. Irrigation Management Using the Water Budgeting Approach**

1. Determining ETo
  - a) The use of California Irrigation Management Information Systems (CIMIS) data to determine average weekly ETo (see Resources section)
  - b) The use of evaporation pans to determine site-specific averages for weekly ETo
2. Review and discuss the calculations used in developing a weekly irrigation schedule to replace water lost through ETo for drip-irrigated crops. Assign and review the Garden Irrigation Exercise (see next section).
3. Discuss and demonstrate the use of rain gauges in monitoring the volumes of water delivered to replace water losses through ETo in overhead-irrigated crops

# Hands-On Exercises 1– 3 (Sample Calculations): Replacing Water Lost through Evapotranspiration (ET) Using the Water Budgeting Approach

*for the student*

## EXERCISE 1

*The following sample calculation will show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the the amount of water lost through evapotranspiration from a 1-acre block of vegetables using drip irrigation.*

### A. NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ET) IN A 1-ACRE FIELD

- Daily average summer evapotranspiration rate (ET<sub>o</sub>) for an actively growing crop in full canopy in Santa Cruz = 0.15 inch/day
- Multiply this by 7 days/week = 1.05 inches/week
- There are 27,158 gallons of water in an acre inch (the volume of water needed to cover an acre of land to a 1-inch depth)
- An acre = 43,560 square feet (roughly 208 feet x 208 feet)
- Multiplying 1.05 inches/week (ET<sub>o</sub>) x 27,158 gallons/acre inch = 28,516 gallons/acre of water lost each week through evapotranspiration in an actively growing crop in full canopy in Santa Cruz, California

### B. DRIP IRRIGATION OUTPUT CALCULATIONS

- Flow rate of high flow T-tape drip irrigation ribbon with 8-inch emitter spacing at 10 pounds per square inch (psi) = .74 gallons/minute/100 feet
- There are 14,520 feet of row per acre when beds are spaced 36 inches center-to-center
- To determine gallons/hour/acre emitted from one acre of drip irrigation ribbon, divide 14,520 (the number of row feet/acre) by 100 = 145 (the number of 100-foot lengths of drip irrigation ribbon in 1 acre). Multiply 145 by .74 gallons/minute/100 feet (the amount of water delivered through each 100 feet of ribbon) = 107.4 gallons/minute/acre.

- 107.4 gallons/minute x 60 minutes = 6,446 gallons/hour/acre. Two lines of drip tape would provide twice this volume, or 12,892 gallons/hour/acre.

### C. CALCULATING IRRIGATION REQUIREMENTS

- 28,516 gallons/acre are lost through evapotranspiration each week from an actively growing crop in full canopy. The drip system described above is capable of delivering 6,450 gallons/hour/acre @ 10 psi. To calculate the amount of irrigation time required to replace the amount of water lost through Et complete the following:
- Divide 28,516 gallons/acre (ET<sub>o</sub>) by 6,450 gal/hour/acre (irrigation system application rate) = 4.4 hours of irrigation time required each week. Running the one acre of single line drip irrigation with 8 inch emitter spacing for 4.4 hours each week will apply 28,516 gallons/acre (~1.05 inches/acre), which is the amount of water needed to replace what is lost through ET. This total of 4.4 hours/week should be divided into 2–3 evenly timed irrigation sets.

## EXERCISE 2

The following sample calculation will show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the amount of water lost through evapotranspiration from a 1-acre block of vegetables using sprinkler irrigation.

### A. NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ET) IN A 1-ACRE FIELD

- Daily average summer evapotranspiration rate (ET<sub>o</sub>) for an actively growing crop in full canopy in Santa Cruz = .15 inch/day
- Multiply this by 7 days/week = ~1.05 inches/week
- There are 27,158 gallons of water in an acre inch (an acre inch is the amount of water needed to cover an acre to a 1-inch depth)
- An acre = 43,560 square feet (roughly 208 feet x 208 feet)
- Multiplying 1.05 inches/week (ET<sub>o</sub>) x 27,158 gallons/acre inch = 28,516 gallons/acre of water lost each week through evapotranspiration in an actively growing crop in full canopy in Santa Cruz, California.

### B. SPRINKLER IRRIGATION OUTPUT CALCULATIONS

- Flow rate from a 1/8 inch nozzle running at an operating pressure of 45 psi is about 3 gallons per minute (gpm)
- There are roughly 109 sprinkler heads per acre using 20-foot pipes set 20 feet apart (20 feet x 20 feet = 400 square feet. 43,560 square feet/acre divided by 400 = 109)
- 109 sprinkler heads x 3 gpm each = 330 gallons per minute
- 330 gal/min x 60 minutes/hour = 19,800 gallons/hour/acre

### C. CALCULATING IRRIGATION REQUIREMENTS:

- 28,516 gallons/acre are lost through evapotranspiration each week from an actively growing crop in full canopy. The sprinkler system is capable of delivering 19,800 gallons/hour/acre @ 45psi. To calculate the amount of irrigation time required to replace the amount of water lost through Et complete the following:
- Divide 28,516 gallons/acre (ET<sub>o</sub>) by 19,800 gallons/hour/acre (irrigation system application rate) = 1.4 hours of irrigation time required each week.

- Running the one acre sprinkler system for 1.4 hours each week will apply 28,516 gallons/acre (~1.05 inches/acre), which is the amount of water needed to replace that lost through ET. This total of 1.4 hours/week should be divided in to 2–3 evenly timed irrigation sets/ week of 40 or 30 minutes respectively.

\*Note: It is also important to factor in an additional 10–20% for evaporative loss due to extreme heat and wind conditions. It is further advisable to use several rain gauges to check the actual amount applied and to assess uniformity of applications.

### CALCULATING AN ADDITIONAL 10–20% WOULD PROCEED AS FOLLOWS:

- $28,516 + 10\% (.10 \times 28,516) = 31,368$  gallons/acre;  $28,516 + 20\% (.20 \times 28,516) = 34,239$  gallons/acre. Dividing each of the above by the irrigation system output results in the following: 31,368 gallons/acre divided by 19,800 gallons/hour/acre = 1.6 hours of irrigation time each week. 34,239 gallons/acre divided by 19,800 gal/hour/acre = 1.7 hours of irrigation time each week. These totals of 1.6 and 1.7 hours/week should also be divided into 2–3 irrigation sets each week for annual vegetables.

### EXERCISE 3

The following sample calculation will show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the amount of water lost through evapotranspiration from a 100-square-foot garden bed.

#### A. CALCULATING THE NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ET) IN A 100-SQUARE-FOOT GARDEN BED

- Daily average summer evapotranspiration rate (ET<sub>o</sub>) in Santa Cruz = 0.15 inch/day
- Multiply this by 7 days/week = 1.05 inches/week
- 25-foot x 4-foot garden bed = 100 square feet
- 100 square feet x 144 (square inches/foot) = 14,400 square inches
- 100 square feet to 1 inch in depth = 14,400 cubic inches
- 1,728 cubic inches/ cubic ft.
- 1 cubic foot = 7.48 gallons
- 14,400 cubic inches (100-square-foot garden bed) divided by 1,728 cubic inches = 8.33 cubic feet
- 8.33 cubic feet x 7.48 gallons/cubic foot = 62.31 gallons/week lost through Et

#### B. DRIP IRRIGATION OUTPUT CALCULATIONS

- Flow rate of high flow T-tape irrigation ribbon with 8-inch emitter spacing @ 10 psi = .74 gallons/minute/100 feet (assuming 100% efficiency)
- There are 133 emitters/100 ft @ 8-inch spacing
- .74 divided by 133 = 0.00556 gallons/minute/emitter
- .00556 X 60 (inches/hour) = .334 gallons/hour/emitter
- A 25-foot row of T-tape = 300 inches
- 300 inches divided by 8-inches emitter spacing = 37.5 emitters/row
- 37.5 emitters/row x 4 rows t-tape/bed = 150 emitters/ bed
- 150 x .334 gallons/hour/emitter = 50.1 gallons/hour

#### C. CALCULATING IRRIGATION REQUIREMENTS

- 62.31 gallons of water are lost from a single 100-square-foot garden bed through evapotranspiration each week. Four lines of high flow T-tape deliver 50.1 gallons/hour @ 10 psi. To calculate the amount of irrigation time required to replace the amount of water lost through ET, complete the following:
- 62.31 gallons/week (ET) divided by 50.1 gallons/hour (output) = 1.25 hours (or 75 minutes) of irrigation time @ 10 psi. This application of water should be divided between two to three equally long irrigation sets each week, 40 or 25 minutes in length respectively.
- 20% more time should be added to compensate for evaporative losses, leakage, etc. These respective times should be increased to two 45-minute sets or three 30-minute sets/week.

# Hands-On Exercise 4: Calculating a Water Budget for a One-Acre Block of Vegetables (using sprinkler irrigation)

## *for the student*

*In the following exercise you will calculate the amount of irrigation time and frequency of irrigations required to replace the the amount of water lost through evapotranspiration in your area from a one-acre block of vegetables using sprinkler irrigation.*

### A. NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ET<sub>o</sub>) IN A ONE-ACRE FIELD:

- Step 1: Daily average summer evapotranspiration rate (ET<sub>o</sub>) for an actively growing crop in full canopy in your area = \_\_\_\_\_ inches/day
- Step 2: Multiply this by 7 days/week = \_\_\_\_\_ inches/week

Given: There are 27,158 gallons of water in an acre inch (the amount of water needed to cover an acre to a 1-inch depth)

Given: An acre = 43,560 square feet (roughly 208 feet x 208 feet)

- Step 3: Multiplying \_\_\_\_\_ inches/week (ET<sub>o</sub>) x 27,158 gallons/acre inch = \_\_\_\_\_ gallons/acre of water lost each week through evapotranspiration in an actively growing crop in full canopy in your area.

### B. SPRINKLER IRRIGATION OUTPUT CALCULATIONS

- Step 4: Flow rate in gallons per minute (gpm) from an individual sprinkler head \_\_\_\_\_
- Step 5: Given: There are roughly 109 sprinkler heads per acre using 20 foot pipes set 20 feet apart. (20 feet x 20 feet = 400 square feet. 43,560 square feet/acre divided by 400 = 109)
- Step 6: 109 sprinkler heads x \_\_\_\_\_ gallons/minute each = \_\_\_\_\_ gallons per minute
- Step 7: \_\_\_\_\_ gallons/minute x 60 minutes/hour = \_\_\_\_\_ gallons/hour/acre total

### C. CALCULATING IRRIGATION REQUIREMENTS

- To calculate the amount of irrigation time required (in hours/week) to replace the amount of water lost through evapo-transpiration each week, complete the following calculations:
  - Divide the total in Step 3 \_\_\_\_\_ gallons/acre ET by the total in Step 7 \_\_\_\_\_ gallons/hour/acre from the irrigation system = \_\_\_\_\_ hours of irrigation time required each week. This total time should be divided in to 2–3 irrigation sets for mixed vegetable operations.
- \* Note: It is also important to factor in an additional 10–20% for evaporative losses due to extreme heat and wind conditions. It is further advisable to use several rain gauges to check the actual amount applied and to assess uniformity of application.



# Hands-On Exercises 5 and 6 (Sample Calculations): How Much Water Do I Need? How Many Acres Can I Irrigate?

## *for the student*

*In the following exercises you will calculate the total rate and volume of irrigation water that must be delivered to support two hypothetical farming operations. This information will help you determine the irrigation system needed to support the delivery of this volume of water.*

### **EXERCISE 5: HOW MUCH WATER DO I NEED?**

I have 10 acres that I want to farm. The climate is Mediterranean with a fairly dry summer season. There is no well or pump on the property. The property is situated over an aquifer that has an adequate water supply. I have adequate capital to invest in a well and pump to supply irrigation water for my farm. I need to decide how much water I need (flow rate in gallons per minute) to irrigate the entire 10 acres, so that I can have the proper-sized well and pump installed.

#### **GIVEN**

- At any time during the summer the entire 10 acres may be in production
- The daily average evapotranspiration rate (ET<sub>o</sub>) during the summer months is about 0.30 inch per day
- There are 27,158 gallons of water in an acre inch
- You only plan to run the pump 12 hours per day
- There are 10,080 minutes per week (60 minutes/hour x 24 hours/day x 7 days/week)
- There are 5,040 minutes per week at 12 hours per day (10,080 divided by 2)

#### **SOLUTION**

1. Multiply 0.30 inches (ET<sub>o</sub>) by 7 (days per week) to get 2.1 inches per week
2. Assume that your application will be 75% efficient and multiply 2.1 (inches per week) by 1.25 to get 2.625 inches per week (application rate to supply actively growing crops with adequate moisture for maximum yield during summer months)
3. Multiply 2.625 inches per week by 27,158 (gallons per acre inch) to get 71,290 gallons per acre per week
4. Multiply 71,290 (gallons per week) by 10 (acres) to get 712,900 gallons per week
5. Divide 712,900 (gallons per week) by 5,040 (minutes per week at 12 hours per day) to get 141.44 gallons per minute

Your pump and well will have to deliver 141.44 gallons of water per minute to keep your 10-acre farm productive during the summer months. If you were willing to irrigate 24 hours per day you would only need an output of 70 GPM (gallons per minute).



### EXERCISE 6: HOW MANY ACRES CAN I IRRIGATE?

Someone has just offered you 10 acres of farmland in the Pajaro Valley on the central coast of California. There is a pump and well on the property capable of delivering 15 GPM. There are no other sources of water in the area. Your daily average ETo in the summer is 0.20 inch. How many acres of irrigated vegetables can you plant during the summer months without running short of water?

#### GIVEN

- The daily average ETo during the summer months is about 0.20 inch per day
- There are 27,158 gallons of water in an acre inch
- The pump flow rate is 15 gallons per minute
- You are only able to run the irrigation 12 hours per day during peak use

#### SOLUTION

1. Multiply 15 gallons per minute (GPM) by 60 (min per hr) to get 900 gallons per hour
2. Multiply 900 gallons per hour by 84 (hours per week @ 12 hours per day) to get 75,600 gallons per week maximum pump output
3. If your average ETo during the summer months is .20 inches per day for an actively growing crop in full canopy, then multiply .20 (daily ETo) by 7 (days per week) to get 1.4 inches per week
4. Multiply 1.4 (inches per week ETo) by 27,158 (gallons per acre inch) to get 38,021 gallons per acre per week to keep your full canopy crops supplied with adequate water during the summer months
5. Assuming your application efficiency is 75%, multiply 38,021 by 1.25 to get 47,526 gallons per week
6. Divide 75,600 (maximum pump output per week) by 47,526 (weekly crop need per acre) to get 1.6 acres

Your 15 GPM well is capable of irrigating 1.6 acres of actively growing crop in full canopy during the summer months assuming 75% application efficiency and with application happening 12 hours per day. If you are willing to irrigate 24 hours per day then you can irrigate 3.2 acres.

If you increase your efficiency by only using overhead during the night, and utilize drip tape, you could increase your crop area slightly. If you plant crops with a low moisture requirement and if your soil and climate are conducive to dry farming (deep clay soil, mild summer temperatures, and at least 30 inches of precipitation annually during the winter) you might be able to farm the entire 10 acres.



# Assessment Questions Key

1) Describe four functions of water in an agroecosystem.

- *plant support/turgidity*
- *nutrient transport (soil solution)*
- *plant cooling through transpiration*
- *plant nutrient (photosynthesis)*
- *soil moisture for soil organisms*

2) What is soil saturation?

*When water is filling all the available pore spaces in a given soil*

3) What is field capacity?

*A soil is at field capacity when the free water/gravitational water drains from a saturated soil*

4) What is the level of soil moisture at which most crop plants require additional water?

*50% of field capacity*

5) Describe two ways that agriculturists determine the need for irrigation.

- *Qualitative: Measuring for relative percentages of field capacity in the root zone of the crop*
- *Quantitative: Determining the evapotranspiration rate of a given site and systematically replacing the amount of water lost each week through calibrated water delivery systems*

6) Number the following stages of crop developmental in terms of their sensitivity to drought/water stress (1 being most sensitive and 4 being least sensitive):

1. *Flowering*
2. *Yield formation/fruit set*
3. *Early vegetative growth*
4. *Fruit ripening*

# Resources

## PRINT RESOURCES

Cleveland, David A. and Daniela Soleri. 1991. *Food from Dryland Gardens: An Ecological and Social Approach to Small-Scale Household Food Production*. Tucson, AZ: Center for People, Food and the Environment.

*An overview of small-scale and community-based food production techniques intended for use by development educators and rural organizers in less developed nations. Encourages the development of gardens that serve local needs, that are based on local knowledge, and that conserve natural resources and the biodiversity of traditional crops. Includes an excellent section on the principles and practices of low-technology garden-scale irrigation.*

Hansen, Blaine, Larry Schwankl, and Allan Fulton. 1999. *Scheduling Irrigations: When and How Much Water to Apply*. Publication 3396. UC Irrigation Program, UC Davis. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A technical reference for irrigation tools and techniques used in production agriculture. Includes many common calculations used to determine when to irrigate and how much water to apply.*

Hansen, Blaine, Larry Schwankl, and Terry Prichard. 1999. *Micro-irrigation of Trees and Vines*. Publication 94-01. UC Irrigation Program, UC Davis. Oakland, CA: Division of Agriculture and Natural Resources.

*Offers an overview of the rationale for micro-irrigation and how to assemble, operate, and maintain such a system.*

## WEB RESOURCES

California Irrigation Management Information Systems

[www.cimis.water.ca.gov](http://www.cimis.water.ca.gov)

*California weather information site designed to help growers, turf managers, and others properly time irrigation applications.*

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see “Course Curriculum”)

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

UC Davis Small Farm Center, Family Farm Series Publications: Vegetable Crop Production—Tips on Irrigating Vegetables

[www.sfc.ucdavis.edu/Pubs/Family\\_Farm\\_Series/Veg/vegcrop.html](http://www.sfc.ucdavis.edu/Pubs/Family_Farm_Series/Veg/vegcrop.html)

*Information on pre-irrigation, timing, irrigation system options, and other useful tips for irrigating vegetable row crops.*

UC Division of Agriculture and Natural Resources: Irrigation

[www.anrcatalog.ucdavis.edu](http://www.anrcatalog.ucdavis.edu)

*Publications and instructional materials on irrigation.*

# Appendix 1: Estimating Soil Moisture By Feel

SOIL MOISTURE LEVEL (% OF FIELD CAPACITY)	COARSE (SAND)	LIGHT (LOAMY SAND, SANDY LOAM)	MEDIUM (FINE, SANDY LOAM, SILT LOAM)	HEAVY (CLAY LOAM, CLAY)
<b>0 –25%</b> No available soil moisture. Plants wilt. Irrigation required. (1 <sup>st</sup> range)	Dry, loose, single grained, flows through fingers. No stain or smear on fingers.	Dry, loose, clods easily crushed and will flow through fingers. No stain or smear on fingers.	Crumbly, dry, powdery, will barely maintain shape. Clods, breaks down easily. May leave slight smear or stain when worked with hands or fingers.	Hard, firm baked, cracked. Usually too stiff or tough to work or ribbon <sup>1</sup> by squeezing between thumb or forefinger. May leave slight smear or stain.
<b>25 –50%</b> Moisture is available, but level is low. Irrigation needed. (2 <sup>nd</sup> range)	Appears dry; will not retain shape when squeezed in hand.	Appears dry; may tend to make a cast <sup>2</sup> when squeezed in hand, but seldom will hold together.	May form a weak ball <sup>2</sup> under pressure but will still be crumbly. Color is pale with no obvious moisture.	Pliable, forms a ball; will ribbon but usually breaks or is crumbly. May leave slight stain or smear.
<b>50 –75%</b> Moisture is available. Level is high. Irrigation not yet needed. (3 <sup>rd</sup> range)	Color is darkened with obvious moisture. Soil may stick together in very weak cast or ball.	Color is darkened with obvious moisture. Soil forms weak ball or cast under pressure. Slight finger stain, but no ribbon when squeezed between thumb and forefinger.	Color is darkened from obvious moisture. Forms a ball. Works easily, clods are soft with mellow feel. Will stain finger and have slick feel when squeezed.	Color is darkened with obvious moisture. Forms good ball. Ribbons easily, has slick feel. Leaves stain on fingers.
<b>75% to field capacity (100%)</b> Soil moisture level following an irrigation. (4 <sup>th</sup> range)	Appears and feels moist. Color is darkened. May form weak cast or ball. Will leave wet outline or slight smear on hand.	Appears and feels moist. Color is darkened. Forms cast or ball. Will not ribbon, but will show smear or stain and leave wet outline on hand.	Appears and feels moist. Color is darkened. Has a smooth, mellow feel. Forms ball and will ribbon when squeezed. Stains and smears. Leaves wet outline on hand.	Color is darkened. Appears moist; may feel sticky. Ribbons out easily, smears and stains hand, leaves wet outline. Forms good ball.

<sup>1</sup> Ribbon is formed by squeezing and working soil between thumb and forefinger.

<sup>2</sup> Cast or ball is formed by squeezing soil in hand.

# Appendix 2: General Irrigation Rules

- During the flowering and fruit set stages of crop development, plants are most sensitive to drought/water stress.
- Most crops require irrigation when the soil moisture in the root zone of the plant has decreased to ~50% of field capacity. Use appendix 1, Estimating Soil Moisture By Feel, to help you determine the moisture content of the soil.
- Seed beds containing small-seeded, directly sown crops require light and frequent water applications. Apply water each time 50% of the surface soil has dried down, showing discoloration (see appendix 4, Unit 1.4).
- Seed beds containing large-seeded, directly sown crops require less frequent water applications. Apply water each time the soil at the depth of the seed has dried to 50% of field capacity. Use appendix 1 to help you determine the moisture content of the soil.

## **ADDENDA TO THE GENERAL RULES**

1. Potatoes: Phase 1 and phase 4 (the planting and maturation stages) require the full soil moisture fluctuation between 50% and 100% of field capacity. Phase 2 and phase 3 (tuber initiation and enlargement) demand less of a fluctuation, responding favorably to a moisture swing between 75% and 100% of field capacity.
2. Other Solanaceae family crops (e.g., tomatoes, peppers, eggplant) respond favorably to a full swing between 50% and 100% of field capacity.
3. Cut flowers: Irrigation 24 hours prior to harvest will help assure full turgor pressure at harvest time and increase the vase life of the stems or bouquets.
4. Leafy greens: 50% of field capacity minimum.
5. Alliums: 50% of field capacity minimum.
6. Established fresh beans and peas: 50% of field capacity minimum.
7. Celery responds favorably to a moisture swing between 75%–100% of field capacity.







# Appendix 5: Amount of Water Needed to Pre-Irrigate a Dry Soil to Different Depths (Approximate)<sup>1</sup>

SOIL TYPE <sup>2</sup>	INCHES WATER PER FOOT SOIL DEPTH	INCHES WATER TO REACH 6 FEET DEEP
Clay	1.4–1.8	8.6–10.8
Silty clay	1.6–1.9	9.6–11.4
Sandy clay	1.6–1.9	9.6–11.4
Silty clay loam	2.2–2.3	13.0–13.7
Clay loam	2.0–2.2	12.2–13.0
Sandy clay loam	2.0–2.2	12.2–13.0
Silt-loam	1.8–2.0	10.8–12.2
Loam	1.7–1.9	10.1–11.4
Very fine sandy loam	1.7–1.9	10.1–11.4
Sandy loam	1.1–1.3	6.5–7.9
Loamy very fine sand	1.1–1.3	6.5–7.9
Loamy fine sand	1.0–1.2	5.8–7.2
Loamy sand	0.7–1.0	4.3–5.8
Very fine sand	0.7–1.0	4.3–5.8
Fine sand	0.7–1.0	4.3–5.8
Sand	0.7–1.0	4.3–5.8
Coarse sand and gravel	0.4–0.7	2.2–4.3

<sup>1</sup>Based on available water holding capacity; plants have dried soil to permanent wilting point, 15 ATM.

<sup>2</sup>Assumes the soil is uniform throughout irrigation depth.

# 1.6 Selecting and Using Cover Crops

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# Introduction: Selecting and Using Cover Crops

## OVERVIEW

*Cover crops can be a key soil fertility and pest management tool for growers. This unit introduces students to the role and selection of cover crops for organic farming and gardening systems. The lecture addresses the influence of cover crops on soil's physical and chemical properties, the role cover crops play in pest management, and the factors to consider when selecting a cover crop for a farm or garden. The resources section includes an annotated list of print and electronic references that students may use in selecting cover crop species or mixes for specific agricultural applications.*

## MODES OF INSTRUCTION

- > LECTURE (1.5 HOURS)  
A lecture covers the advantages and disadvantages of using cover crops and the three-step process of choosing a cover crop based on the agricultural system's needs.
- > ASSESSMENT QUESTIONS (0.5 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The influence of cover crops on the physical and chemical properties of agricultural soils
- The role cover crops play in pest and disease management
- The factors to consider when selecting a cover crop for farm or garden use

### SKILLS

- How to access cover crop information
- How to estimate nitrogen contributions of cover crops



# Lecture Outline: Selecting and Using Cover Crops

## *for the instructor*

### A. Pre-Assessment Questions

1. What benefits can be derived from the regular use of cover crops in a farming system?
2. What role do cover crops play in the management of soil fertility in organic farms and gardens?
3. How can cover crops be used to ensure adequate soil nutrient levels/nutrient budgeting?
4. How can cover crops improve the physical properties of agricultural soils?
5. What role can cover crops play in pest management?
6. What are the factors to consider when selecting a cover crop for your farm or garden?

### B. Why Use Cover Crops?

1. The role of cover crops in organic farming systems: Benefits and disadvantages
2. Cover crop, “green manure,” and “catch crop” defined
  - a) Cover crop: Mainly used to prevent soil erosion by covering soil with living plants
  - b) Green manure: Crop grown mainly to be turned under for soil improvement
  - c) Catch crop: Used to “catch” nutrients left after harvest of a cash crop and prevent leaching
  - d) Most cover crops serve multiple functions

### C. How to Choose a Cover Crop

1. Three steps in selecting a cover crop
  - a) Step 1: Identify what you want the cover crop to do
    - i. Defining primary function of cover crop based on needs of system
      - Provide nitrogen
      - Increase soil organic matter (SOM) and improve nutrient availability
      - Scavenge nutrients
      - Prevent soil erosion
      - Improve soil structure
      - Improve drainage
      - Protect water quality
      - Provide mulch to conserve soil moisture and/or suppress weeds
      - Provide habitat for beneficial insects and spiders
      - Suppress weeds
      - Suppress soil borne pests and diseases
  - b) Step 2: Identify planting niche
    - i. Defining when and where the cover crop fits in your crop rotation
    - ii. Examples of cool weather and warm weather cover crops
  - c) Step 3: Select cover crop species or mix to meet the goals and requirements from steps 1 and 2. Once you have set the priorities for what cover crop effects you are looking for, and you have identified when the cover crop can be grown, the final step is to match the potential candidates identified in step 2 with the required characteristics identified in step 1.

i. Additional considerations

- Consider the characteristics you don't want as well as those you are looking for
- Consider the cost and availability of seed
- Consider the number and types of field operations required for the different options in order to make a sound economic assessment of the alternatives

**D. How to Roughly Estimate N Contribution from a Cover Crop**

1. Calculate above-ground weight for a given area as follows:

- a) Take a number of samples from the field (clip at ground level, and use a yardstick or frame to measure area to be sampled)
- b) Dry for a few days in sun, greenhouse or oven (140°F) until "crunchy" or brittle
- c) Calculate the dry weight produced in pounds/acre (lbs/ac) as follows:

$$\text{Dry wt (lbs/ac)} = \frac{\text{weight of samples} \times 43,560 \text{ sq.ft}}{\text{\# of sq. ft sampled}}$$

2. Multiply dry wt by the % N content of the biomass (see below) to give total N in cover crop in lbs/ac:

$$\text{Total N (lb/ac)} = \text{dry weight} \times \frac{\%N}{100}$$

3. To estimate how much of the N will be available to the crop that season:

If conventionally tilled divide total N by 2

If left on surface divide by 2 in warmer climates, by 4 in cooler climates

4. Typical % N contents for cover crop types

Before flowering:

Annual legumes 3.5–4%

Perennial legumes: 2.5–3%

Grasses, brassicas: 2–3%

When flowering:

Annual legumes: 3–3.5%

Perennial legumes: 2–2.5%

Grasses, brassicas: 1.5–2.5%

From: *Managing Cover Crops Profitably, 2nd Edition*, published by the Sustainable Agriculture Network (see Resources section). Used by permission.

# Detailed Lecture Outline: Selecting and Using Cover Crops

## *for students*

### **A. Pre-Assessment Questions**

1. What benefits can be derived from the regular use of cover crops in a farming system?
2. What role do cover crops play in the management of soil fertility in organic farms and gardens?
3. How can cover crops be used to ensure adequate soil nutrient levels/nutrient budgeting?
4. How can cover crops improve the physical properties of agricultural soils?
5. What role can cover crops play in pest management?
6. What are the factors to consider when selecting a cover crop for your farm or garden?

### **B. Why Use Cover Crops?**

1. The role of cover crops in organic farming systems

Cover crops are one of the primary fertility and soil management tools available to the organic farmer, and are an important strategy for preventing nutrient and soil loss from a field. They are crops grown primarily for soil or ecosystem improvement rather than cash, and can provide a variety of services, from increased nitrogen (N) input, to soil protection, to weed and disease suppression. However, they can also have negative consequences if they are managed incorrectly or the wrong species are chosen. These issues are covered in Unit 1.1, Soil Fertility Management.

2. Cover crop, "green manure," and "catch crop" defined

Though the terms are used interchangeably, cover crop, green manure, and catch crop refer to different primary functions of the crops planted

- a) Cover crop: Mainly used to prevent soil erosion by covering soil with living plants
- b) Green manure: Crop grown mainly to be turned under for soil improvement
- c) Catch crop: Used to "catch" nutrients left after harvest of a cash crop and prevent leaching

These are not mutually exclusive functions. For example, a fall-planted cereal + legume crop that is incorporated the following spring can serve as a cover crop, green manure, and catch crop. However, different species and mixes may perform one function better than another.

### **C. How to Choose a Cover Crop**

1. Deciding whether it is desirable or feasible to include a cover crop in a given production system, and which cover crop to use, involves the following three steps

- a) Step 1: Identify what you want the cover crop to do

The first step is to identify your goals by prioritizing the main effects you want the cover crop to have in your system. This will depend on what you think are the most important factors limiting the productivity and sustainability of your production system. For example, is it low fertility, poor soil structure, weed or pest populations? Deciding this is critical before choosing which cover crop to use.

- i. Defining primary function of cover crop based on needs of system



- *Provide nitrogen.* Here the best choice would be a legume that is well adapted to your area. It is important to ensure that sufficient rhizobia bacteria are present in the soil to give good root nodule formation, and hence N<sub>2</sub> fixation. If it is the first time a legume cover crop has been grown in a field it is recommended that you purchase the appropriate rhizobium inoculant for the species being planted. A rough guide to estimating the N contribution from a cover crop is shown on page 10 (excerpted from *Managing Cover Crops Profitably, 2nd Edition*, published by the Sustainable Agriculture Network).
- *Increase soil organic matter (SOM) and improve nutrient availability by increasing soil biological activity.* To build SOM you would look for a high biomass-producing cover crop. Possible options include non-legumes such as annual rye grass, cereal rye, triticale, or sorghum/sudan grass if a summer niche is identified. High-biomass legumes such as sub-clover or woollypod vetch would also work and provide N, as would a mix of cereals and legumes.
- *Scavenge nutrients left in the soil after the cash crop and prevent loss by leaching.* To maximize nutrient scavenging the cover crop should have an extensive root system that develops quickly after planting. Non-legumes such as small grains, cereal rye, triticale, rapeseed, annual rye grass, oilseed radish, and mustards work well, but some legumes are also suitable.
- *Prevent soil erosion.* Here the key is to choose a species that rapidly covers the soil surface. Many of the species that are good nutrient scavengers also provide excellent ground cover. However, while annual rye grass is a good nutrient scavenger, it has fine leaves and is slow to cover the soil surface.
- *Improve soil structure.* Increasing SOM is the key to improving soil structure, and similar species can be used. It may be beneficial to include a non-legume to provide organic material that breaks down more slowly than a legume alone.
- *Improve drainage.* Some deep-rooted species can help to break through compacted layers in the soil and improve drainage. The roots of soil-penetrating cover crops also create channels through which water can move as the root systems decompose after death or incorporation. Examples include bell beans (*Vicia faba*) and clovers (*Trifolium* spp.). In addition, many grass species with extensive, fibrous root systems add large quantities of organic matter to the soil by sloughing off roots. Such organic matter additions stimulate biological activity and the formation of soil aggregates, which improve soil's drainage. Examples include annual rye, perennial rye, and oats.
- *Protect water quality.* This is achieved by selecting species that both prevent soil erosion and scavenge nutrients during periods of high rainfall. It is also important to avoid turning in high N cover crops when the soils will be vulnerable to leaching, e.g., when there is little or no crop cover and high rainfall.
- *Provide mulch to conserve soil moisture and/or suppress weeds.* A combination of high above-ground biomass and moderate or high C:N ratio residues is desirable. Most legume residues with their high nitrogen content will decompose too rapidly to be effective.
- *Provide habitat for beneficial insects and spiders.* This aspect of cover crop ecology has not been well studied for annual systems, and there may be more potential than has been recognized. From research in orchards and vineyards it is clear that cover crops provide good habitat for beneficials, especially when species with food sources such as extrafloral nectaries (e.g., vetch) or flowers are used. The key in annual systems is to make sure that when the cover crop is turned in there are alternative habitats for the beneficials to move to.

- *Suppress weeds.* Cover crops can reduce weed populations either by outcompeting weeds by more vigorous growth and dense canopy cover, or by releasing allelopathic compounds that inhibit weed seed germination and growth. Some good options include cereal rye, triticales, sorghum/sudan and other cereals, as well as brassicas such as rapeseed and oilseed radish, and high biomass or allelopathic legumes. A well-balanced mix can also work, providing the canopy closes quickly. It is also important to remember that certain cover crops can themselves become weeds if they have persistent or hard seed. Finally, just as crop rotation is important, it is advisable to avoid using the same cover crop every year, particularly a single species. Otherwise populations of weeds that are most competitive with that species will build up, as will pests and disease organisms that also attack that species.
  - *Suppress soil borne pests and diseases.* Certain species are known to suppress particular disease or pest organisms. Similarly others are known to be excellent hosts to certain pests and diseases. If your field is known to have a history of bad pest or disease problems this will affect your choice of cover crop. For example, cereal rye, sorghum/sudan, selected rapeseed varieties (e.g., c.v. humus), oilseed radish, and white mustard are known to suppress root knot nematodes, and soil-borne diseases such as rhizoctonia and verticillium wilt. Conversely many legumes are excellent hosts for nematodes and populations will increase rapidly in the soil with their use unless the crop is turned in before the nematodes complete their life cycle. If the timing is correct the legume may actually reduce nematode populations by stimulating the nematodes' emergence but killing them when the crop is turned in and the infected roots die before their life cycle is complete.
- b) Step 2: Identify the cover crop planting niche
- When and where can the cover crop fit in your crop rotation? What are the climatic and soil conditions at that time? Once these two questions are answered, then you can select the best species or mix to plant.
- i. Defining when and where the cover crop fits in your crop rotation
 

To choose when to plant cover crops, timing of field operations to avoid interfering with cash crop production is critical. Once the opportunity for cover crop growth and incorporation is identified then the species selection will depend on the climatic and soil conditions during the window. The publications and web sites in the Resources section of this unit provide information on climatic and soil requirements for many cover crops and will enable you to identify potential species to consider.

    - Define timing of critical field operations for cash crop production. Field operations and labor needs for cash crop production will take precedence over cover crop management, so it is important to minimize these conflicts.
  - ii. Examples of cool weather and warm weather cover crops
    - Winter cover crops. Most cover crops are planted in the fall to provide cover over the winter months. Examples include: Vetches, fava/bell beans, peas, annual and perennial clovers, rape seed and oilseed radish, and grasses such as oats, annual and perennial rye grass, or barley.
    - Summer cover crops. When temperatures are high during the summer and providing water is available, fast-growing species such as sorghum/sudan grass, cowpeas, annual buckwheat, lab lab, Crotalaria (sun hemp), Sesbania, and others can provide a good biomass return in a short growth period.

- c) Step 3: Select cover crop species or mix to meet the goals and requirements from steps 1 and 2  
Once you've set the priorities for what cover crop effects you are looking for, and you've identified when the cover crop can be grown, the final step is to match the potential candidates identified in step 2 with the required characteristics identified in step 1
- i. Additional considerations:
- Consider the characteristics you don't want as well as those you are looking for. It is rare that the "perfect" cover crop will exist and trade-offs will need to be made amongst different goals.
  - Consider the cost and availability of seed
  - Consider the number and types of field operations required for the different cover cropping options to make a sound economic assessment of the alternatives

#### D. How to Roughly Estimate N Contribution from a Cover Crop

1. Calculate above-ground weight for a given area as follows\*:
  - a) Take a number of samples from the field (clip at ground level, and use a yardstick or frame to measure area to be sampled)
  - b) Dry for a few days in sun, greenhouse, or oven (140°F) until "crunchy" or brittle
  - c) Calculate the dry weight produced in pounds/acre (lbs/ac) as follows:  

$$\text{Dry wt (lb/ac)} = \frac{\text{weight of samples} \times 43,560 \text{ square feet}}{\text{\# of sq. ft. sampled}}$$
2. Multiply dry wt by the % N content of the biomass (see 4, below) to give total N in cover crop in lbs/ac:  

$$\text{Total N (lb/ac)} = \text{dry wt} \times \frac{\%N}{100}$$
3. To estimate how much of the N will be available to the crop that season  
 If conventionally tilled, divide total N by 2  
 If left on surface, divide by 2 in warmer climates, by 4 in cooler climates
4. Typical % N contents for cover crop types
 

Before flowering:

  - Annual legumes: 3.5–4%
  - Perennial legumes: 2.5–3%
  - Grasses, brassicas: 2–3%

When flowering:

  - Annual legumes: 3–3.5%
  - Perennial legumes: 2–2.5%
  - Grasses, brassicas: 1.5–2.5%

\*From: *Managing Cover Crops Profitably, 2nd Edition*, published by the Sustainable Agriculture Network (see Resources section). Used by permission.

# Demonstration: How to Estimate the Nitrogen Contribution of a Cover Crop

## *for the instructor*

### **OVERVIEW**

*Through this hand-on field demonstration and discussion, students will learn how to estimate the nitrogen contribution of a cover crop for nutrient budgeting purposes. (Please see Unit 1.11, Reading and Interpreting Soil Test Reports for more on nutrient budgeting.)*

### **PREPARATION AND MATERIALS**

1. If possible, students should have received the lecture portion of this unit covering the biology and functions of cover crops in agricultural systems.
2. Necessary tools and equipment: greenhouse or oven (for drying cover crops), clippers, measuring tape/stick or measuring frame, scale.
3. A mature stand of actively growing cover crops.
4. Demonstrate procedure and then assign each small group the tasks of cutting, drying, weighing, and calculating the nitrogen contribution of the cover crops (in total N lb/ac).

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION AND DISCUSSION TIME**

(2) 2 hour periods

## DEMONSTRATION OUTLINE

### A. Discuss and demonstrate the collection and calculation of the above-ground weight for a given area of cover crop

1. Demonstrate taking a number of samples from the field: how to use a yardstick or frame to measure area to be sampled, and how to clip the cover crops at the ground level
2. Demonstrate and discuss techniques for sun drying the fresh cover crop material in the greenhouse or in the oven (140°F) until “crunchy” or brittle
3. After drying material, demonstrate how to calculate the dry weight produced in pounds/acre (lbs/ac) as follows:
  - a) Dry weight (lb/ac) =  $\frac{\text{weight of samples} \times 43,560 \text{ square feet}}{\# \text{ of sq. ft. sampled}}$
  - b) Multiply dry weight by the % N content of the biomass (see below) to give total nitrogen in cover crop in lbs/ac:
$$\text{Total N (lb/ac)} = \text{dry wt} \times \frac{\%N}{100}$$

Typical % N contents for cover crop types –

Before flowering –

- Annual legumes: 3.5–4%
- Perennial legumes: 2.5–3%
- Grasses, brassicas: 2–3%

When flowering –

- Annual legumes: 3–3.5%
- Perennial legumes: 2–2.5%
- Grasses, brassicas: 1.5–2.5%

*Note: To estimate how much of the N will be available to the crop that season –*

- If conventionally tilled, divide total N by 2
- If left on surface, divide by 2 in warmer climates, by 4 in cooler climates

4. Discuss variables in nitrogen availability and percentage (above)
5. Discuss the application of the findings to the development of nitrogen budgets for farming systems. (Please see Unit 1.11: Reading and Interpreting Soil Test Reports for more on nutrient budgeting.)
6. Assign the above exercise for groups of students to perform

Adapted from: *Managing Cover Crops Profitably, 2nd Edition*, published by the Sustainable Agriculture Network (see Resources section). Used by permission.

# Assessment Questions

1) Define the following terms:

Cover crop

Green manure

Catch crop

2) In what ways do cover crops serve to improve or maintain the nutrient availability of agricultural soils?

3) In what ways do cover crops serve to improve or maintain the physical properties of agricultural soils?

4) In what ways do cover crops play a preventive pest management role in agricultural systems?

5) What are the factors to consider when selecting a cover crop for your farm or garden?

# Assessment Questions Key

1) Define the following terms:

- *Cover crop = Mainly used to prevent soil erosion by covering soil with living plants*
- *Green manure = Crop grown mainly to be turned under for soil improvement*
- *Catch crop = Used to “catch” nutrients left after harvest of a cash crop and prevent leaching*

2) In what ways do cover crops serve to improve or maintain the nutrient availability of agricultural soils?

- *Legume cover crops are able to “fix” atmospheric nitrogen (N<sub>2</sub>) and convert it into a plant-useable form. Up to 200 lbs/acre of actual N can be fixed by certain species of cover crops. This can be a significant contribution to the N budget of a cash crop. Grains and cereal cover crops with extensive root systems that develop quickly after planting are also able to “scavenge” water-soluble nutrients left in the soil after the cash crop and prevent loss through leaching. Deep-rooted fabaceous cover crops are also able to access normally unavailable nutrients (e.g., phosphorous) from lower soil horizons and bring them to the surface through the distribution of the nutrients through their tissues. Such nutrients are then made available to cash crops when cover crops are tilled into the soil.*

3) In what ways do cover crops serve to improve or maintain the physical properties of agricultural soils?

- *Cover crops help prevent soil erosion. When tilled in, cover crops cycle organic matter through agricultural soils. This cycling of organic matter provides energy (carbohydrates) and nutrients (nitrogen) that increase soil biological activity. Through the process of decomposition, soil organisms bind soil particles together forming stable (erosion-resistant) soil aggregates that improve and maintain desirable soil structure.*

- *Cover crops improve drainage. Some deep-rooted cover crop species can help to break through compacted layers in the soil and improve drainage.*

4) In what ways do cover crops play a preventive pest management role in agricultural systems?

- *Provide habitat for beneficial insects and spiders: Though not well studied in annual cropping systems, it is clear from research in orchards and vineyards that cover crops provide good habitat for beneficial insects especially when species with food sources such as extrafloral nectaries (e.g., vetch) or flowers are used*
- *Certain cover crops suppress soil borne pests and diseases: Certain species are known to suppress particular disease or pest organisms through allelopathy*
- *Cover crops suppress weeds: Cover crops can reduce weed populations either by outcompeting weeds by more vigorous growth and dense canopy cover, or by releasing allelopathic compounds that inhibit weed seed germination*

5) What are the factors to consider when selecting a cover crop for your farm or garden?

- *Step 1: Identify what you want the cover crop to do.*
- *Step 2: Identify where the cover crop can fit in your crop rotation and what the climatic and soil conditions are at that time.*
- *Step 3: Select cover crop species or mix to meet the goals and requirements from steps 1 and 2, considering the characteristics you don't want as well as those you are looking for. Consider the cost and availability of seed and the number and types of field operations required to manage the cover crop.*



# Resources

## PRINT RESOURCES

Chaney, David, and Ann Mayse, eds. 1997. *Cover Crops: Resources for Education and Extension*. Davis, CA: UC Sustainable Agriculture Research and Education Program (UC SAREP), UC Division of Agriculture and Natural Resources.

*A collection of materials that educators will find useful in conveying information about cover crops to farmers and ranchers. The packet includes a variety of materials that may be used in short courses, seminars, workshops, etc. Includes web resources, print publications and articles, cover crop profiles, listings of video and slide sets, and a directory of expertise. Order from the UC SAREP web site, [www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu).*

Sustainable Agriculture Network. 1998. *Managing Cover Crops Profitably, Second Edition*. Handbook Series Book 3. Sustainable Agriculture Network. Beltsville, MD: National Agricultural Library.

*Very useful information on the characteristics, costs, seeding rate, and management of different cover crop species. Contains a good introduction to the potential advantages and disadvantages of using cover crops, and how to manage them effectively to minimize unwanted effects. It also provides comprehensive information on the major species used in the U.S. Though geared primarily toward large-acreage cropping systems, the information is readily adapted for smaller-scale systems. Available from [www.sare.org](http://www.sare.org).*

Miller, P. R., W. L. Graves, et al. 1989. *Cover Crops for California Agriculture*. Leaflet 21471. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A concise overview of the common cover crops used in California agriculture. Addresses annual and perennial cropping systems*

Sarrantonio, M. 1994. *Northeast Cover Crop Handbook*. Emmaus, PA: Rodale Institute.

*Practical information on the selection and management of cover crop species for northeast agriculture.*

## WEB RESOURCES

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

International Development Research Centre (IRDC)

[www.idrc.ca/cover\\_crop/](http://www.idrc.ca/cover_crop/)

*The International Development Research Centre is a public corporation created by the Canadian government to help communities in the developing world find solutions to social, economic, and environmental problems through research. This site contains research on cover crops for sustainable agriculture in the tropics.*



Management of Organic Inputs in Soils of the Tropics (M.O.I.S.T.)

[ppathw3.cals.cornell.edu/mba\\_project/](http://ppathw3.cals.cornell.edu/mba_project/)

*This interdisciplinary group based at Cornell University investigates and exchanges information on cover crops, green manures, managed fallows, and mulches in tropical farming systems. Their goal is to improve and sustain evolving agriculture systems in Asia, Africa, and Latin America.*

UC Sustainable Agriculture Research and Education Program (UC SAREP) Cover Crop Data Base

[www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu)

*Contains a thorough cover crop database, with quantitative information on specific cover crops, and two slide shows covering the use of cover crops for annual and perennial farming systems. The database includes valuable cover crop information such as pounds of nitrogen fixed, seeding rates, suggested timing for seeding, etc. Focuses on California and other similar climatic situations. Includes photographs.*

## VIDEOS

Creative Cover Cropping in Annual Farming Systems. By Robert L. Bugg. University of California Communications Services. UC Davis: UC DANR (27 minutes).

Creative Cover Cropping in Perennial Farming Systems. By Robert L. Bugg. University of California Communications Services. UC Davis: UC DANR (24 minutes).

*Videos discuss how to use cover crops to protect and enhance soil fertility, enhance pest control, and provide other benefits. A wide array of plant materials is presented, along with creative management options.*

# 1.7 Making and Using Compost

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# Introduction: Making and Using Compost

## UNIT OVERVIEW

*High-quality compost is one of the essential organic matter inputs used to manage soil fertility in organic farming and gardening systems. In this unit students will learn the fundamental concepts and practices used to produce quality compost with aerobic high-temperature composting techniques. The lecture introduces the biology of the composting process and the critical elements involved in successful compost production. The demonstrations provide instructions on the materials, suggested content, and activities for teaching students the basic skills and knowledge needed to produce high-quality compost on both field and garden scales. Using step-by-step instructions and a suggested hands-on exercise, students will build and track the progress of a garden-scale compost pile.*

## MODES OF INSTRUCTION

- > LECTURE (1 LECTURE, 1–1.5 HOURS)  
The class lecture outline reviews the benefits of composting and the biology of the composting process, emphasizing the key factors required for quality compost production.
- > DEMONSTRATION 1: GARDEN-SCALE COMPOST PRODUCTION (1–1.5 HOURS)  
The garden-scale compost demonstration details how to construct, troubleshoot, and assess aerobic hot compost piles, including a step-by-step outline for students to follow.
- > HANDS-ON EXERCISE FOR STUDENTS (3 HOURS INITIALLY; MONITORING OVER 6 MONTHS)  
This exercise takes students through the process of building and monitoring a garden-scale compost pile over several months.
- > DEMONSTRATION 2: FIELD-SCALE COMPOST PRODUCTION (1 HOUR)  
The demonstration outline details how field-scale compost windrows are made and monitored.
- > ASSESSMENT QUESTIONS (1–2 HOURS)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The benefits of aerobic hot composting and the benefits of compost in soil
- The different stages of the biological composting process and the key composting organisms responsible at different stages
- The key factors for aerobic hot composting including carbon-to-nitrogen ratio, moisture, aeration, and volume

### SKILLS

- How to assess compost materials
- How to build a compost pile
- How to troubleshoot, turn, and track a compost pile
- How to assess finished compost for various uses



# Lecture Outline: Making and Using Compost

## *for the instructor*

### A. Pre-Assessment Questions

1. What is compost?
2. What are some types of composting and how do they differ?
3. Why is aerobic, hot composting favored for agricultural/horticultural purposes?
4. What are advantages of composting over letting materials rot on surface or turning in raw materials (e.g., crop residues, raw manure, sawdust)?

### B. Benefits of Composting

1. Advantages of the aerobic, high temperature composting process
  - a) Stabilizes nitrogen
  - b) Kills most pathogens and weed seeds
  - c) Introduces wide population of microbes to the organic matter
  - d) Reduces volume of wastes
  - e) Allows for use of raw materials not appropriate for direct use
  - f) Degrades many contaminants
  - g) Recycles organic matter on site
2. Benefits of compost in the soil
  - a) Improves soil structure, resulting in improved drainage, gas exchange, workability
  - b) Increases moisture retention
  - c) Releases nutrients slowly, increases Cation Exchange Capacity (CEC)
  - d) Increases number and diversity of microorganisms in soil
  - e) Buffers pH
  - f) Suppresses disease
  - g) Plays a key role in organic management of soil fertility
3. Discuss potential disadvantages of composting
  - a) Cost and time—labor, special equipment
  - b) Space needed—taking production area
  - c) Odor or other impacts on neighbors
  - d) Regulations (larger producers)

### C. Biology of the Composting Process

1. Compost ecosystem overview
  - a) What makes composting happen? Wide range of decomposers
  - b) Decomposer organisms play different roles (refer to appendix 1, Compost Food Web)
2. Key compost organisms and stages of composting
  - a) Bacteria
    - i. Aerobic bacteria key to first stages—feed on simple carbons like plant saps first
    - ii. Multiply quickly
    - iii. Carbon for energy, nitrogen for building bodies and reproduction
    - iv. Heat of pile is created as bacteria break down organic matter and respire CO<sub>2</sub>

- b) Compost temperature curve and bacteria (refer to appendix 2, Compost Materials and Temperature Chart)
  - i. 50°–113°F: Mesophilic (mid-temperature-loving) bacteria in first 24–48 hours
  - ii. 113°–150°F: Thermophilic (heat-loving) bacteria
  - iii. 150°F and above: May be too hot for thermophilic organisms to survive; temperatures optimally should remain at 150° or below
  - iv. 120°F and below: Mesophilic bacteria repopulate, but fungi, actinomycetes, yeasts, and molds dominate this stage of composting
- c) Actinomycetes
  - i. A type of bacteria, though grow as hyphae (strands) like fungi
  - ii. Produce greyish, cobwebby growths that gives compost earthy smell
  - iii. Decompose complex carbon like chitin and cellulose
  - iv. Responsible for some disease suppression
- d) Fungi
  - i. Decompose complex carbon compounds like chitin and cellulose
  - ii. Improve soil structure by physically binding soil particles into aggregates
  - iii. Suppress disease
- e) Macroorganisms: Earthworms and other later immigrants
  - i. Though not always present in finished compost, macroorganisms feed on the pile's earlier inhabitants
  - ii. Discuss examples from Compost Food Web: Nematodes, mold mites, springtails, wolf spiders, centipedes, sow bugs, earthworms, ground beetles

#### D. Overview of Key Environmental Conditions for Aerobic, Hot Composting

Briefly list the key factors, explaining that each will be discussed in detail in E–I, below

- Carbon-to-nitrogen (C:N) ratio of materials
- Moisture content of materials
- Air (air space within compost pile)
- Surface area of compost materials
- Volume of compost pile
- Turning and trouble-shooting

#### E. Compost Materials: Key Considerations

1. Carbon-to-nitrogen (C:N) ratio
  - a) Define carbon-to-nitrogen ratio (the proportion of carbon to nitrogen by weight in any organic matter). Give examples. Refer to appendix 3, C:N Ratio for Common Compost Materials.
  - b) Factors affecting C:N ratio of a material
  - c) Optimum C:N level for biological activity is between 25:1 and 30:1. Finished compost will be 14:1 to 17:1.
2. Nitrogenous materials
  - a) Low C:N materials are called nitrogenous, sometimes “greens”
  - b) Look at examples of nitrogenous materials on the C:N chart, appendix 3
  - c) C:N ratio of a material can change. Examples:
    - i. A growing plant ages and stores more carbon (e.g., young, green grass growing into tall brownish-green stalks)

- d) Factors to consider when estimating C:N ratio of different materials
    - i. Stage of growth/age of material
    - ii. Storage/treatment
    - iii. Where grown, how fertilized
    - iv. With manures, grain-fed animals will have higher N manure
  - e) Conserve nitrogen in storage by letting material dry and desiccate
3. Carbon materials
- a) High C:N ratio called carbonaceous, sometimes “browns.” Discuss examples on chart.
  - b) Carbon materials can be more or less complex
  - c) High carbon materials can be stored for extended time periods
  - d) Carbon materials can provide aeration
  - e) High carbon materials, if dry, can be difficult to moisten
4. Animal manures
- a) Manure C:N ratio depending on type of animal manure, feed source, bedding, and age
  - b) See C:N chart (appendix 3) for examples
  - c) In general, manures are more biologically active
  - d) Raw manures can carry weed seeds, pathogens, pesticide residues, and antibiotics, so should be composted properly to destroy
5. Balancing C:N range for composting (see appendix 4: need title)
- a) Assess C:N ratio of materials and plan quantities (give examples)
  - b) Estimating proportions when layering by hand
  - c) Estimating proportions with machine-turned composting
  - d) Record-keeping and trouble-shooting trials
6. Other components some advocate adding to compost
- a) Clay soil (Luebke method)
  - b) Rock phosphate
  - c) Inoculants
  - d) Wood ash
  - e) Other rock minerals
7. What not to compost
- a) Feces of carnivores/omnivores, though possible if done carefully
  - b) Pernicious weeds (resistant to decay)
  - c) Some diseased plants
  - d) Meat/dairy may attract pests
  - e) Fats, oils in large quantities
  - f) Walnut, eucalyptus leaves in large quantities
8. Particle size considerations
- a) Chopping materials will speed composting
  - b) The greater the surface area-to-volume ratio, the faster the decomposition
  - c) Compaction can occur if particle size is too small
  - d) Layering can be adjusted to avoid compaction and maintain aeration
  - e) Waxy coated leaves decay very slowly because of coated surface
  - f) Municipal compost tub grinders reduce materials to 1 inch or less. A sharp spade can be used to chop materials by hand.



## F. Moisture

1. Moisture needs of decomposers
2. Moisture content in compost pile should be 50%–60% (moist as a wrung-out sponge)
  - a) First consider the moisture of the materials to be composted
  - b) Add water as pile is built. More water should be put on layers in top half of pile.
  - c) Excess moisture will cause compaction, loss of air
  - d) Insufficient moisture will cause a pile to decompose slowly or stop decomposing
  - e) If going to turn pile frequently, can add more water to begin with
  - f) Turning pile, trouble-shooting—add water if too dry, aerate and add dry material if too wet
  - g) Seasonal moisture considerations (e.g., tarping in winter, shade in summer)

## G. Aeration

1. Aerobic bacteria require oxygen, respire CO<sub>2</sub>
2. Anaerobic bacteria (problem: end product may be antagonistic to germination and seedling growth)
3. Oxygen is often the limiting factor when compost temperature goes down after first weeks
4. At 10%–12% CO<sub>2</sub>, need to turn
5. Turning pile reintroduces oxygen, stimulating aerobic bacteria population

## H. Volume and Temperature

1. 5 feet x 5 feet x 5 feet is minimum pile size for benefits of hot compost
2. 130°–150°F is optimal temperature range (10 days to 2 weeks); NOP rules require pile to reach 131°F for 21 days, with 5 turnings
3. Turn at 150°F or can kill microbes
4. Maximum height and width = 6 feet
5. Compost fabric, soil cap as option to retain heat

## I. Maturation and Turning

1. 6 months minimum for windrows if not turned
2. Advantages of turning
3. Disadvantages of turning
4. Recommendations on when and how much to turn (if once, at 3 weeks)

## J. Assessing Compost Maturity and Stability

1. Parent material largely unrecognizable, crumbly texture
2. Cool temperature (ambient temperature)
3. Signs of macroorganisms (may not be present in large-scale operations)
4. Dark-brown to blackish-brown
5. “Earthy” sweet smell (no ammonium or anaerobic odors)
6. Paste-like texture
7. Maturity vs. stability

## K. Applying Compost

1. Timing
2. Application rates
3. Placement

# Detailed Lecture Outline: Making and Using Compost

## *for students*

### **A. Pre-assessment Questions**

1. What is compost?
2. What are some types of composting and how do they differ?
3. Why is aerobic high-temperature composting favored for agricultural /horticultural purposes?
4. What are advantages of composting over letting materials rot on surface or turning in raw materials (e.g., crop residues, raw manure, sawdust)?

### **B. Benefits of Aerobic Hot Composting**

1. Advantages of aerobic hot composting process
  - a) Stabilizes volatile nitrogen. Composted organic matter contains nitrogen in a more stable form (nitrate) that is more usable by plants.
  - b) Kills most pathogens and weed seeds (if piles are above 131 °F for 15 days).
  - c) Introduces a wider population of microbes than found in the raw ingredients
  - d) Reduces volume of wastes (by approximately 50%)
  - e) Allows for use of raw materials that shouldn't be put directly in soil (e.g., sawdust, raw manure)
  - f) Degrades many contaminants since most pesticides are petroleum- (carbon)-based and thus digestible. The weed killer Clopyralid is an important exception (see [css.wsu.edu/compost](http://css.wsu.edu/compost) for details). Although not a solution to soil contamination, organic matter also has a high capacity to bind heavy metals.
  - g) Recycles organic matter on farm and reduces off-farm inputs
2. Benefits of compost in the soil
  - a) Improves soil structure and soil aggregate stability resulting in better drainage, aeration/gas exchange, erosion resistance, workability (tilth). Microbes secrete glue-like compounds that help bind soil particles together.
  - b) Increases moisture retention (100 pounds of humus can hold 195 pounds of water)
  - c) Slow release of nutrients and increased availability of others. Cation Exchange Capacity (CEC) is increased thus increasing availability of Ca, Mg, and K. Also, humic acids help dissolve minerals in the soil, making more minerals available to plants.
  - d) Increases the population and diversity of microbes in soil that continually make nutrients available to plants. Provides food for microbes.
  - e) Helps buffer soil pH. Compost pH is optimally 6.5–7.
  - f) Promotes disease suppression (different microbes suppress fusarium, pythium, phytophthora, rhizoctonia)
  - g) Plays key role in soil fertility management in organic systems

3. Potential disadvantages of composting
  - a) Cost and time: Many farmers and gardeners don't make their own compost because of equipment needs and labor expenses
  - b) Space needed for composting can take up available production land
  - c) Odor or other impacts on neighbors can create challenges in urban/suburban areas
  - d) Regulations: Regulations on leachate and testing if commercial composter or certified organic grower (see California Integrated Waste Management Board, [www.ciwmb.ca.gov](http://www.ciwmb.ca.gov), and the National Organic Program, [www.ams.usda.gov/nop](http://www.ams.usda.gov/nop), for composting regulations)

## C. Biology of the Composting Process

1. Compost ecosystem overview
  - a) What makes composting happen? A wide range of decomposers that are naturally present in most soils and on organic matter. Microbial decomposers can account for 60%–80% of total soil metabolism.
  - b) Decomposer organisms play different roles in a complex compost food web (see appendix 1, Compost Food Web). Microscopic organisms such as bacteria, fungi, actinomycetes, and yeasts are mostly primary consumers of compost materials, Macroscopic organisms such as mold mites, nematodes, springtails, centipedes, beetles, earthworms feed on the primary and secondary consumers.
2. Key compost organisms and stages of composting
  - a) Bacteria are responsible for first stages of hot compost process
    - i. Aerobic bacteria are the primary decomposers in the first stages of decomposition, feeding first on the most readily available food sources like plant sugars. Their role is to do most of the primary consumption of simple carbon compounds. Aerobic bacteria are the best for creating quality compost. Anaerobic bacteria produce gases, alcohols, and acids that can thwart plant growth (sulfides and methane, which inhibit root growth). Compost made in anaerobic digesters is usually finished aerobically.
    - ii. Bacteria reproduce quickly—under the right conditions, bacteria can double their population every hour
    - iii. Organic matter provides bacteria with carbon as a source of energy, nitrogen for protein to build their bodies, and nucleic acid for reproduction
    - iv. Heat is created as microorganisms respire in the process of breaking down organic matter. Certain thermophilic (heat-loving) bacteria are responsible for the high temperatures in pile.
  - b) Compost temperature curve and bacteria
    - i. 50°–113°F: Mesophilic (mid-temperature loving) bacteria and other organisms populate the pile in the first 24–48 hours, multiplying quickly and causing temperatures to rise with increased metabolism. As internal pile temperatures rise above 113°F, mesophilic organisms start dying out and thermophilic bacteria populations rise.
    - ii. 113°–150°F: Thermophilic (heat-loving) bacteria, which are present as dormant spores at lower temperatures, multiply quickly in the heating compost pile. Temperatures can be sustained at 130°–150°F for two weeks or more. Turning the pile can help sustain high temperatures by reducing density of material and reintroducing oxygen for aerobic bacteria.
    - iii. 150°F and above: May be too hot for thermophilic organisms to survive and biological activity may slow as a result. Temperatures optimally should remain at 150°F or below.

- iv. 120°F and below: After the first month, a compost pile will cool to the point where mesophilic organisms will populate the pile. Mesophilic bacteria repopulate, but fungi, actinomycetes, yeasts, and molds dominate this stage of composting.
- c) Actinomycetes
  - i. Now considered a type of bacteria, though grow as hyphae (strands) like fungi
  - ii. Actinomycetes produce grayish, cobwebby growths that gives compost earthy smell
  - iii. Can decompose complex carbon like chitin and cellulose
  - iv. Responsible for some disease suppression (produce enzymatic compounds and antibiotics)
- d) Fungi
  - i. Fungi decompose complex carbon compounds like chitin and cellulose
  - ii. Fungi improve soil structure by physically binding soil particles into aggregates
  - iii. Suppress disease
- e) Macroorganisms: Earthworm and other later immigrants
  - i. Though not always present in finished compost, macroorganisms feed on the pile's earlier inhabitants
  - ii. Examples: Nematodes, mold mites, springtails, wolf spiders, centipedes, sow bugs, earthworms, ground beetles (for more information, see Unit 2.3, Soil Biology and Ecology)

#### **D. Overview of Key Environmental Conditions for Aerobic, Hot Composting**

Successful composting requires creating the right environmental conditions for decomposers to function optimally. Key conditions include:

- Carbon-to-nitrogen (C:N) ratio of materials
- Moisture
- Aeration
- Surface area of compost materials
- Volume of compost pile
- Turning and trouble-shooting

#### **E. Compost Materials: Key Considerations**

1. Carbon-to-nitrogen (C:N) ratio
  - a) The carbon-to-nitrogen ratio refers to the proportion of carbon to nitrogen by weight in any organic matter. Different types of organic matter have different carbon-to-nitrogen or C:N ratios. For example, wood, which is very high in carbon, has a C:N ratio of 500:1 while grass clippings have a C:N ratio of 17:1. (See appendix 3 for examples.)
  - b) C:N ratio of a material can change due to many factors: Plant growth, storage, how fertilized, what an animal was fed. Numbers on a chart are approximations.
  - c) The optimum C:N ratio for biological activity is between 25:1 and 30:1. Compost piles should ideally start with an overall C:N ratio in this range. Finished compost will be 14:1 to 17:1. Much of the carbon in the pile is released as CO<sub>2</sub> as decomposers metabolize organic matter.
2. Nitrogenous materials
  - a) Compost materials with low C:N ratios are often called nitrogenous, sometimes “greens”
  - b) There is a range of nitrogenous materials as demonstrated on the C:N ratio charts (see appendix 3)
  - c) C:N ratio of a material can change. Examples:
    - i. As a growing plant ages it stores more carbon (e.g., young green grass growing into tall brownish-green stalks)

- d) Factors to consider when estimating C:N ratio of different materials
    - i. Stage of growth/age of material
    - ii. Storage/treatment
    - iii. Where grown, how fertilized
    - iv. With manures, grain-fed animals will have higher N manure
  - e) Conserve nitrogen by letting materials dry and desiccate. Most of the material stays in an organic or  $\text{NO}_3^-$  form, neither of which will volatilize. Tarping greens may actually have the opposite effect; by holding in moisture, tarping may stimulate decomposition of low C:N materials, which release N gas.
3. Carbon materials
- a) Compost materials with high C:N ratio are called carbonaceous, sometimes “browns”
  - b) Carbon materials can be more or less complex as shown on C:N chart (e.g., wood chips can have C:N ratio of 400:1, straw 70:1, brown leaves 40:1; see appendix 3)
  - c) High carbon materials can be stored easily to use later (e.g., store brown leaves or straw stubble from fall to mix with the abundance of greens in the spring)
  - d) Carbon materials can be bulkier and thus can provide aeration in a pile
  - e) High carbon materials often are dry and can be difficult to properly moisten (can be spread out and soaked or left out in rain)
4. Animal manures
- a) Manures are usually considered nitrogenous, but can have a wide range of C:N ratios depending on type of animal manure, feed source, bedding material, and age
  - b) See C:N chart (appendix 3) for examples
    - i. Poultry manure (approximately 6–12:1 C:N ratio) is high in nitrogen
    - ii. Horse manure (approximately 20:1 C:N ratio) mixed with bedding can vary widely in its overall C:N ratio due to type and quantity of bedding material (e.g., is the “horse manure” pile mostly wood shavings? Think high carbon. Straw is a good bedding source: less extreme C:N ratio, absorbs urine well).
  - c) In general, manures are more biologically active than plant residues due to having passed through an animal’s digestive system
  - d) Raw manures can carry weed seeds, pathogens, pesticide residues, and antibiotics, so should be composted properly
5. Balancing the carbon and nitrogen in a pile (see appendix 4)
- a) Consider approximate C:N ratio of each ingredient as a reference in deciding on quantity. Formulas are not necessary for composting on a small scale. Larger compost operations may test the C:N ratio of each ingredient and come up with formulas for quantities (see Resources section—web site offers equations for calculating C:N formulas for compost piles).
  - b) For hand-built piles, layering is a good way to estimate proportions and “homogenize” the pile. Thin layers are recommended to put the diversity of ingredients in closer proximity. Examples of proportions, by volume:
    - 3 inches of fresh horse manure
    - 3 inches of loose succulent greens
    - 1/2 inch of loose oat straw
  - c) For machine composting, materials are often laid out along windrow to gauge proportions and then turned with compost turner.
  - d) Trial and error: make observations and keep records about what works, what doesn’t (see appendix 2)

6. Other components some advocate adding to compost
  - a) Clay soil: Those who use the Luebke method of compost think it's beneficial to use 10% clay soil in pile because it reduces N losses, makes end-product more stable
  - b) Rock phosphate can increase usable phosphorus by making P more available to crops and help reduce volatilization of  $\text{NH}_3$
  - c) Inoculants (purchased biological "activators"): May be useful for dealing with some problems, e.g., high oil content plant residues, but considered unnecessary by most because compost organisms are present in manures, soils, and on plant materials. Some use aged compost as an inoculant if composting area is new or on concrete.
  - d) Wood ash: Using small amounts of wood ash in compost eliminates possible negative effects of high pH of ash when added directly to soil, doesn't compromise potassium (K) availability to crop
  - e) Rock minerals (to help speed their availability through chemical breakdown)
7. What not to compost
  - a) Though often discouraged, composting waste of humans and other carnivorous or omnivorous animals (dogs, cats, pigs) is possible but you must be very careful about pathogens (see EPA and World Health Organization guidelines, and [www.jenkinspublishing.com/humanure.html](http://www.jenkinspublishing.com/humanure.html))
  - b) Perennial weeds that are resistant to decay such as Bermuda grass, mint, bindweed
  - c) Some diseased plants (examples)
  - d) Meat and dairy (if worried about attracting pests). Small amounts okay in center of pile.
  - e) Large quantities of fats and oils can't readily be broken down by compost organisms
  - f) Leaves of eucalyptus, walnut, and other trees with tannins or known allelochemicals; conifers (acidic, slow). Small amounts of these materials are okay.
8. Particle size of materials
  - a) Shredding or chopping materials, especially large, woody stalks, will speed the composting
  - b) The greater the surface area to volume ratio, the faster the rate of potential decomposition. Decomposers work on surfaces, so the more surface exposed, the more decomposers can work.
  - c) Compaction can occur if particle size is too small, and material is wet and nitrogenous (e.g., all lawn clippings), leading to loss of aeration and anaerobic conditions
  - d) Layering sequence and thickness can be adjusted to avoid compaction and maintain aeration
  - e) Waxy coated leaves decay very slowly because of coated surface
  - f) Municipal compost tub grinders reduce materials to 1 inch or less. A sharp spade can be used to chop materials by hand.

## F. Moisture

1. Moisture needs of decomposers
  - a) All decomposers involved in composting need  $\text{H}_2\text{O}$
  - b) Aerobic microbes, similar to marine mammals, need  $\text{H}_2\text{O}$  around them all the time, but also need  $\text{O}_2$  to survive. They live and move around on a film of water.
2. Moisture content in compost pile should be 50%–60% (moist as a wrung-out sponge)
  - a) First consider the moisture of the materials to be composted
  - b) Add water as pile is built, watering dry layers especially. More water should be put on layers in top half of pile, as much will trickle down (approximately two-thirds in top half, one-third in bottom half).
  - c) Excess moisture will cause compaction, loss of air (you shouldn't be able to squeeze water out of compost)

- d) Insufficient moisture will cause a pile to decompose slowly
- e) If you're going to turn pile frequently, can add more water as you build and add water as you turn
- f) Turn pile, trouble shoot—add water if too dry, aerate and add dry material if too wet
- g) Seasonal moisture considerations: Tarp piles in winter to keep rain off; use compost covers, tarps or straw cap to conserve moisture in summer

## G. Aeration

1. Aerobic bacteria, which make hot composting happen, require oxygen and respire CO<sub>2</sub>
2. Anaerobic bacteria populate portions of the pile where oxygen is low. They create methane gas and sulfur compounds (the rotten eggs smell) and can be harmful to soil life (commercial compost made in anaerobic digesters are often finished aerobically in windrows).
3. Oxygen is often the limiting factor when compost temperature goes down after first weeks
4. CO<sub>2</sub> can be monitored with special equipment—at 10–12% CO<sub>2</sub> need to turn if possible
5. Turning pile reintroduces oxygen, stimulating new growth of aerobic bacteria. Can also break up anaerobic pockets of pile as you turn.

## H. Volume and Temperature

1. Minimum pile size recommended is 5 feet x 5 feet x 5 feet to achieve the benefits of the hot composting process
2. At this volume pile is self-insulating and can reach 130–150°F for 10 days to 3 weeks
3. 131°–145°F = optimal temperature range. Turn if reaches 150°F. EPA and NOP standard (set for killing *E. coli* in sludge) is 131°F for 21 days with 5 turnings within that time period.
4. Maximum height and width should be 6 feet so as not to limit aeration or increase compaction of pile
5. Compost fabric, straw cap, or soil cap can help retain some heat

## I. Maturation and Turning

1. Most windrow piles take about 6 months minimum (spring into fall) to mature if not turned; longer in winter depending on climate
2. Advantages of turning include:
  - a) Speeds composting process by aerating the pile
  - b) Achieves more thorough composting by moving outer materials to pile center
  - c) Allows for trouble shooting and adjustments to pile (great learning opportunity)
  - d) Additional mixing of ingredients
  - e) Physical (mechanical) breakdown of particle size of materials
3. Disadvantages of turning include:
  - a) Time, energy, expense
  - b) Loss of nitrogen as pile is turned
  - c) Additional space needed unless turning out and back
4. Turn at least once (more speeds process but is labor intensive by hand)
  - a) If you turn compost only once, ideally do so at 3 weeks or when temperature curve has clearly started back down. After turning at this stage, temperature curve will go up again. (At this point oxygen is the limiting factor—turning reintroduces oxygen for aerobic organisms to continue using as they digest the still relatively fresh materials.)
  - b) If you turn the pile twice, ideally turn at about 3 weeks and 6 weeks, again referring to heat curve for information

## **J. Assessing Compost Maturity and Stability**

1. Parent material should be largely indistinguishable, texture should be crumbly
2. Temperature has cooled down to ambient temperature
3. Signs of macro life (e.g., redworms, sowbugs, springtails), though may not be present in large-scale operations
4. Dark brown to blackish-brown color
5. Earthy smell (no ammonium or anaerobic odor)
6. Feels “greasy” or slick when squeezed between fingers
7. Maturity vs. stability: A set of 7 quantitative indicators are used to define the maturity and stability of compost
  - pH: 6.5 to 8.0
  - Sulfides: zero to only trace
  - Ammonia = <0.05 ppm
  - Ammonium: 0.2 to 3.0 ppm
  - Nitrites: <1.0 ppm
  - Nitrates: <300 ppm
  - CO<sub>2</sub>: <1%

*Quantitative indicators adapted from “Quality Guidelines for Compost Chart,” compiled by Jon Nilsson (East Coast Compost) and Atrusa Compost Consulting criteria (George Leidig, Blue Bell, PA)*

## **K. Applying Compost**

1. Timing
  - a) Spring, prior to planting
  - b) Mid season, as “side dress”
  - c) Fall, with a planting of cover crops
2. Application rates
  - a) Application rates vary with intensiveness of cropping system and use of cover crops
  - b) Field scale: ~4–7 tons/acre on an annual basis
  - c) Garden scale: ~10–20 tons/acre on an annual basis (1–2 lbs/square foot for soil development, 0.5–1 lb/square foot for maintenance)
3. Placement
  - a) Field-scale: Top 8–12 inches of soil
    - i. Side dress: In the root zone of the crop
  - b) Garden-scale
    - i. Initial stages of soil development: 12–24 inches in depth (see appendix 3 in Unit 1.2, Garden and Field Tillage and Cultivation)
    - ii. Soil fertility maintenance: Top 4–8 inches





# Demonstration 1: Garden-Scale Compost Production

## *for the instructor*

### **INSTRUCTOR OVERVIEW**

*Key to the process of building quality compost is the ability to assess the materials that will make up the pile. Before starting the pile-building demonstration, spend time discussing the materials you've gathered for the pile's construction. Providing a range of compost materials for discussion will enhance students' understanding of and skills in assessing carbon-to-nitrogen ratios, moisture content, and other variables of compostable materials. Variety also brings a wider range of nutrients and different feedstock for different types of microorganisms.*

Useful comparisons for discussion include:

- green young weeds/grass clippings vs. older carbonaceous plants (same plant, different life stage)
- fresh manure vs. aged manure (horse, cow, chicken, other examples if possible)
- horse manure with straw bedding vs. horse manure with wood chips or shavings
- food scraps vs. crop residues

Spend time assessing various materials at the beginning of the demonstration and then review each as they are layered on the pile. Let students know that there is no one recipe for compost; each pile will differ based on the materials available, time of year, and the composter's own experience.

### **PREPARATION AND MATERIALS**

1. At the compost site mark a 5 feet x 5 feet to 6 feet x 6 feet or longer area as the desired base of the pile.
2. Gather compost materials such as straw, greens (cover crops, crop residues, weeds), fresh horse manure, food scraps, chicken manure, brown leaves, older dried-out weeds or crop residues, etc. Make sure to have materials in sufficient quantities to complete at least a 5 x 5 x 5 pile. Keep each material in its own distinct pile (for comparison).
3. Gather tools, materials, and handouts: hose with sprayer, wheelbarrows, manure forks, spades, compost thermometer, compost materials and temperature record sheet (see appendix 2) and assignment sheet (see Hands-On Exercise, page 27).
4. Assess existing compost piles for examples of various stages of decomposition, piles built with different techniques or materials, and piles that may be too wet, too dry, etc. As an option, bring in some different compost samples. Include good examples of finished compost. Plan which to visit at end of demonstration.

### **PREPARATION TIME**

1–2 hours

### **DEMONSTRATION TIME**

1–1.5 hours

## DEMONSTRATION OUTLINE

### A. Plan the Pile with Students

#### 1. Compost materials assessment

Ask students to assess each compost material in terms of:

- a) Carbon-to-nitrogen ratio
- b) Moisture content
- c) Particle size
- d) Aeration

#### 2. Pile location, size, shape

Discuss considerations for:

- a) Location
- b) Size
- c) Shape of pile

#### 3. Considerations for layering

Plan how the pile will be built by discussing:

- a) Thickness of layers (as per material)
- b) Order of layers
- c) Amount of water to add to which layers (with more added in top layers than bottom)

### B. Demonstrate Pile Building

#### 1. Demonstrate proper tool techniques for safety and efficiency

- a) Discuss which tools are used and why
- b) Demonstrate proper use of each tool

#### 2. Pile base

- a) Mark area for base size and discuss size parameters
- b) Demonstrate and discuss loosening soil within area
- c) Make first layer with manure or greens

#### 3. Demonstrate layering (ask for 2–3 students to help)

Map out layering sequence and for each layer:

- a) Review considerations for each material to make appropriate thickness
- b) Show how to judge layer thickness, uniformity
- c) Demonstrate how to “scratch” top layer slightly into layer below
- d) Show how to keep pile square (mind corners and edges)
- e) Demonstrate how to add water as needed

#### 4. Review layers and sequencing as pile progresses

- a) Ask students to build a several-layer sequence and explain their process
- b) Are there new considerations as pile progresses or as materials available change?
- c) Assess pile shape and size

#### 5. Demonstrate finishing a pile

- a) 5 feet high = maximum
- b) Finish with a carbon layer (e.g., straw cap)
- c) Show use of tarp or compost cloth
- d) Show how to label pile with date, materials used, other information

### **C. Monitoring the Composting Process**

1. Why monitor and why keep records
2. Demonstrate/discuss compost thermometer (and other monitoring devices if available)
3. Demonstrate how to use materials and temperature record sheet (appendix 2); show examples of record sheets from past, including timing of turning/aeration with temperature dip

### **D. Demonstrate Turning a Pile**

1. Review the pros and cons of turning
2. Review when to turn, how often to turn
3. How to turn—outside materials to inside
4. Trouble-shooting as you turn

### **E. Assess Existing Piles or Compost Samples**

1. Examine piles at different stages of decomposition looking for:
  - a) Heat, temperature curve examples (record book)
  - b) Odor, color, texture
  - c) Moisture
  - d) Recognizable parent materials
  - e) Different materials or techniques used
  - f) Show examples in continuum from coarse to finished
  - g) Examples of good, finished compost
2. Look for examples of problems to have students troubleshoot

### **F. Give students their compost-building and monitoring assignment (see Step-by-Step Instructions and Hands-On Exercise)**



# Demonstration 1: Garden-Scale Compost Production

## *step-by-step instructions for students*

### INTRODUCTION

*Use this set of instructions as a reference as you build and monitor compost piles.*

### A. Planning the Pile

1. Compost materials assessment  
Assess each of the gathered compost materials in terms of:
  - a) Carbon-to-nitrogen ratio
    - i. Is the material high in carbon? High in nitrogen? Or nearer to the ideal composting range of 25:1 to 30:1 carbon-to-nitrogen (C:N) ratio?
    - ii. How might age and storage have affected its C:N ratio?
    - iii. If manure, how would the quantity and type of bedding affect its C:N ratio?
  - b) Moisture content
    - i. How much moisture is coming in with material? (e.g., lawn clippings can be 70% moisture)
    - ii. How much water should be added given time of year, ambient temperatures, rainfall?
    - iii. Aiming for 50%–60% moisture content — “moist as a wrung-out sponge”
  - c) Particle size
    - i. How will the particle size of the material affect the pile’s compost process?
    - ii. Should something be chopped up? How?
  - d) Aeration
    - i. How will this material affect the overall aeration of the pile?
    - ii. If it might tend to compact, what can be done to lessen this effect?
2. Plan pile location, size, shape
  - a) Location considerations
    - i. Proximity to use area, water source, materials source
    - ii. Ease of construction and access around pile
    - iii. Shaded area best to reduce drying in summer
    - iv. Compost piles located beneath trees may lose nutrients to tree roots
  - b) Size considerations
    - i. Width and height—5 to 6 feet (for aeration and for easier access as building)

- ii. Length: 5 feet (minimum) to any length
- iii. Assess quantity and quality of usable material. How long a pile can you plan to make?
- c) Shape of pile
  - i. Aim for vertical sides to maximize volume of pile
  - ii. To retain moisture through summer, build pile with a flat top and a thick “cap” of straw
  - iii. Piles built to overwinter should have a more rounded top to shed rain (with straw cap)
- 3. Considerations for layering
  - a) Thickness of layers (as per materials)
 

Use thin layers for materials at either extreme of the C:N ratio range. Examples:

    - i. Approximately 1- to 3-inch layers for things that are high C (straw)
    - ii. Approximately 1- to 3-inch layers for things that are high N (fresh horse manure)
    - iii. Approximately 4- to 6-inch layers for mid-range C:N materials (mixed weeds/ crop residues)
    - iv. Use thin layers if particle size and/or moisture content make compaction likely
  - b) Order of layers
    - i. Some say you can speed decomposition by putting the manure layer (with its high population of microorganisms) on top of the green layer (with the most readily available food source in the form of plant saps)
    - ii. Mixing or scratching layers slightly together helps homogenize pile, avoid compaction
  - c) Amount of water to add (to which layers; top vs. bottom)
    - i. Consider the material of each layer—moisture, particle size
    - ii. Water each layer that needs additional moisture
    - iii. Add more water to layers in top half of pile (some will trickle down to lower layers)

## B. Building the Pile

1. Review proper tool techniques for safety and efficiency
2. Establish the pile base
  - a) Mark off area for base size (5 feet x 5 feet or longer)
  - b) Loosen soil in area with a spading fork to enhance aeration and migration of organisms
  - c) Make first layer with manure or greens (enhance migration of soil organisms to higher N food source)
  - d) Pile will be most compacted and thus least aerated at bottom. Bulky materials in base can aid in aeration but may make pile harder to turn.
3. Building layers
 

As each layer is made

  - a) Review key considerations for each material to make appropriate thickness (relative C:N, particle size, moisture, aeration)
  - b) Make layer uniformly thick
  - c) Scratch (mix) each layer slightly into the next using spading fork or manure fork
  - d) Keep pile square by pulling/adding material to corners and edges and tamping walls with fork
  - e) Use hose sprayer to add water to layers that need it, paying attention to the corners and edges. Some materials (straw, dry manure) should be scratched with forks as watered to allow more even distribution of water.

4. Review key considerations as pile progresses
  - a) Build a several-layer sequence and review key considerations as you go
  - b) Assess new considerations as the pile progresses or as materials change (e.g., the weed pile first had fresh green weeds on the top, but now it's just older, brownish weeds)
  - c) Assess the pile shape and size as you progress
5. Finishing a pile
  - a) 5 feet high = maximum for access/ease of building and for aeration
  - b) Finish with a carbon layer (if pile is not to be finished that day, end with carbon)
  - c) Use a tarp or compost cloth as protection from rain and from drying. Compost cloth "breathes"; tarps can limit aeration so some just use for rain.
  - d) Label pile with date, materials used, other information

### **C. Monitoring and Recording the Composting Process**

1. Monitor temperature with compost thermometer
  - a) Take temperature daily for first month and after turning; then weekly
  - b) Temperature should be taken at several points in the pile and averaged
  - c) Thermometer should be inserted 18 inches to 2 feet into pile
  - d) Hold thermometer by probe while inserting and removing
2. Record temperature and observations on record-keeping sheet (see appendix 2)
  - a) Track pile through decomposition process, creating heat curve graph as you go
  - b) Use heat curve graph to assess pile performance, indicate when to turn

### **D. Turning a Pile**

1. Review the pros and cons of turning
2. Turn at least once (more often speeds process but is labor intensive by hand)
  - a) If only turning once, ideally do so at 3 weeks or when temperature curve has clearly started back down. At this point oxygen is the limiting factor—turning reintroduces oxygen for aerobic organisms to continue using as they digest the still relatively fresh materials.
  - b) If turning twice, ideally turn at about 3 weeks and 6 weeks, again referring to heat curve for information (e.g., dip in temperature)
3. Turn outside materials to inside and inside to outside
  - a) Pull outside materials off pile (outer foot of material will be drier, less decomposed). Set aside.
  - b) Water outer layer of materials
  - c) Spread a base layer of inner materials in space next to original pile
  - d) Mix outer materials into center of new pile as you rebuild with inner materials (don't try to recreate original layers)
4. Trouble-shoot any problems as you turn the pile
  - a) Break up dry pockets or compacted clumps
  - b) Water if too dry
  - c) Leave overly-wet materials spread out to dry.
  - d) Add nitrogenous materials if pile has not heated up and moisture is fine
  - e) Low heat piles will still compost with time if you can't "fix" problem
  - f) "Failed" piles can be used as material for a new pile



## **E. Assessing Piles and Documenting Observations**

1. Examine piles at different stages of decomposition for:
  - a) Heat, temperature curve
  - b) Odor
  - c) Moisture
  - d) Recognizable parent materials
  - e) Different materials or techniques used
  - f) Examples of good, finished compost
2. Look for trouble signs
  - a) Too wet (can squeeze water out)
  - b) Too dry (usually doesn't heat up properly, may have dry pockets)
  - c) Anaerobic conditions (smells like sulfur, usually wet and compacted)
  - d) Didn't heat up (could be lack of moisture, improper C:N ratio)
3. Make written recommendations for achieving desired rate of decomposition and implement them

# Hands-On Exercise: Build and Monitor a Compost Pile

## SUMMARY

In groups of 2 to 3, you will build a group compost pile, and monitor its progress over the next 6 months. The step-by-step outline (pages 21–24) can serve as a guideline as you build the pile and later as you turn it. Use the Compost Materials and Temperature Chart (appendix 2) to list materials and the sequence of layers, and to record temperatures, observations, and other data.

Group responsibilities include:

- Assessing the available compost materials
- Planning compost layering
- Building the pile
- Keeping records on the pile (see record sheet in appendices) including labeling (name of pile, ingredients, date); record observations; daily temperature readings for first month; weekly temperature readings for subsequent months
- Turning the pile at least once (at 3 weeks or so)
- Trouble-shooting any problems
- Answering the questions below after 1–2 months

## QUESTIONS ABOUT YOUR PILE

1. How hot did your pile get and how long did it sustain this heat?
2. How does the heat curve on your pile compare to others you have seen? What assumptions can you make based on this heat curve?
3. When you turned your pile, what was your assessment of it? What if any trouble shooting did you need to do?
4. When you dig into your pile now, what recognizable materials remain? How does the pile smell, feel, look?
5. What other observations have you made about your pile?



# Demonstration 2: Field-Scale Compost Production

## *for the instructor*

### **OVERVIEW**

*This demonstration introduces the considerations, techniques, and mechanical equipment used in on-farm production of compost for use on a multi-acre scale. Students will first review the characteristics of compost feedstock, the importance of adequate moisture during the composting process, and be provided with examples of the temperature changes occurring in previously built compost piles. The instructor should also discuss optimal and necessary temperature ranges for organic certification, materials and techniques used to maintain optimal conditions for aerobic decomposition, and the various indicators used to determine compost maturity. In the second part of the demonstration, the instructor presents the specific techniques and equipment used in combining materials, monitoring and turning large compost piles, and factors to consider in applying finished compost.*

### **PREPARATION AND MATERIALS**

Ideally, materials for this demonstration would include mature compost, immature compost, an active compost pile, sample feedstock, and compost turning and application equipment, as well as temperature, turning, and feedstock records from recent compost piles. A laboratory nutrient analysis of compost should also be available.

### **DEMONSTRATION RESOURCES**

- Magdoff, Fred, and Harold Van Es. 2000. *Building Soils for Better Crops, Second Edition*. Handbook Series Book 4, Sustainable Agriculture Network. Chapter 12: Making and Using Composts. Available from [www.sare.org](http://www.sare.org).
- *Field Guide to On-Farm Composting*. 1999. Available from Natural Resource, Agriculture, and Engineering Service (NRAES) Cooperative Extension, 152 Riley-Robb Hall, Ithaca, New York 14853-5701, [www.nraes.org](http://www.nraes.org).

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

1 hour

## **DEMONSTRATION OUTLINE**

### **A. Field-Scale Compost Making**

1. Review compost-making process
  - a) Examine feedstocks
  - b) Discuss C:N ratios of various feedstocks
  - c) Discuss importance of supplying adequate moisture during the composting process
2. Review temperature curves from past piles
3. Discuss National Organic Program definition of compost and requirements for compost production and use
4. Discuss importance of monitoring CO<sub>2</sub> levels as a guide for turning
5. Discuss optimum and required temperatures
6. Examine breathable tarp used for covering pile
7. Review and discuss nutrient profile of laboratory analysis of finished compost
8. Discuss indicators of compost quality and maturity (see J on page 15 of Lecture Outline)

### **B. Equipment and Techniques for Windrowing, Turning, and Field Application of Compost**

1. Explain and demonstrate how feedstock is layered for initial mixing
2. Explain and demonstrate how water is applied as necessary during the mixing process
3. Explain and demonstrate how feedstock is run through spreader to form windrow
4. Explain and demonstrate how compost pile is turned
5. Demonstrate and discuss techniques used in field application of compost

# Assessment Questions

- 1) List four benefits of aerobic, high temperature composting.
- 2) List four improvements to soil quality that would result from regular incorporation of compost into the soil.
- 3) Name the key decomposer organisms and describe their role at the various composting stages/temperatures.
- 4) What temperature range is considered best for composting and why? What is too hot?
- 5) List the key conditions necessary for aerobic, high temperature composting.

6) Why consider the Carbon-to-Nitrogen ratio of the various compost materials? What is considered the ideal C:N range for composting and why?

7) What factors can influence the C:N ratio of a material?

8) What may happen if too much water is added to a compost pile? What may happen if the materials are too dry?

9) Why is aeration important in a compost pile?

10) What are some advantages and disadvantages to turning a compost pile? When and how often should compost piles be turned? (Please explain.)

11) Describe five qualitative indicators of compost maturity. What are some quantitative ways of assessing compost maturity and stability?

12) Imagine that you have an unlimited amount of each of the following materials for composting: straw, chicken manure, horse manure, food scraps, greenish-brownish crop residues and weeds, and sawdust. How would you make a pile using these materials? Draw a diagram of the pile you would create. Discuss your layering, including thickness of each layer, order, water added or not. Add a short description of your suggested management plan (turning, monitoring).



# Assessment Questions Key

1) List four benefits of aerobic, high temperature composting.

- *Stabilizes volatile nitrogen. Composted organic matter contains nitrogen in a more stable form that is more usable by plants.*
- *Kills most pathogens and weed seeds (if piles are above 131°F for 15 days)*
- *Introduces a wider population of microbes than found in the raw ingredients*
- *Reduces volume of wastes (by approximately 50%)*
- *Allows for use of raw materials that shouldn't be put directly in soil (e.g., sawdust, raw manure)*
- *Degrades contaminants since most pesticides are petroleum- (carbon-) based and thus digestible. Organic matter also has a high capacity to bind heavy metals.*
- *Guarantees that most of the end product will be humus and slowly-decomposing material that will become humus in the soil*
- *Recycles organic matter on the farm and reduces off-farm inputs*

2) List four improvements to soil quality that might result from regular incorporation of compost into the soil.

- *Improves soil structure and soil aggregate stability resulting in better drainage, aeration/ gas exchange, erosion resistance, workability (tilth). Microbes secrete glue-like compounds that help bind soil particles together.*
- *Increases moisture retention (100 lbs. of humus can hold 195 lbs. of water)*
- *Slow release of nutrients and increased availability of others. Cation Exchange Capacity (CEC) is increased thus increasing availability of Ca, Mg, and K. (Also humic acids help dissolve minerals in the soil, making more minerals available to plants.)*
- *Increases the population and diversity of microbes in soil that continually make nutrients available to plants. Provides food for microbes.*

- *Helps buffer soil pH (compost pH is optimally 6.5–8)*
- *Promotes disease suppression (different microbes suppress Fusarium, Pythium, Phytophthora, Rhizoctonia)*
- *Plays key role in soil fertility management in organic systems. Along with soil organic matter and cover crops, compost is a major source of plant available N, P, and K.*

3) Name the key decomposer organisms and describe their role at the various composting stages/temperatures.

- *Bacteria: Aerobic bacteria are the primary decomposers in the first stages of decomposition, feeding first on the most readily-available food sources like plant sugars. Their role is to do most of the primary consumption of simple carbon compounds, resulting in the liberation of heat and the warming of the compost pile and creating the environmental conditions for the subsequent colonization of microorganisms (below).*
- *Fungi: Fungi decompose complex carbon compounds like chitin and cellulose*
- *Actinomycetes: Actinomycetes decompose complex carbon, like chitin and cellulose*
- *Macroorganisms: Earthworms and other later immigrants such as nematodes, mold mites, springtails, wolf spiders, centipedes, sow bugs, earthworms, ground beetles continue to break down organic matter after the pile has cooled*

4) What temperature range is considered best for composting and why? What is too hot?

- *Between 131°–150°F for a minimum of 15–21 days. This should kill potential pathogenic organisms and weed seeds and prevent the volatilization of nitrogen containing compounds (e.g., ammonia) at higher temperatures.*
- *Maximum temperatures of the compost pile should not exceed 150°F*

5) List the key conditions necessary for aerobic, high temperature composting.

- *Proper carbon to nitrogen ratio of materials: 25:1–40:1*
- *Moisture: 50%–60% by weight or “moist as a wrung-out sponge”*
- *Aeration: Periodic re-aeration through turning*
- *Surface area of compost materials: Small particle size will result in more rapid decomposition*
- *Volume of compost pile: A minimum of 5x 5x 5 is recommended*
- *Turning and trouble-shooting: Compost piles should be turned when temperatures exceed 150°F and when the temperature of the pile has begun to decline. National organic standards require 5 turnings within a 15-day period with a sustained temperature of 131°–170°F.*

6) Why consider the Carbon-to-Nitrogen ratio of the various compost materials? What is considered the ideal C:N range for composting and why?

- *C:N ratio affects the rate of decomposition. A low C:N ratio (below 25:1) may result in too rapid decomposition and the loss of nitrogen in the form of ammonia. A C:N ratio that is too high may result in a too long a decomposition process and a low quality end product.*
- *Ideal C:N ratio range is 25:1–40:1*

7) What factors can influence the C:N ratio of a material?

- *C:N ratio of a material can change due to many factors: plant growth, storage, how fertilized, and what an animal was fed*

8) What happens when a pile is too wet or too dry?

- *If a compost pile is too wet it may not heat up, turn anaerobic, forming compounds that may be offensive smelling and detrimental to plant growth if not aerated prior to application*

- *If a compost pile is too dry it may not heat up or not sustain heat long enough to degrade the organic materials into a finished and useable product. Will often require reassembling the materials and moistening.*

9) Why is aeration important in a pile?

- *To assure adequate amounts of oxygen for aerobic decomposition*

10) What are some advantages and disadvantages to turning a pile? When and how often should piles be turned? (Explain)

- *Compost piles should be turned when temperatures exceed 150°F or when the temperature of the pile has peaked, plateaued, and begun to decline. National organic standards require 5 turnings within a 15-day period with a sustained temperature of 131°–170°F. The greater the number of turnings, the faster the material will break down.*

11) Describe five qualitative indicators of compost maturity.

- *“Parent material” should be largely indistinguishable*
- *Texture should be crumbly*
- *Very small particle size*
- *Temperature has cooled down to ambient temperature*
- *Signs of macro life (e.g., redworms, sowbugs, springtails)*
- *Dark brown to blackish-brown in color*
- *Earthy smell (no ammonium or anaerobic odor)*
- *Feels “greasy” or slick when squeezed between fingers*

What are some additional ways of assessing compost maturity and stability?

- *Compost maturity and stability may also be determined through measurements of carbon dioxide and ammonium levels. This is commonly done in large-scale and commercial composting operations.*

# Resources

## PRINT RESOURCES

### BOOKS

Gershuny, Grace. 1993. *Start with the Soil*. Emmaus, PA: Rodale Press.

*Includes an introduction to the tools and techniques of home- and garden-scale composting.*

Smillie, Joe, and Grace Gershuny. 1999. *The Soul of Soil: A Soil-Building Guide for Master Gardeners and Farmers*. White River Junction, VT: Chelsea Green Publications.

*Contains a brief section on farm-scale composting.*

Jeavons, John. 2002. *How To Grow More Vegetables, Fruits, Nuts, Berries, Grains, and Other Crops Than You Ever Thought Possible on Less Land Than You Can Imagine, Sixth Edition*. Berkeley, CA: Ten Speed Press.

*Contains an introduction to the tools and techniques of home- and garden-scale composting.*

Martin, Deborah, and Grace Gershuny, eds. 1992. *The Rodale Book of Composting*. Emmaus, PA: Rodale Press.

*A comprehensive introduction to home- and garden-scale composting, including a chapter on large-scale composting.*

Stell, Elizabeth P. 1998. *Secrets to Great Soil*. North Adams, MA: Storey Publications.

*Contains an introduction to the tools and techniques of home- and garden-scale composting.*

Van Horn, Mark. 1995. *Compost Production and Utilization: A Growers Guide*. Publication 21514. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Includes sample calculations for achieving optimal C:N ratios, suggestions on compost management, nutrient profiles, and nutrient release patterns of composts.*

## PERIODICALS

BioCycle. JG Press, Inc., 419 State Ave, Emmaus. PA 18049

*Offers business-oriented information on composting, anaerobic digestion, and biofuels processing.*

## WEB RESOURCES

Biocycle Magazine

[www.environmental-expert.com/magazine/bio-cycle/](http://www.environmental-expert.com/magazine/bio-cycle/)

*BioCycle magazine on line.*

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

California Integrated Waste Management Board

[www.ciwmb.ca.gov](http://www.ciwmb.ca.gov)

*Provides health and safety information for composting.*

Cornell University

[www.cfe.cornell.edu/wmi/Composting.html](http://www.cfe.cornell.edu/wmi/Composting.html)

*Provides access to a variety of composting educational materials and programs developed at Cornell University.*

EPM, Inc.

[www.wormwigwam.com](http://www.wormwigwam.com)

*Procedures for composting using earthworms, and a worm-composting system offered for sale.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

Klickit County, Washington Solid Waste

[www.klickitatcounty.org/solidwaste](http://www.klickitatcounty.org/solidwaste)

*Resources for calculating the C:N ratio of compost piles.*

National Organic Program

[www.ams.usda.gov/nop](http://www.ams.usda.gov/nop)

*Provides regulations and standards for meeting composting requirements for organic certification.*

Washington State University

[css.wsu.edu/compost/](http://css.wsu.edu/compost/)

*WSU's compost research and education program provides useful information on large- and small-scale composting, use of composts, regulations, and the issue of Clopyralid contamination.*

Worm Digest

[www.worndigest.org](http://www.worndigest.org)

*Information, networking, and resources on all aspects of vermicomposting.*

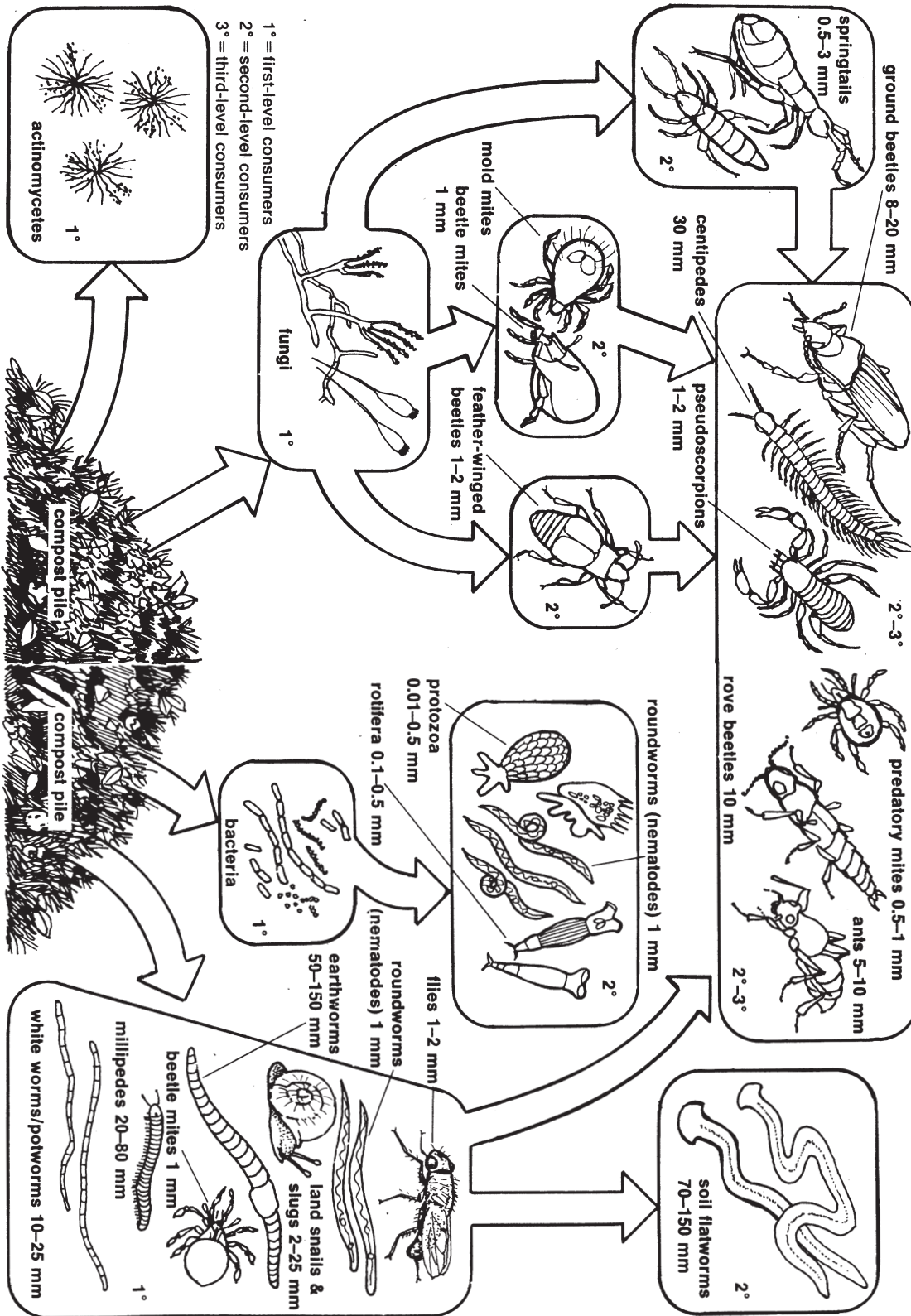
## VIDEO

Do the Rot Thing: The Simple Art of Home Composting. 1998. Alameda, CA: Alameda County Waste Management Authority and Recycling Board (20 minutes).

*Covers all the basics of home-scale composting.*

# Appendix 1: Compost Food Web

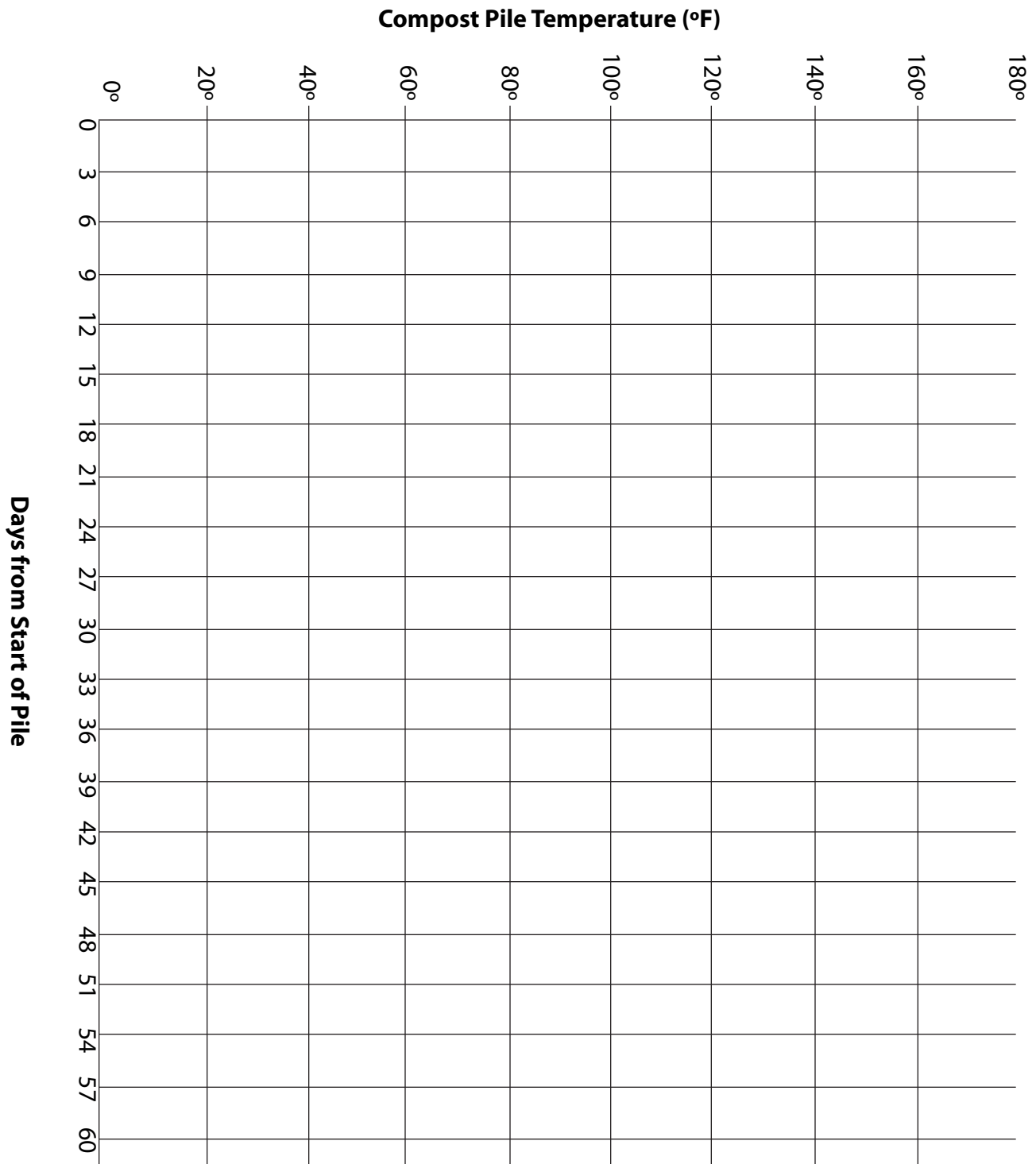
Energy flows in the direction of the arrows







# Appendix 2 (cont'd): Compost Materials & Temperature Chart



# Appendix 3: C:N Ratio of Common Compost Materials

MATERIAL	C:N RATIO	
Fresh chicken manure (laying)	6:1	
Tomato processing waste	11:1	
Vegetable waste	12:1	
Alfalfa hay	13:1	
Fresh chicken manure (broiler)	14:1	
Sheep manure	16:1	
Fresh turkey manure	16:1	
Grass clippings	17:1	
Seaweed	19:1	
Fresh cattle manure	19:1	
Rotted manure	20:1	
Apple pomace	21:1	
Fresh horse manure	22:1	Optimum C:N range
Grape pomace	28:1	
Legume shells	30:1	
Cereal hay	32:1	
Dry leaves	40–80:1	
Corn stalks	50:1	
Oat straw	74:1	
Grain chaff and hulls (e.g., rice hulls)	80–120:1	
Straw	80:1	
Timothy hay	80:1	
Paper	170:1	
Newsprint, cardboard	400:1	
Sawdust	400:1	
Wood chips, shavings	500+:1	

From *Start with the Soil*, by Grace Gershuny. Used by permission of Chelsea Green Publishing Co.



## Appendix 4: Calculating C:N Ratios for Compost – A Rough Guide

You have 5 pounds of grass clippings (C:N ratio = 20:1).

You have 5 pounds of leaves (C:N ratio = 40:1).

You have a total of 10 lbs. of material:

1/2 (50%) are grass, 1/2 (50%) are leaves.

Multiply the % of grass by the C:N ratio of grass, add the multiplication of the % of leaves by the C:N ratio of leaves:

$$(50\% \times 20/1) + (50\% \times 40/1) =$$

$$10 + 20 = 30 \text{ ---> which in fraction notation is } 30/1 \text{ or } 30:1.$$

The C:N ratio is 30:1. (\*Optimal C:N Ratio is 25–30:1)

Adapted from “Calculation of Carbon-to-Nitrogen Ratio (C:N)” by Master Composter, available online at [www.mastercomposter.com](http://www.mastercomposter.com). See also: [http://compost.css.cornell.edu/calc/cn\\_ratio.html](http://compost.css.cornell.edu/calc/cn_ratio.html)

# 1.8 Arthropod Pest Management

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# Introduction: Managing Arthropod Pests

## UNIT OVERVIEW

*Although organic growers work to prevent or minimize pest damage, more direct treatment measures are sometimes required to prevent economic loss. This unit introduces students to the principles, practices, and skills used to manage beneficial and problem arthropods within the standards set for certified organic production systems. The first lecture introduces the role of pest management in organic farming systems and how specific practices used in sustainable production serve to prevent the growth of pest populations beyond economic thresholds. In lecture 2 and through field and laboratory exercises, students will be introduced to the basic biology and ecology of arthropods as they relate to identification for management purposes. The principles and practices of field monitoring, determining thresholds at which various management options would be exercised, and the treatment options that are available for certified organic farms are then discussed. The design principles and practices used to enhance biological control through the use of non-crop vegetation will also be introduced. Students will be encouraged to address arthropod pest problems in a manner that makes best use of local resources, and is compatible with certified organic production standards and an ecological approach to the design and management of agricultural ecosystems.*

## MODES OF INSTRUCTION

- > LECTURES (2 LECTURES, 1.5 HOURS EACH)  
Lecture 1 covers the role of pest management in organic farming systems, the farming practices that aim to prevent the unchecked growth of pest populations, the components of a pest management program, and the common procedures used in arthropod monitoring. Lecture 2 introduces the basic biology and ecology of arthropods as they relate to identification and management
- > DEMONSTRATION 1: PEST MONITORING, SAMPLING, AND IDENTIFICATION (2 HOURS)  
Demonstration 1 introduces the practices of field monitoring. Students practice systematic monitoring techniques for sampling arthropods and crop damage, then identify the samples, and research and discuss the economic thresholds for control action intervention and control action options.
- > DEMONSTRATION 2: FIELD OBSERVATIONS (2 HOURS)  
In this demonstration, students and instructor visit a working farm and review the pest management program growers have developed for their certified organic farming operation.
- > ASSESSMENT (0.5 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The role of pest management in organic farming systems
- Farming and gardening practices that serve to prevent unchecked growth of pest populations
- Essential components of a sound pest management program for certified organic farming systems
- Basic arthropod biology and ecology as they relate to management
- Simple and practical methods for monitoring and identifying arthropods, classifying them by functional group, and classifying their damage
- Commonly available active control treatments suitable for use on certified organic farms and gardens
- An ecosystem approach to enhancing biological control through the use of non-crop vegetation

### SKILLS

- How to sample for arthropods
- How to identify insects to Order, genus, species, and common name using printed and on-line resources
- How to classify insects by functional grouping
- How to recognize key pest groups and their damage symptoms
- How to recognize the basic groups of beneficial arthropods
- How to use IPM printed and on-line resources to determine control action thresholds
- How to evaluate a range of control measures available and their relative strengths and weaknesses

# Lecture 1 Outline: Managing Arthropod Pests

## *for the instructor*

### A. Pre-Assessment Questions

1. Why is the management of arthropods important in crop production?
2. Why are pesticides ineffective in controlling insect pests?
3. What are some of the things insects and other arthropods do that enhance agricultural and environmental quality?
4. Which agricultural practices can you describe that serve to prevent the growth of pest populations beyond economic thresholds?
5. What would be some of the components of a sound pest management program for a certified organic farm or garden?
6. What would be the best ways to monitor for pests in the garden and small farm?
7. How would you go about determining if an insect is a “pest” or a “beneficial”?
8. What are several different organically acceptable ways to actively control pests?

### B. Why Managing Arthropods Is Important in Crop Production

1. Reduced productivity/yield
2. Spread of plant pathogens
3. Reduced visual aesthetics and thus marketability of crop (cosmetic damage)
4. Crop loss
5. Build up of pest populations in subsequent years

### C. A Sketch of Arthropod Natural History

1. Insects
  - a) The number of insect species
  - b) Example: The diversity and abundance of Coleoptera (beetles)
  - c) Estimates on the number of species of insects yet to be described: 2 and 100 million species
  - d) Tropical diversity: At least 6 million to 9 million species
2. Why have insects been so successful throughout natural history?
  - a) Insects have been around for more than 350 million years
  - b) Except for marine habitats, insects have adapted to almost every environment possible
  - c) The reasons for their success include the following factors:
    - i. Short generation times and high numbers of offspring
    - ii. A highly efficient body plan and construction
    - iii. The ability to fly, aiding dispersal to new and potentially favorable environments
    - iv. The development of “complete” metamorphosis
3. Ecosystem “services” provided by arthropods in agroecosystems
  - a) Pollination
  - b) Organic matter decomposition
  - c) Natural or intrinsic levels of pest suppression
  - d) Summary

4. Crop losses attributed to arthropods
  - a) Much more attention is given to insects as “pests” than is often warranted by evidence
  - b) The influence of multi-national chemical companies over the adoption of synthetic pest control strategies
  - c) Example
5. Ineffectiveness of attempts to control pests with agricultural chemicals
  - a) Herbivorous vs. predaceous insects’ tolerance to pesticide exposure
  - b) Insecticide-induced resurgence due to disproportionate mortality of predaceous natural enemies
  - c) Development of genetic resistance in pest populations leads to loss of insecticide effectiveness
  - d) Loss of effectiveness leads to the need for increased application rates of insecticides

#### **D. Sustainable Agricultural and Preventive Pest Management: Preventing the Growth of Pest Populations Beyond Economic Thresholds**

1. Crop rotation
2. Cover cropping
3. Polyculture cropping patterns
4. Sound soil fertility management
  - a) Soil organic matter management
  - b) Nutrient budgeting, soil amending, and supplemental fertilizing: Balancing nutrient inputs with outputs
  - c) Sound irrigation and tillage practices
5. Native plant associations, farmscaping, and the use of non-crop vegetation (see Bugg 1998)
  - a) Diversity vs. functional diversity
  - b) Farmscaping defined
  - c) Insectary plantings
  - d) Trap crops
  - e) Companion planting
6. The use of resistant crop varieties

#### **E. Components of a Pest Management Program for Certified Organic Farming Systems**

1. Prevention of pests (see above)
2. Identifying pests and understanding the ecology of agronomically important arthropods
  - a) Accurate identification (see Demonstration 1)
  - b) Understanding of how environmental conditions affect populations of both pest and beneficials arthropods
    - i. Example: Degree days and the emergence of codling moth (*Cydia pomonella*)
3. Monitoring for presence and abundance of arthropod populations and/or damage
4. Establishment of thresholds for pest control intervention (see Flint 1998)
  - a) Control action thresholds
  - b) Quantitative control action thresholds exist for some but not all crops and pests (see [www.ipm.ucdavis.edu/](http://www.ipm.ucdavis.edu/); Flint 1998)
  - c) General rule: Any time you find a lot of one type of pest insect (more than 5 on 2–3 plants in a row with no predators found in that same area) the pest/beneficial ratio is out of balance and some outside control will be necessary
  - d) For those crops without control action thresholds, growers must determine thresholds themselves through observation, trial and error

- e) Established control action guidelines do not include the influence of beneficial arthropods
- 5. Active (non-preventive) control methods (see Flint 1998; [www.ipm.ucdavis.edu/](http://www.ipm.ucdavis.edu/))
  - a) Biological control
  - b) Cultural control
  - c) Physical controls
  - d) Chemical controls

## F. Arthropod Monitoring and Management Procedures

1. Monitoring methods commonly used
  - a) Visual inspection/observation
  - b) Pest-specific monitoring and sampling procedures (see Flint 1998)
  - c) Larger-scale monitoring and sampling (see [ucanr.org/](http://ucanr.org/))
  - d) Arthropod sampling techniques for the garden and small farm
    - i. Traps
      - Pheromone traps
      - Sticky traps
      - Light traps
      - Pit fall traps
    - ii. Catching
      - Sweep nets
      - Aspirators
      - Shaking plants
    - iii. Degree-day monitoring
2. Monitoring protocol for in-field visual inspections
  - a) Survey crops systematically and on regular basis
    - i. Frequency: 1x/week; 2x/week during peak growing season
    - ii. Vegetable crops
      - Walk furrows, check both sides of leaves on every few plants
      - Remove wilted plants and examine root system
      - Root crops: Check the soil before you plant from the soil level to 4 inches down by running your fingers through the soil looking for small insects. Collect and identify samples.
    - iii. Orchards
      - Check trunk for injury
      - Check fruit for scars or points of entry
      - Check interior of grounded fruit for pest presence
      - Examine both sides of leaves on each side of the tree
  - b) Assess and record the following (see appendix, Arthropod Pest Management Field Observations Record Sheet)
    - i. Date, time, crop, and weather conditions
    - ii. Is proper cultural care being delivered?
    - iii. Number of pests observed
    - iv. Amount and type of damage
    - v. Presence and numbers of beneficials/natural enemies
    - vi. Evidence of parasitism or predation
    - vii. Stage of crop development



3. Management procedures
  - a) Determine if control action threshold has been exceeded
  - b) Research control action options
  - c) Implement control actions
  - d) Document control actions taken and responses to treatment

## G. Select Examples of Commonly Used Forms of NOP-Certified Control Strategies

1. Biological control methods
  - a) Classical biocontrol
  - b) Inoculative biocontrol
  - c) Inundative biocontrol
    - i. Microbial biocontrol
      - *Bacillus thuringiensis*—Bt
      - Naturalis
      - Predatory nematodes
      - Your own collections
    - ii. Selected beneficial insects
      - Aphytis
      - Encarsia
      - Lacewings
      - Ladybugs
      - Geocoris
      - Praying mantids
      - Predatory mites
      - Trichogramma wasps
      - Anaphes
2. Chemical control methods
  - a) Powders, soaps, and oils
    - i. Diatomaceous earth
    - ii. Drax
    - iii. Soaps
    - iv. Oils and neem oil
  - b) Botanicals
    - i. Garlic barrier
    - ii. Hot pepper wax
    - iii. Neem extracts
    - iv. Pyrethrins
    - v. Rotenones
3. Cultural control methods
  - a) Changes in frequency or timing of irrigation
  - b) Pruning to increase air circulation or prevent contact with soil
  - c) Field sanitation between cropping

#### 4. Physical control methods

- a) Row covers
- b) Solarization
- c) Vacuums
- d) Traps
- e) Flooding
- f) Tillage
- g) Field sanitation
- h) Netting
- i) Hand picking
- j) Reflective mulches
- k) Petroleum oil barriers

#### 5. Pheromones

- a) Pheromones defined
- b) Trapping out
- c) Mating disruption



# Detailed Lecture 1 Outline: Managing Arthropod Pests

## *for students*

### **A. Pre-assessment Questions**

1. Why is the management of arthropods important in crop production?
2. Why are pesticides ineffective in controlling insect pests?
3. What are some of the things insects and other arthropods do that enhance agricultural and environmental quality?
4. Which agricultural practices can you describe that serve to prevent the growth of pest populations beyond economic thresholds?
5. What would be some of the components of a sound pest management program for a certified organic farm or garden?
6. What would be the best ways to monitor for pests in the garden and small farm?
7. How would you go about determining if an insect is a “pest” or a “beneficial”?
8. What are several different organically acceptable ways to actively control pests?

### **B. Why Management of Arthropods Is Important in Crop Production**

1. Reduced productivity/yield: Unchecked growth of pest populations of plant-juice-sucking insects may lead to reductions in crop vigor, size, visual aesthetics, and overall yield
2. Spread of plant pathogens: Arthropods may create points of injury in plant tissues that allow fungal, bacterial, and viral diseases to successfully attack the plant. This is particularly important in perennial fruits and vegetables (e.g., Pierce’s disease).
3. Reduced visual aesthetics of crop: Directly feeding on the crop (fruits, vegetables, or flowers) reduces the visual aesthetics thereby rendering the crop unmarketable
4. Death of crop plants: Certain arthropods that feed on root systems of crops can cause death of the plants
5. Build up of pest populations: The absence of management may lead to the build up of pest populations, eventually causing increased crop losses in subsequent years

### **C. A Sketch of Arthropod Natural History**

1. Insects
  - a) The number of insect species is greater than the number of all other species of organisms combined (excluding prokaryotic organisms)
  - b) The number of taxonomically described beetles (only one of 31 orders of insects) is more than 250,000 species—more than all the species of flowering plants
  - c) Estimates on the number of species of insects yet to be described range from between 2 and 100 million species
  - d) At least 6 million to 9 million species of arthropods are now thought to live in the tropics, with only a small fraction currently described
2. Why have insects been so successful throughout natural history?
  - a) Insects have been around for more than 350 million years
  - b) Except for marine habitats, insects have adapted to almost every environment possible

- c) The reasons for their success include the following factors:
  - i. Short generation times and high numbers of offspring result in populations that are highly adaptable under the stress of environmental changes (rapid adaptation/evolution)
  - ii. A highly efficient body plan and construction: The insect “exoskeleton” is a light-weight, but incredibly strong “suit of armor” whose external waxy coating protects against moisture loss. Outwardly directed ridges and spines serve to protect or hide the insect from enemies, or are colored and modified to attract mates, while inward protruding ridges and spines serve as points of attachment for muscles.
  - iii. The ability to fly: Active flight was first to evolve in the insects, aiding dispersal to new and potentially favorable environments
  - iv. The development of “complete metamorphosis” in some orders, allowing the juvenile stages to no longer compete with the adults for space or resources. Body forms could be solely adapted to a specific and independent role or function.
- 3. Ecosystem “services” provided by arthropods in agroecosystems
  - a) Pollination: Many species of native bees and flies pollinate crops
  - b) Organic matter decomposition: Mold mites, springtails, wolf spiders, centipedes, sow bugs, ground beetles exist at different trophic levels and serve to break down organic matter into its constituent parts. They feed directly on organic matter or prey on those that do.
  - c) Natural or intrinsic levels of pest suppression: The great diversity of insects includes predaceous, parasitic and parasitoid adaptive strategies (see descriptions below) and are “natural enemies” of agricultural pests. These “beneficial insects” may serve to effectively suppress the development of pest populations if habitat for these species is effectively managed.
  - d) Summary: Organic growers and researchers have an important role to play in this regard as they are attempting to manage agroecosystems without the use of synthetic chemicals. Their task requires that they adopt a “whole-systems approach”—replacing externally derived synthetic inputs with an understanding of how the biological resources of the system can be optimized to provide a full range of services, including insect pest and disease suppression.
- 4. Crop losses attributed to arthropods
  - a) While there is no doubt that insects can and do cause significant losses to farms and gardens, it is also increasingly clear that much more attention is given to insects as “pests” than is often warranted by the evidence.
  - b) This is in large measure due to the fact that multi-national chemical companies have enjoyed decades of profits from chemical insecticides on the order of \$35 billion per year, and in order to justify their continued profit taking—at the expense of the health of ecosystems and millions of people—insect pests need to be sold as “serious threats,” even when they might not be so
  - c) Example: Research on tropical rice shows that the current \$3 billion/year industry in rice insecticides could conservatively be reduced by more than 95% without any increase in losses (Bill Settle, pers. comm.). In fact, the evidence shows insecticides cause pest outbreaks more than they prevent them (Bill Settle, pers. comm.).
- 5. Ineffectiveness of attempts to control pests with agricultural chemicals
  - a) Herbivorous insects are less susceptible to insecticides than predaceous insects
  - b) Insecticide-induced resurgence: The rapid expansion of pest populations following a pesticide application resulting from pest populations being “released” from the population-control mechanism of predation by beneficial insects and spiders killed by pesticide exposure
  - c) Due to the highly adaptable nature of insect populations, repeated exposure to insecticides often leads to insecticide resistance—an inherited increase in the physiological range of tolerance to synthetic chemical controls
  - d) This often leads to the need for increased application rates of insecticides to achieve similar degrees of control, leading to further resistance and eventual loss of effectiveness of insecticide

#### **D. Sustainable Agricultural and Preventive Pest Management: Preventing the Growth of Pest Populations Beyond Economic Thresholds**

1. Crop rotation: Changing on an annual basis the place in the garden or field where crops are grown interrupts the host/pest cycle and thereby reduces or limits the development of populations of both arthropod pest and pathogens
2. Cover cropping: A form a crop rotation, cover cropping interrupts the host/pest cycle, and with certain cover crop species serves as habitat for natural enemies of insect pests, which often suppress pests. Be aware that inappropriate choices of cover crop species can increase pest populations (see Unit 1.6, Selecting and Using Cover Crops).
3. Polyculture cropping patterns: An agricultural landscape that is populated with a diversity of crops reduces the carrying capacity of the land for a given pest population and increases the possibility of supporting natural enemies of insect pests
4. Sound soil fertility management
  - a) Soil organic matter management: Regular additions of organic matter (e.g., compost, cover crops, and/or manure) stimulate soil biological activity and diversity, which may prevent certain pest populations from increasing beyond economic thresholds
  - b) Nutrient budgeting, soil amending, and supplemental fertilizing: Designing efficient amendment and fertilization plans around crop nutrient requirements and avoiding unnecessary nutrient inputs may prevent pest problems associated with both nutrient deficiencies and excesses
  - c) Sound irrigation and tillage practices: Maintaining desirable soil physical and chemical properties through properly applied irrigation and tillage will help prevent the pest problems associated with poor soil quality
5. Native plant associations, farmscaping, and the use of non-crop vegetation

A greater diversity of non-crop vegetation (native and planted) in and around the farm may increase the carrying capacity for natural enemies of arthropod pests that often suppress pests before they become a problem (see Bugg 1998)

  - a) Diversity vs. functional diversity: Functional diversity favors optimal pest/beneficial population dynamics
  - a) Farmscaping may be defined as the use of non-crop vegetation for increasing and managing on-farm functional biodiversity to favor beneficial insects
  - b) Insectary plantings: Plants known to produce abundant nectar used by natural enemies as a secondary food source. Help provide habitat for beneficial insects.
  - c) "Trap crops": Intentionally planted alternative food sources for pest organisms. Trap crops reduce or prevent large numbers of pest arthropods from feeding on cash crops.
  - d) Companion planting: Plants intentionally planted adjacent to cash crops that repel pests
6. The use of resistant crop varieties: Certain crop species have undergone extensive selective breeding in order to develop greater resistance and resilience to common agricultural pests. Such varieties should be used where appropriate.

#### **E. Components of a Pest Management Program for Certified Organic Farming Systems**

1. Prevention of pests (see above): Sustainable agriculture practices, when properly used in concert, create the optimal growing conditions in which crop plants are more resistant and resilient to both pests and pathogens
2. Identifying pests and understanding the ecology of agronomically important arthropods
  - a) Accurate identification of arthropods is essential in assessing the potential for natural enemies to control pest populations and in determining the need for active control and the type of treatments that one might effectively use
  - b) An understanding of how environmental conditions affect populations of both pest and beneficial arthropods will further assist a grower in making effective management decisions

- c) Example: Degree days and the emergence of codling moth (*Cydia pomonella*)
- 3. Monitoring: Regular and systematic field assessments provide essential information on the status of the crop in relation to populations of pests and natural enemies (see below)
- 4. Establishment of thresholds for pest control intervention (see Flint 1998)
  - a) "Control action thresholds": Control action thresholds inform a grower when specific control actions must be taken in order to avoid additional crop damage or losses
  - b) Quantitative control action thresholds exist for some but not all crops and pests (see [www.ipm.ucdavis.edu/](http://www.ipm.ucdavis.edu/); Flint 1998)
  - c) General rule: Any time you find a lot of one type of pest insect (more than 5 on 2–3 plants in a row with no predators found in that same area) the pest/beneficial ratio is out of balance and some outside control will be necessary
  - d) For those crops without control action thresholds, growers must determine thresholds themselves through observation, trial and error
  - e) As there are few control action guidelines that include monitoring of beneficial arthropods, growers or IPM specialists must use records of previous seasons' occurrences of pest and natural enemies to determine the need for treatment
- 5. The use of acceptable active (non-preventive) control methods when thresholds have been exceeded (see Flint 1998; [www.ipm.ucdavis.edu/](http://www.ipm.ucdavis.edu/))
  - a) Biological control: Biological control may be defined as "the actions of parasites, predators and pathogens in maintaining pest density at a lower average population density than would occur in their absence" (e.g., the release of predaceous or parasitic wasps)
  - b) Chemical controls: The use of least toxic materials that interfere with normal physiology or behavior of arthropods (e.g., spraying elemental sulfur to control fungal organisms)
  - c) Cultural controls: Altering the growing conditions such that arthropod pest populations are discouraged (e.g., crop spacing, irrigation timing, tillage)
  - d) Physical controls: Prevent access to the crop itself (e.g., Tanglefoot on fruit trees)

## F. Arthropod Monitoring and Management Procedures

1. Monitoring methods commonly used
  - a) Visual inspection/observation: Regular visual inspection and observation of plant parts in field and lab is the most effective monitoring method for small growers.
  - b) Pest-specific monitoring and sampling procedures for the garden and small farm (see Flint 1998)
  - c) Larger-scale monitoring and sampling: See [ucanr.org](http://ucanr.org) for a listing of IPM manuals for crop-specific monitoring and management
  - d) Arthropod sampling techniques for the garden and small farm
    - i. Traps: Less effective as they tell what is on the farm and not necessarily what is affecting the crops. Traps may also catch arthropods that come from outside the farm or garden.
      - Pheromone traps: Attract insects by chemical lure
      - Sticky traps: Capture flying adult insects
      - Light traps: Select for nocturnal insects
      - Pit fall traps: Capture ground-dwellings arthropods and spiders
    - ii. Catching: Most effective in determining abundance and correlating arthropods with crop damage
      - Sweep nets: Use to capture insects on vegetation
      - Aspirators: Use to capture very small insects on vegetation

- Shaking plants: Shaking or beating plants or branches onto paper for later sampling is a useful way to gather insects for identification that might normally go unseen
  - iii. Degree-day monitoring: For some pests and beneficial insects researchers have developed temperature development thresholds at which time management actions may best be taken
2. Monitoring protocol for in-field visual inspections
- a) Survey crops systematically and on regular basis
    - i. Frequency: 1x/week; 2x/week during peak growing season
    - ii. Vegetable crops:
      - Walk furrows and check both sides of leaves on every few plants
      - Remove wilted plants and examine root system for indications of soil borne insects, pathogens
      - Root crops: Check the soil before you plant from the soil level to 4 inches down by running your fingers through the soil looking for small insects. Collect and identify samples.
    - iii. Orchards
      - Check trunk for injury (e.g., sap oozing from wounds)
      - Check fruit for scars or points of entry
      - Check interior of grounded fruit for pest presence
      - Examine both sides of leaves on each side of the tree
  - b) Assess and record the following:
    - i. Date, time, crop, and weather conditions
    - ii. Determine whether proper cultural care is being delivered (e.g., water)?
    - iii. Number of pests observed
    - iv. Amount and type of damage
    - v. Presence and numbers of beneficials/natural enemies
    - vi. Evidence of parasitism or predation of pest organisms
    - vii. Stage of crop development
3. Management procedures
- a) Determine if control action threshold has been exceeded
  - b) Research control action options
  - c) Implement control actions
  - d) Document control actions taken and responses to treatment

## **G. Select Examples of Commonly Used Forms of NOP-Certified Control Strategies**

1. Biological control methods
  - a) Classical biocontrol: The importation and release of exotic biocontrol agents, with the expectation that the agents will become permanently established and no further releases will be necessary
  - b) Inoculative biocontrol: Natural enemy releases are made when pest populations are low, giving the population of natural enemies enough time to develop with the pest population. Inoculative biocontrol relies on subsequent generations to manage the target pest. As the released natural enemies are not necessarily adapted to the release environment populations, releases (inoculations) are made at the start of each growing season.



- c) Inundative biocontrol: Similar to the use of chemical pesticides, this method relies on mass releases of natural enemies to control a large population of target pests that are causing damage close to the economic threshold. Relies on sheer numbers and periodic and seasonal releases to suppress a given pest population.
    - i. Microbial biocontrol
      - *Bacillus thuringiensis*—Bt
      - Naturalis
      - Predatory nematodes
      - Your own collections
    - ii. Selected beneficial insects
      - Aphytis
      - Encarsia
      - Lacewings
      - Ladybugs
      - Geocoris
      - Praying mantids
      - Predatory mites
      - Trichogramma wasps
      - Anaphes
2. Examples of chemical control methods
- a) Powders, soaps, and oils
    - i. Diatomaceous earth
    - ii. Drax
    - iii. Soaps
    - iv. Oils and neem oil
  - b) Botanicals
    - i. Garlic barrier
    - ii. Hot pepper wax
    - iii. Neem extracts
    - iv. Pyrethrins
    - v. Rotenones
  - c) Minerals/Naturally occurring elements
    - i. Sulfur
    - ii. Copper
3. Examplese of cultural control methods
- a) Changes in frequency or timing of irrigation
  - b) Pruning to increase air circulation or prevent contact with soil
  - c) Field sanitation between cropping
4. Examples of physical control methods
- a) Row covers
  - b) Solarization
  - c) Vacuums
  - d) Traps
  - e) Flooding
  - f) Tillage
  - g) Field sanitation

- h) Netting
  - i) Hand picking
  - j) Reflective mulches
  - k) Petroleum oil barriers
5. Pheromones/Chemical lures
- a) Pheromones defined: The chemical sex attractant used by many insect species to draw mates
  - b) Trapping out: The use of pheromone traps to trap and kill
  - c) Mating disruption: The timed mass release of synthetic pheromones with the mating times of agricultural pests resulting in the inability of mating pairs to form



# Lecture 2: The Biology and Ecology of Arthropods

## *for the instructor*

### A. Basic Biology and Ecology of Arthropods

1. Taxonomic context
  - a) Systematics defined
  - b) Taxonomy and taxonomic organization of insects  
Example:  
Kingdom (Animalia)  
Phylum (Arthropoda)  
Class (Hexapoda = Insects)  
Order (Hemiptera = true bugs)  
Family (Miridae)  
Genus (*Lygus*)  
Species (*hesperus*)  
Common name = lygus bug
  - c) Orders of the class Hexapoda
    - i. 659 families for North America north of Mexico
    - ii. Family designation and the biology of an insect
    - iii. Example: “hover flies” (family Syrphidae) are predators on other insects
    - iv. Variation within families
2. Insect and spider body plans (illustrate with slides, transparencies, Powerpoint)
  - a) Head and mouthparts; thorax; abdomen
  - b) Circulatory system
  - c) Respiratory system
3. Insect development
  - a) Metamorphosis
  - b) “Primitive” metamorphosis
  - c) “Incomplete” metamorphosis
  - d) “Complete” metamorphosis
  - e) Life cycles of insects
    - i. Eggs
    - ii. Larvae/nymphs
    - iii. Larvae
    - iv. Pupae
      - Diapause
4. Basic ecological categories
  - a) Trophic levels
    - i. Scavengers/Detritivores
    - ii. Herbivores
    - iii. Predators
    - iv. Parasitoids
    - v. Hyperparasitoids
  - b) Functional groups

## B. Arthropod Groups Commonly Found on the Farm and in the Garden

1. Arachnids
  - a) Spiders (Araneae)
  - b) Mites (Acari)
  - c) Harvestmen or “daddy long legs” (Opiliones)
2. Garden Symphylan (Symphyla)
3. Centipedes (Chilopoda)
4. Millipedes (Diplipoda)
5. Smaller crustaceans
  - a) Pillbugs or “Rolly-poly” (Isopoda)
6. Insects (Hexapoda)—selected orders
  - a) Spring-tails (Collembola)
  - b) Dragonflies (Odonata)
  - c) Preying mantids (Mantodea)
  - d) Grasshoppers and crickets (Orthoptera)
  - e) Planthoppers, leafhoppers, aphids, scale, and mealybugs (Homoptera)
  - f) True “bugs” (Hemiptera)
  - g) Beetles (Coleoptera)
  - h) Flies (Diptera)
  - i) Bees and wasps (Hymenoptera)
  - j) Butterflies and moths (Lepidoptera)

# Lecture 2: The Biology and Ecology of Arthropods

## *for students*

### A. Basic Biology and Ecology of Arthropods

#### 1. Taxonomic context

- a) Systematics: The study of the diversity of organisms and of the relationships between them is called systematics. This discipline encompasses the study of the methods of classifying organisms, known as *taxonomy*. Systematics is one of the oldest areas of biological enquiry dating back to Aristotle in the fourth century B.C.)
- b) Taxonomy: In a formal biological classification species are grouped according to estimates of their similarity into groups called taxa. These taxa are arranged in a hierarchical pattern; the most common levels as follows (using an insect example in parenthesis):

Kingdom (Animalia)

Phylum (Arthropoda)

Class (Hexapoda = Insects)

Order (Hemiptera = true bugs)

Family (Miridae)

Genus (*Lygus*)

Species (*hesperus*)

Common name = lygus bug

- c) Orders of the class Hexapoda: Currently, there are 31 orders of the class Hexapoda listed in the most widely used taxonomic textbooks. A general field entomologist, or someone working at an ecosystem level, will be looking to identify insects to the family level.
  - i. 659 families are listed for North America north of Mexico
  - ii. The family level can often tell you a great deal about the biology of an insect. For example, all leafhoppers (family Cicadellidae) are plant-sucking herbivores.
  - iii. Similarly, all “hover flies” (family Syrphidae) are predators on other insects—especially aphids
  - iv. Variation within families: Even at the family level a great deal of variation can exist. For example, in the “shore flies” (family Ephydriidae) there is a range of species, some of which act as plant feeders, while others are detritus feeders (feeding on organic matter), and still others behave as predators and even as parasites.

#### 2. Insect and spider body plans

- a) Head and mouthparts; thorax; abdomen
- b) Circulatory system
- c) Respiratory system

#### 3. Insect development

- a) Metamorphosis: Insects grow by shedding their exoskeletons (molting), revealing a new, soft “skin” underneath that rapidly hardens into the next (larger) exoskeleton. Most insects go through several such molting stages before finally molting to the mature adult form.
- b) “Primitive” metamorphosis: Very early insect groups and proto-insects such as collembolans exhibit a “primitive” metamorphosis, in which adults differ from juveniles only in that they are larger and have sex organs

- c) "Incomplete" metamorphosis: Somewhat more recently evolved insect orders, such as the grasshoppers and crickets, preying mantids, termites, planthoppers and leafhoppers exhibit "incomplete metamorphosis" in which juveniles look very much like adults, except for size, sex organs, and the existence of wings during the adult phase of the life cycle.
- d) "Complete" metamorphosis: Even farther down the evolutionary road insects made a radical shift in developmental strategy, one that ended up being highly successful. Insect orders that exhibit "complete metamorphosis" (e.g., beetles, flies, ants, bees and wasps, and butterflies) are able to manifest entirely different body forms between sexually immature and mature stages
- e) Life cycles of insects and management implications: When we find an insect what we see is only a snapshot of its entire life. One tactic in seeking a solution against a specific insect pest is to look for the "weak link" in the chain of its life cycle. (See Resources for a list of technical books on life cycles.)
  - i. Eggs: Insect eggs constitute a "weak link" for insect pests. Because they are stationary and lack an effective defense system, eggs offer an easy target for many predators, parasitoids, and parasites.
  - ii. Larvae/Nymphs: The immature stages of insect orders having incomplete metamorphosis or hemimetabolous insects (e.g., grasshoppers and true bugs) are called nymphs. Nymphs often look similar to their adult stage (usually just missing the wings and sexual organs, but often different colors as well). Similarly they are often found in the same location, and exhibit the same feeding behavior as their adults.
  - iii. Larvae: The immature stages of insect orders exhibiting complete metamorphosis, or holometabolous insects (e.g., butterflies, flies, and wasps) are called larvae. Larvae and adults of the holometabolous insects, on the other hand, look nothing like each other and are adapted for entirely different functions. Juveniles (both larvae and nymphs) are often difficult for all but an expert to identify. One tactic you can employ if you find an unknown larva attacking your garden is to conserve the larva, together with its fruit or vegetable meal, in a cloth-covered container for later identification as an adult.
  - iv. Pupae: For the orders that undergo complete metamorphosis, the larva must make a radical transformation from larva to adult. To do so requires more than a mere shedding of the skin; this process is usually accomplished by creating some kind of protected resting stage (e.g., spinning a cocoon) and then spending days or weeks undergoing metamorphosis. During this resting stage, pupae are mostly defenseless from attack by predators and parasitoids, and pupal mortality can be significant. As the pupal stage lends itself easily to a resting stage, many holometabolic insects choose the pupal stage as a convenient way to pass a long, cold winter or a hot, dry summer (where in both cases there may otherwise be no food for the insect). This resting stage is termed a physiological "*diapause*". Diapause can often be a convenient "weak link" for controlling insect pests, as many insects burrow into the ground to undergo diapause.
- 4. Basic ecological categories: From a practical perspective, with so many different kinds of insects one of the best ways to categorize insects you find in the field is by how they live; principally, how and what they eat, and where they are found. This can sometimes be seen right away by a non-specialist, but with a little training and experience a majority of insects can be classified by their ecological role.
  - a) Trophic levels: The term "trophic" can be thought of as "feeding level" in a hierarchy. At the first level are the producers (plants and other chlorophyll-bearing organisms). The second level consists of the herbivores, followed by the "carnivores" in the broadest sense, who can themselves be separated out into different levels, depending on who eats whom. The scavengers are organisms that consume dead and decaying organic matter. For our purposes we can borrow from the trophic-level concept to create five useful categories:

- i. Scavengers, also called “detritivores”: Insects that consume dead animal or vegetable material as the first phase in the decomposition of organic matter. Scavengers are found everywhere on an organic farm, but are often mostly absent in commercial farms where little organic matter is returned to the soil, and where toxic chemicals are commonly used.  
Scavengers can also play an important role as *alternative food sources* for generalist predators, a potentially important relationship that has been mostly overlooked by conventional agronomic science.
  - ii. Herbivores: Most every “pest” on the farm is an herbivore. Even herbivores that we easily identify as “pests,” such as spotted cucumber beetles, are only truly “pests” if their numbers are above an economic threshold for the farmer.
  - iii. Predators: Predatory insects and spiders kill and consume their prey, and tend to be “generalists.” That is, they have a fairly wide scope of arthropod prey—both pest and beneficial—that they can feed on.
  - iv. Parasitoids: Parasitoids are defined as insects that lay eggs inside the eggs or bodies of other insects. These eggs hatch and the emerging larva begins to consume the “host” insect, eventually killing the host and emerging as a free-living adult. The difference between a “parasite” and a “parasitoid” is that the parasite (e.g., a flea or a tick) does not directly kill the “host.” The difference between a predator and a parasitoid is that the predator directly kills and eats the “prey,” whereas in the case of the parasitoid, it is the next generation or offspring that actually does the killing.  
Parasitoids are mostly restricted to several dozen families of small to minute wasps, although there are several parasitic fly families as well. Parasitoids have been a favorite subject for biological control programs because they tend to be highly specific for one or a few species of host, and therefore can be used to target specific pests. Predators are generally better at reducing large numbers of pests, while parasitoids—because of their highly host-specific nature—are generally better at preventing populations of a pest from reaching high numbers in the first place. A coordinated strategy of using predators and parasitoids may be most effective in reducing and maintaining pest populations.
  - v. Hyperparasitoids: Hyperparasitoids are parasitoids of parasitoids
- b) Functional groups: Functional groups are a non-definitive but quick and easy means of categorizing insects based on the experience of the practitioner of what insects in their farm or garden system *do*. This may give the practitioner a more “fine grained” description of his or her agroecosystem. Categories for functional groups commonly involve some, but usually not all of the following: Where an insect lives, its trophic level, how it feeds or what it feeds on, and some reference to a taxonomic label. Some hypothetical examples could include: “brassica-feeding beetles,” “egg parasitoids,” “aphid parasitoids,” “stem-boring moths,” “hunting spiders,” “web spiders,” and so on. You’ll find that defining a list of functional groups for the commonly found insects in your small farm or garden gives you around 15–20 different categories. This is just about the right size for properly defining the system without getting lost in non-intuitive names.

## B. Arthropod Groups Commonly Found on the Farm and in the Garden

1. Arachnids
  - a) Spiders (Araneae)
  - b) Mites (Acari)
  - c) Harvestmen or “daddy long legs” (Opiliones)
2. Garden Symphylan (Symphyla)
3. Centipedes (Chilopoda)
4. Millipedes (Diplipoda)
5. Smaller crustaceans
  - a) Pillbugs or “Rolly-poly” (Isopoda)



6. Insects (Hexapoda)—selected orders:
- a) Spring-tails (Collembola)
  - b) Dragonflies (Odonata)
  - c) Preying mantids (Mantodea)
  - d) Grasshoppers and crickets (Orthoptera)
  - e) Planthoppers, leafhoppers, aphids, scale and mealybugs (Homoptera)
  - f) True “bugs” (Hemiptera)
  - g) Beetles (Coleoptera)
  - h) Flies (Diptera)
  - i) Bees and wasps (Hymenoptera)
  - j) Butterflies and moths (Lepidoptera)

# Demonstration 1: Pest Monitoring, Sampling, and Identification

## *for the instructor*

### **OVERVIEW**

*This demonstration introduces students to the principles and practices of pest management, field monitoring, and identification for the garden and small farm. Using the demonstration outline, the instructor should review with students the basic steps in visually monitoring different types of crops and documenting the presence and abundance of insect pests, pest damage, and beneficial arthropods. Following this, the instructor introduces several field sampling techniques commonly used in pest management monitoring on small farms and gardens. Then ask students to collect samples of crop damage and arthropod samples using sweep nets and aspirators, and retrieve insect samples from previously placed traps.*

*Working in small groups in a laboratory setting, students will then review collected specimens and practice identifying the collections to Order, common name, and/or genus and species. Using printed visual keys and on-line resources, help students identify the insects they've collected as either "pest" or "beneficial." After identifying the insects and crop damage, students should research and discuss the thresholds for each of the pests observed, and the National Organic Program-accepted control options available had the thresholds been exceeded.*

### **PREPARATION AND MATERIALS**

- Gardens or fields with actively growing crops
- Insect traps placed in several field/garden locations several days prior to instruction
- Sweep nets
- Aspirators
- Film containers (for insect samples)
- Alcohol (for insect samples)
- Notebook for documenting field observations
- Hand lenses and/or dissecting scopes
- Lab with multiple computer terminals with internet access (see Resources for identification web sites) and/or
- Insect identification books (see Flint 1998 in Resources)

### **PREPARATION TIME**

1–2 hours

### **DEMONSTRATION TIME**

2 hours

## **DEMONSTRATION OUTLINE**

### **A. Review Monitoring Protocol for In-field Visual Inspections**

1. Surveying crops systematically and on regular basis
  - a) Frequency: 1x/week; 2x/week during peak growing season
  - b) Time of day to sample
  - c) Vegetable crops
    - i. Demonstrate walking furrows and checking both sides of leaves on every few plants
    - ii. Demonstrate removing any wilted plants and examining root system for indications of soil borne insects or pathogens
  - d) Orchards
    - i. Demonstrate checking trunk for injury (e.g., exuding sap)
    - ii. Demonstrate checking fruit for scars or points of entry
    - iii. Demonstrate checking interior of grounded fruit for pest presence
    - iv. Demonstrate examining both sides of leaves on each side of the tree
2. Review record keeping procedures, including the following (see Appendix, Arthropod Pest Management Field Observations Records Sheet)
  - a) Date, time, crop and weather conditions
  - b) Is proper cultural care being delivered (e.g., water)?
  - c) Number of pests observed
  - d) Amount and type of damage
  - e) Presence and numbers of beneficials/natural enemies
  - f) Evidence of parasitism or predation
  - g) Stage of crop development
  - h) Management actions taken

### **B. Demonstrate Sampling Procedures**

1. Sweep nets
2. Aspirators
3. Hand picking
4. Preservation in alcohol
5. Sampling damaged plants

### **C. Students Collect Samples and Return to Lab for Identification Exercise**

1. Instructor demonstrates use of on-line and printed resources in identifying samples of arthropods and plant damage (see Resources section)
2. Working in small groups, students practice identifying the collections to Order, genus, and species (when possible), common name, “pest” or “beneficial” designation
3. Small student groups share/report identification to peers and instructor
4. Instructor confirms identification
5. Students research and discuss the thresholds for each of the pests observed on the crops (whether or not a threshold has been exceeded should include a discussion of the presence and abundance of natural enemies)
6. Students research and present NOP-accepted physical, biological, and chemical control options available had the thresholds been exceeded
7. Instructor shares anecdotal information on control options

# Demonstration 2: Field Observations

## *for the instructor*

### **OVERVIEW**

*In this field demonstration students will visit a working farm to review the pest management program different growers have developed for their certified organic farming operations. Request from the grower a brief overview of the current soil fertility and pest management practices used in the operation. The overview should include the components outlined below.*

### **DEMONSTRATION TIME**

2 hours

### **DEMONSTRATION OUTLINE**

#### **A. Soils and Soil Fertility Management**

1. Soil textural classification
2. Hydrology of fields
3. History of cultivation
4. Tillage and irrigation practices
5. History of soil testing and amending
6. Organic matter management: Cover crops, compost, and manure application rates and timing
7. Crop rotation history or practices
8. Supplemental fertilizers and tillage practices used

#### **B. Pest Management**

1. Persistent pests
2. Persistent diseases
3. Plant growth response and/or crop quality concerns
4. Brief overview of the arthropod monitoring practices
5. Explanation of the treatment options used, including at what defined thresholds they were applied and how effective the treatments have been



# Assessment Questions

- 1) Describe five practices used in sustainable horticultural and agricultural and how they serve to prevent the growth of pest populations beyond economic thresholds.
- 2) What are the essential components of a sound pest management program for a certified organic farm or garden?
- 3) Describe the protocol you would use in monitoring your fields for insect/arthropod pests and natural enemies.
- 4) List five arthropod pests and the crops they affect in your region. What are the National Organic Program-certified physical, chemical, biological, and cultural control options available for these pests?
- 5) How might non-crop vegetation help manage insect pests? How might it be detrimental? Name five different non-crop plants that farmers use in your area to enhance biological control. How do each of these plants serve to enhance biological control?

# Assessment Questions Key

1) Describe five practices used in sustainable horticultural and agricultural and how they serve to prevent the growth of pest populations beyond economic thresholds.

- *Crop rotation: Crop rotation interrupts pest/ host cycle by changing the crop grown on a given piece of ground.*
- *Cover cropping: Cover cropping is a form of crop rotation; some cover crop species attract natural enemies of agricultural pests. Many cover crops also have allelopathic qualities that suppress pest populations. It's also important to avoid choosing inappropriate crops that would attract pests.*
- *Polyculture cropping patterns: Provide greater plant diversity within the agricultural ecosystem, thereby maintaining the carrying capacity for pests at a lower level than in a monoculture. Also increase the possibility of beneficial insect habitat.*
- *Sound irrigation and tillage practices to retain essential plant nutrients, avoid soil erosion and compaction, and maintain desirable soil physical properties.*
- *Maintain native plant associations in and around the farm and farmscaping: Serve to attract natural enemies of agricultural pests or repel pests*
- *The use of resistant crop varieties*

Sound soil fertility management including the following components:

- *Soil organic matter management (maintaining soil organic matter levels ideally between 3–5%) will help maintain soil biological activity and diversity, optimizing soil physical properties and some naturally occurring pest suppression.*
- *Supplying optimal levels of essential plant nutrients without overfertilizing. Through soil analysis and accurate nutrient budgeting, combined with efficient soil amending and supplemental fertilizing, pest problems associated with both overfertilization and plant nutrient deficiencies should be reduced.*

2) What are the essential components of a sound pest management program for a certified organic farm or garden?

- *The use of preventive agricultural and horticultural practices (above)*
- *Systematic monitoring and documentation of pest populations, crop damage, and the presence and abundance of beneficial insects*
- *Accurate identification of arthropods present in the farm and garden and an understanding of the ecology of agronomically important arthropods, including natural enemies of agricultural pests*
- *Research and establishment of control action thresholds for each crop*
- *Active (non-preventive) control methods: Physical, cultural, chemical, and/or biological control options*

3) Describe the protocol you would use in monitoring your fields for insect/arthropod pests and natural enemies.

- *Survey crops systematically for visual inspection/observation 1x/week, and 2x/week during peak growing season*

*For vegetable crops:*

- *Walk furrows and check both sides of leaves on every few plants. Collect samples and identify.*
- *Remove wilted plants and examine root system for indications of soil borne insects or pathogens. Collect and identify samples.*

*For root crops:*

- *Check the soil before you plant from the soil level to 4 inches down by running your fingers through the soil looking for small insects. Collect and identify samples.*

*For orchards:*

- *Check trunk for injury*
- *Check fruit for scars or points of entry. Collect samples and identify.*
- *Check interior of grounded fruit for pest presence. Collect and identify.*
- *Always examine both sides of leaves on each side of the tree.*

*Assess and record the following:*

- *Date, time, crop, and weather conditions*
- *Is proper cultural care being delivered?*
- *Number of pests observed*
- *Amount and type of damage*
- *Presence and numbers of beneficials/natural enemies*
- *Evidence of parasitism or predation*
- *Stage of crop development*
- *Management actions taken*

4) List five arthropod pests and the crops they affect in your region. What are the National Organic Program-certified physical, chemical, biological, and cultural control options available for these pests?

*(answers will vary)*

5) How might non-crop vegetation help manage insect pests? How might it be harmful? Name five different non-crop plants that farmers use in your area to enhance biological control. How do each of these plants serve to enhance biological control?

*(answers will vary)*



# Resources

## PRINT RESOURCES

### BOOKS

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Flint, Mary Louise. 1998. *Pests of the Garden and Small Farm: A Grower's Guide to Using Less Pesticide, Second Edition*. Publication 3332. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Covers insects, mites, plant diseases, nematodes, and weeds of fruit and nut trees and vegetables. Individual sections describe the biology, identification, and control of 95 common pests; includes symptom-identification tables organized by crop. Recommended methods rely primarily on organically acceptable alternatives.*

Flint, Mary Louise, and Steve H. Dreistadt. 1998. *Natural Enemies Handbook: The Illustrated Guide to Biological Pest Control*. Publication 3386. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A valuable resource for biological control of pests and pathogens.*

Pickett, Charles H., and Robert Bugg, eds. 1998. *Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests*. Berkeley: University of California Press.

### PERIODICALS

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Common Sense Pest Control Quarterly

[www.keyed.com/birc/index.html](http://www.keyed.com/birc/index.html)

*Features least-toxic solutions to pest problems of the home and garden.*

The IPM Practitioner

[www.keyed.com/birc/index.html](http://www.keyed.com/birc/index.html)

*Focuses on management alternatives for pests such as insects, mites, ticks, vertebrates, weeds, and plant pathogens. Each issue contains an in-depth article ("Updates") on a research topic in integrated pest management (IPM).*

## WEB RESOURCES

Agriculture Research Service Plant Sciences Institute

[www.barc.usda.gov/psi/](http://www.barc.usda.gov/psi/)

*Includes links to information on insect biocontrol, systematic entomology, insect behavior, and other research efforts within the USDA.*

Association of Natural Biological Control Producers

[www.anbp.org/index.htm](http://www.anbp.org/index.htm)

*Resources, meetings, and other information on biocontrol*

ATTRA: Farmscaping to Enhance Biological Control

[www.attra.org/attra-pub/farmscape.html](http://www.attra.org/attra-pub/farmscape.html)

*Excellent "how-to" information on increasing and managing biodiversity on a farm to favor beneficial organisms. Can be downloaded in PDF format.*

Bioquip

[www.bioquip.com](http://www.bioquip.com)

*Books, equipment, and supplies for entomology and related sciences.*

Brooklyn Botanical Garden Natural Pest Control

[www.bbg.org/gar2/pestaalerts/](http://www.bbg.org/gar2/pestaalerts/)

*Lists "alerts" on insects, diseases, and invasive plants.*

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)

(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

#### California Pest Management Guidelines

[www.ipm.ucdavis.edu/PMG/crops-agriculture.html](http://www.ipm.ucdavis.edu/PMG/crops-agriculture.html)

*Database supplies the University of California's official guidelines for pest monitoring techniques, pesticides, and nonpesticide alternatives for managing insect, mite, nematode, weed, and disease pests in agricultural crops, floriculture and ornamental nurseries, commercial turf, and in homes and landscapes.*

#### Cornell University Biological Control: A Guide to Natural Enemies in North America

[www.nysaes.cornell.edu/ent/biocontrol](http://www.nysaes.cornell.edu/ent/biocontrol)

*Provides photographs and descriptions of biological control (or biocontrol) agents of insect, disease, and weed pests in North America. It is also a tutorial on the concept and practice of biological control and integrated pest management (IPM).*

#### Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

#### Peaceful Valley Farm Supply

[www.groworganic.com](http://www.groworganic.com)

*Contains listing of many Organic Materials Review Institute-approved pest management resources for monitoring and control.*

#### Pennsylvania State University IPM Links

[paipm.cas.psu.edu/websites/Links.html](http://paipm.cas.psu.edu/websites/Links.html)

*Links to a wide variety of sites on IPM, biological control, insects, invasive species, etc.*

#### University of California Division of Agriculture and Natural Resources (UC DANR)

[ucanr.org](http://ucanr.org)

*Contains a on-line catalogue of UC DANR crop-specific IPM publications and links to IPM websites.*

#### UC IPM Publications and other educational materials

[www.ipm.ucdavis.edu/IPMPROJECT/pubs.html](http://www.ipm.ucdavis.edu/IPMPROJECT/pubs.html)

*A guide to publications, newsletters, slides, videos, and other educational material produced by the University of California's IPM program. Some materials is available on-line in PDF format.*

#### UC Sustainable Agriculture Research and Education Program (UC SAREP)

[www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu)

*Includes information on biologically integrated farming systems and other alternative pest management programs.*

#### USDA Forest Service and the Bugwood Network

[www.insectimages.org](http://www.insectimages.org)

*More than 5,400 high-quality insect and insect damage photographs available in digital format. Entries are classified by subject, common name, scientific name, life stage, and host. From the easily navigated web site one can quickly click to the desired target. Available for downloading and use for educational applications with no royalties or fees required, as long as appropriate credit is given to the source.*



# Appendix: Arthropod Pest Management Field Observations Records Sheet

	Crop:	Crop:	Crop:	Crop:
Date, time				
Stage of crop development				
Is proper cultural care being delivered? Describe				
Genus, species, common name of pests observed				
Number of pests observed				
Amount, type of crop damage observed				
Name, number of beneficial insects				
Evidence of parasitism or predation				
Description of control action threshold for pest				
Management actions taken and date				



# 1.9 Managing Plant Pathogens

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# Introduction: Managing Plant Pathogens

## UNIT OVERVIEW

*Prevention and early diagnosis are critical to limiting damage by plant pathogens. This unit introduces students to the fundamental concepts and basic skills needed to identify and manage plant pathogens in certified organic production systems. Topics include the economic importance of plant pathogen management and the basic biology (especially life cycles) of bacteria, fungi, viruses, nematodes, mycoplasma-like organisms, and parasitic higher plants that are common plant pathogens and vectors in agricultural systems. Abiotic diseases such as nutrient deficiencies and air pollution are presented, along with the interactions among environment, pathogen, and crop plant. Management techniques for each pathogen and vector are also discussed.*

## MODES OF INSTRUCTION

- > LECTURE (1 LECTURE, 3.0 HOURS)  
The class lecture covers the basics of plant pathology: History and causes of disease, biology of causal organisms, disease diagnosis, ecological management, climatic factors.
- > DEMONSTRATION: DISEASE IDENTIFICATION (1.5 HOURS)  
During the disease identification demonstration, students will collect and diagnose diseases and disease-like samples they gather. Management techniques for each disease will be discussed.
- > ASSESSMENT QUESTIONS: (0.5–1 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The economic importance of plant pathogen management
- Basic biology (especially life cycles) of bacteria, fungi, viruses, nematodes, mycoplasma-like organisms, parasitic higher plants
- Abiotic diseases: Nutrient deficiencies and air pollution
- The disease triangle: Interactions among environment, pathogen, and plant
- Disease management from an ecological perspective

### SKILLS

- How to diagnose diseases and use diagnostic resources





# Lecture Outline: Managing Plant Pathogens

## *for the instructor*

### **A. Pre-assessment Questions**

1. What is plant disease?
2. How do pathogens cause disease symptoms?
3. What are the main causal organisms for plant diseases?
4. What is the disease triangle, and how do we use it in ecological disease management?
5. What are the steps involved in identifying plant diseases?

### **B. Description and History of Plant Disease**

1. What is plant disease?
2. Economic importance of plant disease
3. Evolution of hosts and pathogens
  - a) Probable evolutionary history
  - b) Nutritional strategies of pathogens
  - c) Obligate and non-obligate pathogens
  - d) Co-evolution of plants and pathogens

### **C. How Pathogens Cause Disease**

1. Enzymatic degradation
2. Toxins
3. Growth regulators
4. Genetic manipulations

### **D. Causal Organisms**

1. Bacteria
2. Fungi
3. Oomycetes
4. Viruses
5. Nematodes
6. Phytoplasmas
7. Parasitic higher plants
8. Abiotic

### **E. Disease Diagnosis**

1. Field-scale patterns of disease
2. Symptoms and signs
3. Koch's Postulates
4. Resources for disease diagnosis

## **F. Ecological Disease Management**

1. Disease triangle
2. Environment manipulations
3. Host manipulations
4. Pathogen manipulations
5. Climate and weather patterns that encourage the rate of growth, development, and distribution of certain plant pathogens

# Detailed Lecture Outline: Managing Plant Pathogens

## *for students*

### **A. Pre-assessment Questions**

1. What is plant disease?
2. How do pathogens cause disease symptoms?
3. What are the main causal organisms for plant diseases?
4. What is the disease triangle, and how do we use it in ecological disease management?
5. What are the steps involved in diagnosing plant diseases?

### **B. Description and History of Plant Disease**

1. What is plant disease?

A disruption in normal physiology—usually with some kind of negative effect on survival or fitness of the individual. For most plant pathologists, this includes infectious agents, nutrition, and air pollution. They also include nematodes but not insects, mites, or genetic abnormalities, unless infectious agents cause them. In practice, most plant pathologists work with infectious agents.

2. Economic importance of plant disease

Diseases are important to humans because they cause damage to plants and plant products, commonly with an associated economic effect, either positive or negative. Negative economic effects include crop failure, incremental loss from lower quality or failure to meet market standards, elimination of crop options because of disease propagule buildup, or the costs of control methods. Plant diseases are also responsible for the creation of new industries to develop control methods.

3. Evolution of hosts and pathogens

- a) Probable evolutionary history

Early life forms died and saprophytes (decomposers) evolved to “clean up” and recycle their bodies—the only way to have life in the earth’s closed system. Gradually, saprophytes gained the ability to “feed” on early life forms while still alive, and became pathogens. Ancient fossil records of plant symbionts indicate that some pathogens such as oomycetes are more closely related to photosynthetic algae.

- b) Nutritional strategies of pathogens

Bacteria and fungi do not ingest their host, but use absorptive nutrition (enzymatic degradation outside the pathogen). Nematodes use alimentary nutrition (enzymatic- and bacterial-mediated degradation inside the pathogen). Viruses skip the nutrition phase and take over the genetic and protein-synthesizing processes of the cell and force it to produce new viruses. Viruses have no role in “cleaning up” the dead, but may lead to evolutionary change in their hosts through transfer of genetic materials. Viruses hop in and out of different hosts and by accident, bring along bits of DNA with them—the original genetic engineers.

c) Obligate and non-obligate pathogens

Obligate pathogens can only live on the plants within their host range and have no saprophytic ability (i.e., cannot live on dead tissue). They cannot exist in an active form without a live host. Non-obligate pathogens have saprophytic ability, which ranges from survival only on their dead host to survival and growth on a wide range of organic materials. The implications of obligate vs. non-obligate survival on disease management will be discussed below.

d) Co-evolution of plants and pathogens

A completely successful obligate pathogen (able to attack and kill all individuals of its host range) would result first in extinction of its host, followed quickly by extinction of the pathogen itself. Thus, survival for both host and pathogen depends on a dynamic, genetic relationship between host resistance and pathogen virulence, in which neither organism can gain complete domination over the other. Plants and pathogens have genetic flexibility such that reproduction produces diverse individuals containing a variety of resistance and virulence genes. In undisturbed systems, natural selection prevents a plant or pathogen from being completely resistant or virulent.

Agriculture, and in particular the use of hybrids, provides continuous, large quantities of genetically similar hosts, thus skewing natural selection to accelerate the evolution of highly virulent pathogens, leading to highly damaging, uncontrollable diseases. Ecological plant pathology attempts to decelerate the evolution of virulent pathogens by reducing the pathogens' access to these hosts. It isn't easy to control agricultural plant diseases ecologically because agriculture, by definition, is an unnatural environment, where we artificially favor specific plant genes. However, we can use our knowledge of ecology and evolution to design the whole growing system to slow down, reduce, or avoid disease on plants. "Pesticide-based" agriculture has often ignored ecological principles in designing cropping systems.

## C. How Pathogens Cause Disease

1. Enzymatic degradation

In their most basic form, pathogens secrete enzymes, which catalyze the breakdown of host tissues, similar to the digestion of food in mammals.

2. Toxins

Pathogens often benefit by producing toxins, which kill the tissue in advance of enzymatic degradation. In many pathogens, particularly non-obligate pathogens, toxins cause the majority of damage to the host.

3. Growth regulators

Pathogens often find it advantageous to produce growth regulators (or cause the host to produce them). The most common are those that cause translocation of nutrients to host cells and/or cause host cells to enlarge or divide in the vicinity of the pathogen, thus providing an increase in food for the pathogen. Obligate pathogens allow the host to go on living, but still provides extra food for the pathogen.

4. Genetic manipulations

All viruses plus a few bacteria are able to force the plant to produce pathogen gene products from pathogen genetic material. This starves plant cells and disrupts their function.

## D. Causal Organisms

### 1. Bacteria

Bacteria are single celled, have no nucleus, and one chromosome. They have a limited overall size, but unlimited reproduction by fission (no chromosomal segregation). This allows bacteria to reproduce faster than fungi and may result in quick epidemics. They exhibit absorptive nutrition, and most in nature are saprophytic. Pathogens cause blights (rapid, toxic killing of plant tissue), rots (mushy breakdown), wilts (plugging of vasculature), and galls (growth regulator-mediated enlarged areas on plants). Bacteria are very sensitive to the environment—when active, they don't have much protection from sunlight and drying. When not active, they have found ways to survive unfavorable conditions such as living inside seed coats. They spread by wind, water, seeds, and vectors (such as insects, people). Examples: fire blight on pear, crown gall on many woody plants, soft rot on many herbaceous plants.

### 2. Fungi

Fungi are connected cells with nuclei, multiple chromosomes, mitochondria, and chitin for strength. Their overall size is unlimited, but without a vascular system they don't have good connections/"communication" among segments and easily fragment into multiple bodies. Most are able to form differentiated structures, e.g., mushrooms, spores. Like bacteria, most are saprophytic. Plants infected with fungi exhibit many symptoms, including rot, blight, leaf spots, and wilts. Fungi are fairly sensitive to light and dry conditions when growing, but can make very resistant structures to survive. They spread by wind, water, seed, and vectors. Examples: apple scab, powdery mildews, peach leaf curl.

### 3. Oomycetes

Oomycetes are like fungi in many ways, but have a different evolutionary history, perhaps arising from photosynthetic algae that lost the ability to photosynthesize. They produce zoospores (mobile spores) and oospores. Most are water or soil inhabitants, and favored by free water or a film of water in which zoospores can swim. Oomycetes are spread by wind, water, seed, and vectors. Examples: downy mildew, *Pythium* (damping-off), *Phytophthora* root rots.

### 4. Viruses

Viruses are pieces of nucleic acid (RNA or DNA)—those with a protein coat are viruses, those without are viroids. They are always a parasite, although not necessarily a pathogen. The nucleic acid in a virus or viroid codes for a few proteins and takes over a cell, upsetting normal metabolism and causing an excess or shortage of molecules used to make new cell components. Symptoms mimic genetic abnormalities and include mosaics, yellows, distortions, and death. Viruses spread by mechanical means, seeds, or vectors, which is an important consideration when choosing a control method. Examples: squash mosaic on zucchini, yellow viruses on many plants, tobacco mosaic on tomato.

### 5. Nematodes

Nematodes are microscopic worms; the presence of a stylet (a needle-like mouthpart that is stabbed into the host) differentiates plant parasitic nematodes from saprophytes. They occur as ecto-nematodes (all but the head is outside the plant) and endo-nematodes (the entire nematode is inside the plant), and can be sedentary or migratory. Injection of the nematode's saliva upsets plant metabolism, causing an excess or shortage of nutrients or hormones. Symptoms include tumors and death of affected parts. Nematodes spread slowly unless carried by water or humans and occur most often in sandier soils and warmer climates. Examples: rootknot nematode on many plants, beet cyst nematode on vegetables.

## 6. Phytoplasmas

“Bacteria without a cell wall,” phytoplasmas are only found in plant sap. They spread by grafting or insects. Examples: pear decline, Pierce’s disease on grapes.

## 7. Parasitic higher plants

Parasitic vascular plants rely on a host for water and minerals (green-colored leaves) and sometimes carbohydrates as well (non-green-colored leaves). Deleterious effects are from hormonal upset of the host rather than nutrient or water loss. These parasites occur primarily in forestry, perennials, and poorly managed annual crops. Examples: mistletoe on trees, dodder on vegetables.

## 8. Abiotic

Nutrient toxicities and deficiencies occur as a result of nutrient toxicities or deficiencies in the rock from which the soil formed, or from poor management. Examples: zinc, copper, boron toxicities or deficiencies. Air pollution: lead, NO<sub>2</sub>, CO, HF, Ozone, SO<sub>2</sub>.

## E. Disease Diagnosis

### 1. Field scale patterns of disease

Identify the host. Look for patterns of damage—circular, down rows, or across rows can provide clues of how the disease spreads. Focus on borders between healthy and diseased; this is likely where the pathogen is most active making the observation of signs, and pathogen isolation in the lab, more probable.

### 2. Symptoms and signs

Be clear on whether you are looking at a symptom or a sign. A symptom is an observation of the host response to infection by the pathogen. A sign is a visible structure of the pathogen itself, and is much more diagnostic. Observe the full range of symptoms; compare symptoms to pictures. Find out what diseases are common locally. Don’t be surprised if you aren’t sure: Many diseases need to be identified with laboratory techniques. Don’t guess.

### 3. Koch’s Postulates

Koch’s Postulate is a method for proving that a particular organism causes disease. The organism is removed from the plant, grown in pure culture, and inoculated to healthy plants. If disease results and the same organism is re-isolated, the pathogenicity is confirmed.

### 4. Resources for disease diagnosis

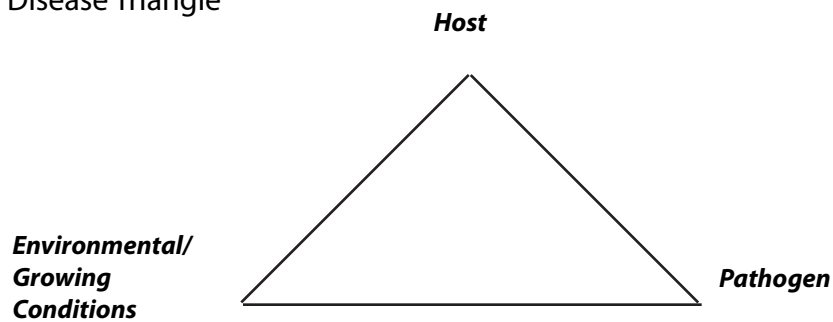
Resources to help diagnose plant diseases include Cooperative Extension services, other professionals, and pictorial disease guides (see Resources section for print and web-based diagnostic resources).

## F. Ecological Disease Management

### 1. Disease triangle

In general, disease results from a susceptible host, a virulent pathogen, and a favorable environment. Together, these three factors make up the disease triangle. All three must occur at the same time for disease to occur. Pesticide-based agriculture concentrates on reducing the disease after it is first seen, or on a spray schedule using a calendar or forecaster. Ecological disease management concentrates on avoiding conditions that predispose plants to disease.

## Disease Triangle



Theoretically, approaches that avoid disease make more sense than those that try to fix things afterwards. Chemical fixes may have unintended effects, including plant toxicity and removal of natural enemies that were controlling other pest problems. In general, strongly growing, healthy plants are most able to resist disease, although exceptions occur. Plant susceptibility to a particular disease usually changes depending on the amount and type of physiological stress. To some extent, growers can manipulate the Disease Triangle (above)—the host, the pathogen, or environmental conditions—as outlined below.

### 2. Environment manipulations

The grower usually has most control over the cropping environment; examples include increasing plant spacing (to reduce humidity and decrease infection), regulating the amount of irrigation and drainage, choosing where the crop is grown (climate, soil, nutrition, landscape diversity, soil biodiversity), etc.

### 3. Host manipulations

We often have less control of the host, since we have already chosen it in the crops one is growing. We can look for resistant cultivars, use pathogen-free planting materials (through quarantine or eradication techniques such as hot-water seed treatment), and practice crop rotation (both temporal and spatial, such as intercropping).

### 4. Pathogen manipulations

We try to keep the pathogen out of the field, or get rid of it when it is seen (either manually by removing affected host tissue, or by using chemical controls). Copper, sulfur, Neem, and potassium bicarbonate are the primary disease-controlling chemicals allowed in certified organic production. A newer technique that still needs a lot of understanding is the role non-pathogenic microbes have in competing, killing, eating, and inducing resistance to pathogens. Ecological agriculture, with its goal of both high numbers and diversity of microbes in soil and on leaves, may increase its reliance on non-pathogens for disease control in the future.

### 5. Climate and weather patterns that encourage the rate of growth, development, and distribution of certain plant pathogens

In general, most plant pathogens like wet, warm weather with an abundance of free moisture on plant surfaces. However, some pathogens, such as powdery mildew, will be inhibited by rainfall, and overhead irrigation is sometimes used to control this disease. Weather that is too hot or too cold for the plant to grow properly can make the host susceptible to disease. Some pathogens, such as many of the anthracnose diseases, need rain to spread their spores; others need wind (such as the powdery and downy mildews), and some need both wind and rain (some bacterial diseases). A critical pest management step is to insure the compatibility of one's crop and crop varieties with the regional growing climate where production will take place.





# Demonstration: Disease Identification

## *for the instructor*

### **OVERVIEW**

*Through this hands-on field exercise and discussion, students will learn how to collect representative samples of diseased plant tissues and practice identifying plant pathogens using printed and web-based diagnostic resources. The instructor should also discuss management techniques for each pathogen and vector.*

### **PREPARATION AND MATERIALS**

1. If possible, students should have received the lecture portion of this unit covering disease diagnosis. If not, present this material.
2. Gather good samples of 8 different diseases from as many different hosts and plant pathogen groups as possible. Arrange the samples in 8 well-separated stations.
3. At each station, place an appropriate reference book\* that covers that particular host (or provide a computer with online access), a 2–10x hand lens or dissecting scope, and a small knife. (\*Web-based resources may be used as substitute where available. See Resources section.)
4. Divide the students into eight groups
5. Each group moves through each of the stations (with a four-minute time limit) and attempts to identify each host and diagnose each disease. The instructor should be on-hand to provide guidance. When all groups have finished all the stations, the entire group meets to compare notes. The instructor should explain the elements of both correct and incorrect diagnoses, as well as management options for each pathogen and vector identified.

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

1.5 hours

## **DEMONSTRATION OUTLINE**

### **A. Review/Discuss Collection of a Suitable Sample**

1. Symptoms should exist on several individual plants and not have an obvious non-pathogen cause
2. Observe the pattern of symptoms or signs in the field, and don't forget to look at the roots if the symptoms include wilting
3. Whenever possible, collect a sample that includes the border between healthy and diseased tissue (this is likely where the pathogen is most active, making the observation of signs, and pathogen isolation in the lab, more probable)
4. Collect a range of symptoms from light to heavy. Bring as much of each diseased plant as possible, including roots; bring samples from more than one plant.

### **B. Review/Discuss Considerations in Disease Diagnosis**

1. Field-scale patterns of disease
2. Symptoms and signs
3. Koch's Postulates
4. Resources for disease diagnosis

### **C. At Each Station, Have Each Group Present Their Diagnosis**

### **D. Discuss Each of the Following**

1. Host
2. Type and extent of symptoms
3. How relatively useful the symptoms are for diagnosis
4. The importance of professional help, Koch's Postulates, and lab analysis in accurate diagnosis
5. Discuss the danger of guessing

### **E. Provide Illustrations of Pathogens or Characteristic Symptoms**

### **F. When Possible, Give a Synopsis of the Disease and Management Practices**

1. The relative importance of actively managing the pathogen (i.e., potential agricultural and economic consequences of unchecked growth)
2. Biology: Life cycle and timing for intervention
3. Review of ecological disease management practices accepted under certified organic farming standards
  - a) Environment manipulations
  - b) Host manipulations
  - c) Pathogen manipulations

# Demonstration: Disease Identification

## *step-by-step instructions for students*

### OVERVIEW

*The key to successful disease diagnosis is the collection of a suitable sample. These step-by-step instructions will assist you in collecting suitable samples of affected plants and accurately diagnosing the cause of the disease.*

### PROCEDURE

1. Collect a suitable sample
  - Symptoms should exist on several individual plants and not have an obvious non-pathogen cause
  - Observe the pattern of symptoms or signs in the field (they can provide information about how the disease spreads) and don't forget to look at the roots whenever possible
  - Whenever possible, collect a sample that includes the border between healthy and diseased tissue
  - Collect a range of symptoms from light to heavy. Bring as much of the plant as possible, including roots. Bring samples from more than one plant.
2. Attempt diagnosis
  - Observe under magnification
  - Use reference books and pictorial disease guides; good pictures of most diseases can be obtained on the worldwide web
  - Ask professionals
  - Submit a sample to local farm advisor, or nursery professional



# Assessment Questions

- 1) List five different plant diseases, including the pathogen, plant host, and how each one interferes with normal plant physiology.
- 2) What are three environmental conditions that often encourage the growth, development, and distribution of bacterial and fungal blights?
- 3) Describe three specific environmental manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.
- 4) What are the four techniques that should always be included when taking a suitable sample for disease diagnosis?
- 5) Describe three specific plant host manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.

# Assessment Questions Key

- 1) List five different plant diseases, including the pathogen, plant host, and how each one interferes with normal plant physiology.
  - *Bacteria*
  - *Fungi*
  - *Viruses*
  - *Nematodes*
  - *Mycoplasma-like organisms*
  - *Parasitic higher plants*
  - *Nutrient deficiencies*
  - *Air pollutants*
- 2) What are three environmental conditions that often encourage the growth, development, and distribution of bacterial and fungal blights?
  - *High relative humidity*
  - *Warm (temperatures 55°F or higher)*
  - *Free moisture on plant surfaces*
- 3) Describe three specific environmental manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.
  - *Increase crop spacing (to reduce humidity)*
  - *Regulate amount or timing of irrigation (to reduce humidity, moisture on foliage, or soil moisture levels)*
  - *Regulate drainage (to influence soil moisture levels)*
  - *Changes to crop and soil type*
  - *Changes to soil nutrient levels*
  - *Changes to crop location relative to climate and microclimate*
- 4) What are the four techniques that should always be included when taking a suitable sample for disease diagnosis?
  - *Symptoms existing on several individual plants*
  - *Make observations of patterns of symptoms*
  - *Make observations of both foliage and roots*
  - *Collect samples from the border between healthy and potentially diseased plant tissues*
  - *Collect a range of samples exhibiting symptoms including heavily and lightly affected*
- 5) Describe three specific plant host manipulations that farmers/gardeners may use to manage or prevent plant pathogens ecologically.
  - *Select disease-resistant cultivars*
  - *Use only certified disease-free plant materials*
  - *Crop rotations in both space and time*

# Resources

## PRINT RESOURCES

### BOOKS

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Agrios, G.N. 1988. *Plant Pathology, Fourth Edition*. New York: Academic Press.

*A textbook of plant pathology from general to specific topics.*

*Compendium of Diseases*. St. Paul, MN: APS Press.

*A series of publications covering diseases of many common crops, published by the American Phytopathological Society's APS Press.*

Flint, Mary Louise. 1998. *Pests of the Garden and Small Farm: A Grower's Guide to Using Less Pesticide, Second Edition*. Publication 3332. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Covers insects, mites, plant diseases, nematodes, and weeds of fruit and nut trees and vegetables. Individual sections describe the biology, identification, and control of common pests and pathogens; includes symptom-identification tables organized by crop. Recommended methods rely primarily on organically acceptable alternatives.*

Flint, Mary Louise, and Steve Dreistadt. 1998. *Natural Enemies Handbook: The Illustrated Guide to Biological Pest Control*. Publication 3386. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*How-to book describes ways to combine cultural, physical, and chemical methods with biological control; to minimize pesticide impacts on natural enemies; release natural enemies and enhance their activity; and identify and use natural enemies to control pests.*

Koike, Steve, Mark Gaskell, Calvin Fouche, Richard Smith, and Jeff Mitchell. 2000. *Plant Disease Management for Organic Crops*. Publication 7252. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Describes various techniques for managing diseases in organic crops, including use of resistant plants, site selection, pest exclusion, and compost use.*

University of California IPM Program. Integrated Pest Management Manual Series. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Comprehensive IPM manuals for growers and pest control advisors offer detailed information on numerous agricultural crops, landscape trees and shrubs, and home gardens.*

### PERIODICALS

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Annual Review of Phytopathology

*Excellent summaries of major topics.*

Biocontrol Science and Technology

Canadian Journal of Plant Pathology

IPM Practitioner

Journal of Sustainable Agriculture

*Basic research on social and agronomic aspects of sustainable agriculture.*

Microbial Ecology

Phytopathology

*Primary research journal.*

Organic Farming Research Foundation Reports

*Summarizes research projects (many by growers) on practical organic farming topics, including pest and disease control.*

Plant Disease

*Primary practical research journal.*



## WEB RESOURCES

Agriculture Research Service Biological Control of Plant Diseases

[www.barc.usda.gov/psi](http://www.barc.usda.gov/psi)

*Information on biological control of pests and diseases.*

California Pest Management Guidelines

[www.ipm.ucdavis.edu/PMG/crops-agriculture.html](http://www.ipm.ucdavis.edu/PMG/crops-agriculture.html)

*Official guidelines for pest monitoring techniques, pesticides, and nonpesticide alternatives for managing insect, mite, nematode, weed, and disease pests in agricultural crops, floriculture and ornamental nurseries, commercial turf, and in homes and landscapes*

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

Consortium for International Crop Protection, IPMnet

[www.ipmnet.org](http://www.ipmnet.org)

*New research, links, bulletin board, newsletter.*

IPM Resources-Vegetables

[www.ippc.orst.edu/cicp/Vegetable/veg.htm](http://www.ippc.orst.edu/cicp/Vegetable/veg.htm)

*Database of resources on vegetable pest management*

Northwest Plant disease guidelines.

[www.bcc.orst.edu/bpp/](http://www.bcc.orst.edu/bpp/)

*Disease guidelines for Oregon and Washington.*

UC Sustainable Agriculture Research and Education Program

[www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu)

*Includes reports and resources on organic farming and on SAREP-funded research projects, including Biologically Integrated Farming Systems (BIFS).*

# 1.10 Managing Weeds

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# Introduction: Managing Weeds

## UNIT OVERVIEW

*Managing weeds with organically acceptable techniques is one of the biggest challenges that organic growers face. This unit introduces students to the basic biology of common weed plants found in agricultural systems, and the concepts and strategies used to effectively minimize weed pressure in sustainably managed annual vegetable cropping systems. The lecture material emphasizes field-scale weed management. Demonstrations also address hand-weeding techniques and tools used in a garden or small farm setting, as well as weed identification skills.*

## MODES OF INSTRUCTION

- > LECTURES (2 LECTURES, 1.5 HOURS EACH)  
Lecture 1 presents basic weed biology, including the problems and benefits of weeds, as well as weed classifications and factors affecting germination and dispersal. Lecture 2 presents information on cultural practices commonly used in sustainable systems for weed management.
- > DEMONSTRATION 1: MECHANICAL WEED MANAGEMENT (1 HOUR)  
The instructor's outline details how to demonstrate the various tractor-mounted tools used for field-scale cultivation of fallow and planted beds.
- > DEMONSTRATION 2: HAND WEEDING IN THE GARDEN AND SMALL FARM (1 HOUR)  
The instructor's outline details how to demonstrate the use and maintenance of various hand tools for managing weeds in the garden and small farm.
- > DEMONSTRATION 3: WEED IDENTIFICATION LAB EXERCISE (1 HOUR)  
With the instructor's guidance and the use of texts and web-based resources, students will learn to collect and identify common weeds at various growth stages.
- > ASSESSMENT QUESTIONS (1–2 HOURS)  
Assessment questions reinforce key unit concepts and skills.
- > VIDEO PRESENTATION (1 HOUR)  
See Resources section for recommended videos.

## LEARNING OBJECTIVES

### CONCEPTS

- The need for managing weeds in cropping systems
- The biology of weeds

### SKILLS

- How to identify weeds
- How to design a cropping rotation specifically for weed management
- How to manage a cropping system for maximum weed suppression
- How to assess a cropping system for potential weed problems

# Lecture 1 Outline: Weed Biology

## *for the instructor*

### A. Pre-Assessment Questions

1. What is a weed?
2. How are weeds dispersed?
3. What are some benefits of weeds in a cropping system?
4. What are some of the characteristics of weeds that allow them to compete so well in cropping systems?
5. Why control weeds?

### B. Definition—What Is A Weed?

1. A weed is a plant that does more harm by competing with crop plants for nutrients, sunlight, and/or water, and has a habit of encroaching where it's not wanted

### C. Weed Problems

1. Crop competition and its effect on crop yield and quality
  - a) Nutrient competition
  - b) Light competition
  - c) Water competition
2. Interference with harvesting operations
3. Allelopathic effect
4. Ability of weeds to reproduce in cropping systems
5. Weeds can harbor diseases and pests

### D. Weed Benefits

1. Provide vegetative cover and thus minimize erosion
2. Enhance biological activity and soil tilth through additional organic matter: Root exudates and residues
3. Cycle nutrients
4. Indicate soil characteristics
5. Provide habitat for beneficial insects
6. Improve soil water infiltration

### E. Weed Biology

1. Life-habit classification (give examples of each)
  - a) Annuals
    - i. Summer annuals (e.g., pigweed, lambsquarters, purslane)
    - ii. Winter annuals (e.g., chickweed, yellow mustard, annual bluegrass)
  - b) Biennials (e.g., bullthistle, wild carrot, poison hemlock)
  - c) Perennials
    - i. Simple perennials (reproduce by seed, e.g., dandelion, curly dock, plantain)
    - ii. Creeping perennials (reproduce by seed and by vegetative structures that can propagate new plants asexually)

2. Plant-type classification (give examples)
  - a) Grasses (monocots, e.g., annual bluegrass, johnson grass)
  - b) Broadleaves (dicots, e.g., pigweed, black mustard)
  - c) Brushes (e.g., coyote brush)
  - d) Woody plants (e.g., willow)
3. Daylength classification (give examples)
  - a) Short-day weeds
  - b) Long-day weeds
  - c) Day-neutral weeds
4. Seed germination
  - a) Factors affecting seed dormancy and germination include type of seed coat, temperature, moisture, oxygen, light, and presence of chemical inhibitors
5. Dispersal
  - a) Weed seed dispersal mechanisms
    - i. Wind
    - ii. Irrigation water, seed
    - iii. Importation on farm equipment
    - iv. Compost and animal manures
    - v. Facilitated by birds, gophers, and other animals
    - vi. Contaminated crop seed

# Detailed Lecture 1 Outline: Weed Biology

## *for students*

### **A. Pre-Assessment Questions**

1. What is a weed?
2. How are weeds dispersed?
3. What are some benefits of weeds in a cropping system?
4. What are some of the characteristics of weeds that allow them to compete so well in cropping systems?
5. Why control weeds?

### **B. Definition—What is a Weed?**

1. A weed is any plant, native or non-native, that interferes with crop production by competing with crops for nutrients, sunlight, and/or water and has a habit of encroaching where it is not wanted

### **C. Weed Problems**

1. Crop competition and its effect on crop yield and quality
  - a) Nutrient competition: Weedy plants, like crop plants, use soil nutrients for growth. Weeds can outcompete crops for essential plant nutrients, resulting in lower yields and/or poor crop quality.
  - b) Light competition: Weedy plants, like crop plants, use light for growth. Weeds can outcompete crops for sunlight, resulting in lower yields and/or poor crop quality.
  - c) Water competition: Weeds can outcompete crops for water, resulting in unnecessary water use, lower yields, and/or poor crop quality
2. Interference with harvesting operations
  - a) Example: Weed roots such as bindweed wrap around sub-soil blades used for undercutting root crops during harvest
3. Allelopathic effect of weeds on crop germination and growth: Certain weedy plants produce and secrete chemical compounds that are known to retard the germination of crop seed and the growth of crop plants
4. Ability of weeds to reproduce in cropping systems: Due to the high fertility and irrigation used in agricultural soils, weedy plants can themselves produce abundant seed and create a very large seed bank in a single season.
5. Weeds can harbor diseases such as viruses and plant pathogenic fungi

### **D. Weed Benefits**

1. Enhance soil structure: Weed cover in a cropping system can enhance soil structure by protecting the soil surface from heavy rain, minimizing surface soil particle dispersion, and thus minimizing erosion
2. Improve soil tilth: Weeds can indirectly help improve soil tilth and aggregation by enhancing soil microbial activity through root exudates during growth and by providing additional residue at time of incorporation
3. Cycle nutrients: Like intentionally planted cover crops, weeds can retain mobile soil nutrients such as nitrate and prevent them from leaching during rains. Some weedy plants are able to access and concentrate certain soil nutrients making them available for subsequent crop growth.
4. Indicate soil characteristics: Certain species of weedy plants are known to grow only in soils with certain nutrient profiles, hydrology, and/or physical properties (see *Start With the Soil* by Grace Gurshuney pp. 18-20)



5. Provide habitat for beneficial insects: Weeds can be important habitat for beneficial insects by providing nectar, pollen, and places to breed
6. Improve soil water infiltration: Weeds can improve soil water infiltration by providing channels for water movement from decaying roots

## E. Weed Biology

### 1. Life-habit classification

- a) Annual: A plant that completes its life cycle (germination through death) in one year or growing season, essentially non-woody
  - i. Examples of summer annuals
    - Pigweed (*Amaranthus* spp.)
    - Lambsquarters (*Chenopodium album*)
    - Purslane (*Portulaca oleracea*)
  - ii. Examples of winter annuals
    - Common chickweed (*Stellaria media*)
    - Yellow mustard (*Brassica* spp.)
    - Annual bluegrass (*Poa annua*)
- b) Biennial: A plant that completes its life cycle (germination through death) in two years or growing seasons (generally flowering only in the second), is non-woody (at least above ground), often with a rosette the first growing season
  - i. Examples of biennials
    - Bullthistle (*Cirsium vulgare*)
    - Wild carrot (*Daucus* spp.)
    - Poison hemlock (*Conium maculatum*)
- c) Perennial: A plant that lives for a number of years, often producing seed each year once it reaches maturity
  - i. Simple perennials that reproduce by seed
    - Dandelion (*Taraxacum officinale*)
    - Curly dock (*Rumex crispus*)
    - Plantain (*Plantago* spp.)
  - ii. Creeping perennials: Reproduce by seed and asexually through rhizomes, stolons, tubers, and rootstalk
    - Johnson grass (*Sorghum halepense*)
    - Bermuda grass (*Cynodon dactylon*)
    - Nutsedge (*Cyperus* spp.)
    - Field bindweed (*Convolvulus arvensis*)

### 2. Plant-type classification

- a) Grasses (monocots): Members of a subclass of Angiosperms characterized by the presence of one cotyledon in their seeds
  - i. Annual bluegrass
  - ii. Johnson grass
- b) Broadleaves (dicots): Members of a subclass of Angiosperms characterized by having two cotyledons in their seeds
  - i. Pigweed
  - ii. Black mustard (*Brassica* spp.)
- c) Bushes
  - i. Coyote brush (*Baccharis pilularis*)

- d) Woody plants
  - i. Willow (*Salix* spp.)
- 3. Daylength classification
  - a) Short-day weeds: Weeds that increase in vegetative growth when days are long and flower when days are short
    - i. Lambsquarters (*Chenopodium album*)
  - b) Long-day weeds: Weeds that increase in vegetative growth when days are short and flower when days are long
    - i. Henbane (*Hyoscyamus niger*)
  - c) Day-neutral weeds: Weeds that flower under any photoperiod conditions
    - i. Nightshade (*Solanum* spp.)
- 4. Seed germination
  - a) Factors affecting seed dormancy and germination
    - i. Type of seed coat
    - ii. Temperature, moisture
    - iii. Oxygen
    - iv. Light
    - v. Presence of chemical inhibitors
- 5. Dispersal: Seed and plant movement
  - a) Weed seed dispersal mechanisms
    - i. Wind: It is critical to work with neighbors to reduce or eliminate weedy plants from surrounding areas in order to avoid wind-dispersed contamination
    - ii. Seed movement in irrigation water: Critical to have filters on irrigation system to avoid contamination
    - iii. Seed importation on farm equipment: Critical to clean equipment when moving from one field to another or borrowing equipment
    - iv. Seed importation through compost and animal manures: Critical to thoroughly compost materials aerobically prior to application while sustaining temperatures of 131°F+ for a minimum of 15 days
    - v. Movement facilitated by birds, gophers, and other animals
    - vi. Use of contaminated crop seed: Critical to check seed source for percent pure seed. Always use high quality seed supply.



# Lecture 2 Outline: Cultural Weed Management Practices

## *for the instructor*

### A. Pre-Assessment Questions

1. How can crop rotations be used to minimize weed pressure?
2. What tools do growers use to mechanically control weeds?
3. What steps can be taken to minimize weed seed dispersal?

### B. Weed Prevention Strategies

1. Improve soil tilth, aeration, water infiltration, and fertility to optimize crop growth and minimize weed pressure
2. Thoroughly clean equipment before moving it from one farm or location to another to avoid transporting weed seeds from infested fields
3. Do not allow weeds to form seed heads and/or perennial rooting structures in the cropping system
4. Thoroughly compost all imported animal manure to insure destruction of viable weed seed
5. Filter surface irrigation water to avoid importing weed seeds
6. Work with neighbors to eliminate or minimize the potential for spread of noxious and problematic weeds from adjacent lands

### C. Crop Rotation Strategies for Optimum Weed Management

1. Rotate between summer and winter production systems
2. Use weed-suppressive cover crops in your rotation to suppress problem weeds
  - a) Examples of weed-suppressive cover crops
    - i. Sudan grass (*Sorghum bicolor*)
    - ii. Buckwheat (*Fagopyrum esculentum*)
    - iii. Sesbania (*Sesbania macrocarpa*)
    - iv. Annual rye grass (*Lolium multiflorum*)
    - v. Perennial rye grass (*Lolium perene*)
3. Use smother production crops and crops that compete well with weeds when weed pressure becomes high
  - a) Examples: Corn, winter squash, potatoes
4. Optimize timing of cover crop planting to insure strong uniform growth

### D. Tillage Strategies to Minimize Weed Pressure

1. Maintain good soil structure
  - a) Minimize the use of rototillers to maintain good aggregation
  - b) Work soil at optimum moisture content to avoid compaction (see Unit 1.2, Garden and Field Tillage and Cultivation)
2. Use moldboard plows selectively to bury problem weed seeds

## **E. Planting and Cultivation Techniques to Minimize Weed Pressure**

1. Plant large-seeded crops (e.g., corn, beans, squash) to moisture and don't irrigate until necessary
2. Plant straight, perfectly spaced seed lines on straight, firm, uniform beds to allow for ease and accuracy of cultivation
3. Use sleds or other guidance systems to keep implements tracking straight
4. Use transplants where practical to get a jump on weeds
5. Keep weed cultivations (either tractor mounted or hand held) shallow to avoid bringing up new weed seeds from lower soil horizons
6. Pay close attention to soil moisture, tilth, and weed growth to optimize timing of cultivation
7. "Dirting": Weed cultivation where soil is moved to cover and smother weeds adjacent to crop plants

## **F. Irrigation Techniques to Minimize Weed Pressure**

1. Pre-irrigate beds and lightly cultivate prior to planting to destroy newly germinated weeds
2. Maintain uniform irrigations to avoid areas of high water concentration
3. Use drip tape to avoid wetting the entire soil surface
4. Allow deep-rooted crops to establish deep root systems and irrigate deeply and infrequently to avoid excessive surface wetting
5. Delay irrigation following cultivation long enough to allow for weeds to desiccate

## **G. Fallow Period for Perennial Weed Control**

1. Use a fallow period to control problem perennials
  - a) Use a springtooth cultivator during fallow periods to bring perennial weed roots to surface for desiccation and/or freezing

## **H. Flame Weeding Techniques and Strategies**

1. Pre-irrigate "stale" beds (beds that have been formed but not planted) to germinate weeds and use flame weeder to kill newly germinated broadleaf weeds prior to planting crops
2. Use flame weeder on beds of slow-germinating crops such as garlic and carrots after irrigation and before crop emergence to kill newly germinated broadleaf weeds
3. Flamers are only effective on very small newly germinated broadleaf weeds with no surface moisture (dew) on leaves

## **I. Soil Solarization**

1. How to solarize
  - a) Soil must be irrigated and saturated to at least 70% of field capacity to a depth of 24 inches prior to tarping
  - b) Lay 2 ml clear plastic tarp as close to smooth soil surface as possible during warmest time of year
  - c) Plastic should be left in place for 4 to 6 weeks
  - d) Tillage deeper than 3 inches must be avoided after solarization
2. Results of solarization
  - a) Solarization controls many annual weeds, and is especially effective in controlling winter annuals
3. Limitations to soil solarization
  - a) Control of purslane, crabgrass, and many perennials may be difficult to achieve
  - b) Soil solarization is most effective in very hot summer areas (90°F+ conditions)
  - c) Costs associated with production on large acreage

## **J. Weed-Suppressive Mulches**

1. Dark plastic mulches can be used as a weed-suppressive mulch in many cropping systems
  - a) Example: Strawberries

## **K. Organic and “Living” Mulches**

1. Organic mulches
  - a) Straw, sawdust
2. Living mulches
  - a) Intercropping with a cover crop in main season crop, serving to prevent erosion and limit weed growth
  - b) Important in low- and no-till systems



# Detailed Lecture 2 Outline: Cultural Weed Management Practices

## *for students*

### **A. Pre-Assessment Questions**

1. How can crop rotations be used to minimize weed pressure?
2. What tools do growers use to mechanically control weeds?
3. What steps can be taken to minimize weed seed dispersal?

### **B. Weed Prevention Strategies**

1. Improve soil tilth, aeration, water infiltration, and fertility to optimize crop growth and minimize weed pressure. Fertile agricultural soils with good tilth promote ease of weed removal by hand and/or by mechanical cultivation.
2. Thoroughly clean equipment before moving it from one farm or location to another to avoid transporting weed seeds from infested fields
3. Do not allow weeds to form seed heads and/or perennial rooting structures in the cropping system. A single season of allowing weeds to set seed may create years of weed management problems. Annual preventive clean cultivation will exhaust the existing seed bank.
4. Thoroughly compost all imported animal manures to insure destruction of viable weed seed. Aerobically composted manures and plant materials in which temperatures are sustained at 131°F+ for 15 or more days should destroy all viable weed seed.
5. Filter surface irrigation water to avoid importing weed seeds
6. Work with neighbors to eliminate or minimize the potential for spread of noxious and problematic weeds from adjacent lands

### **C. Crop Rotation Strategies for Optimum Weed Management**

1. Rotate between summer and winter production systems. Alternating ground from winter to summer production combined with the use of weed-suppressive cover crops further exhausts the weed seed bank.
2. Use weed-suppressive cover crops in your rotation to suppress problem weeds
  - a) Examples of weed-suppressive cover crops
    - i. Sudan grass (*Sorghum bicolor*): Heat-loving summer cover crop quickly grows to 8 feet, shades other weedy plants. Prevents successful weed reproduction, exhausting seed bank.
    - ii. Buckwheat (*Fagopyrum esculentum*): A fast-growing, broad leaf summer cover crop. Smothers weeds quickly such as Canada thistle, nutgrass, quack grass, etc.
    - iii. Sesbania (*Sesbania macrocarpa*): Vigorous growth in hot summer areas, outcompetes and shades weeds
    - iv. Annual rye grass (*Lolium multiflorum*)
    - v. Perennial rye grass (*Lolium perene*): Adapted to cooler areas (e.g., Pacific Northwest). Dense growth and allelochemicals suppress germination and growth of weedy species.
3. Use smother production crops and crops that compete well with weeds when weed pressure becomes high
  - a) Examples: Corn, winter squash, potatoes



4. Optimize timing of cover crop planting to insure strong uniform growth. Uniform plantings of cover crops assures uniform ground cover and canopy of shade, reducing viability of weed populations.

#### **D. Tillage Strategies to Minimize Weed Pressure**

1. Maintain good soil structure
  - a) Minimize the use of rototillers to maintain good aggregation. Agricultural soils with good tilth allow for ease of weed removal through hand and/or mechanical cultivation.
  - b) Work soil at optimal soil moisture content (~50% of field capacity) to avoid compaction (see Unit 1.2, Garden and Field Tillage and Cultivation)
2. Use moldboard plows selectively to bury problem weed seeds such as annual bluegrass. Deep burial of certain weeds is possible but should be done very selectively.

#### **E. Planting and Cultivation Techniques to Minimize Weed Pressure**

1. Plant large-seeded crops (e.g., corn, beans, squash) to moisture rather than irrigating them up. Planting such large-seeded crops to moisture and allowing the crop to become established prior to any irrigation prevents germination of weedy competitors and unnecessary cultivation. Though soil and climate dependent, many of the crops listed above can grow to near maturity without irrigation, if not completely dry-farmed.
2. Plant straight, perfectly spaced seed lines on straight, firm, uniform beds. Uniform spacing and straight lines of production crops reduces weed pressure by allowing close mechanical cultivation, thereby reducing costs associated with hand weeding.
3. Use sleds or other guidance systems on all tractor-mounted planters and cultivators. These will help create straight, perfectly spaced seed lines on straight, firm, uniform beds.
4. Use transplants where practical to get a jump on weeds. Because they are larger than recently germinated weed seeds, transplants are easy to recognize when cultivating weedy ground. The larger transplants are also more mature, leading to rapid growth and successful competition with weeds.
5. Keep weed cultivations (either tractor mounted or hand held) shallow. This will avoid bringing up new weed seeds from lower soil horizons.
6. Pay close attention to soil moisture, tilth, and weed growth to optimize timing of cultivation. Cultivating weeds at the right soil moisture (~50% of field capacity) and at the early stages of weedy growth when surface soils are in need of aeration allows for two essential cultivation tasks to be completed simultaneously, thereby avoiding soil compaction.
7. "Dirtting": Configure beds and seed lines so that dirt can be moved into the planted row with cultivation equipment on long-stemmed crops (e.g., tomatoes, potatoes, sweet corn, peppers). This "dirtting" technique will effectively smother newly germinated weeds within the plant row.

#### **F. Irrigation Techniques to Minimize Weed Pressure**

1. Pre-irrigate beds and lightly cultivate prior to planting to destroy newly germinated weeds. Repeated pre-irrigation and light cultivation passes may be used to exhaust the seed bank prior to planting the production crop in a known weedy area.
2. Maintain uniform irrigations to avoid areas of high water concentration. Uneven moisture will result in uneven germination and growth of weed populations, often leading to the need for repeated cultivations.
3. Use drip tape to avoid wetting the entire soil surface. Reducing the soil surface area exposed to moisture will reduce the surface area of land able to support weed populations.
4. Allow deep-rooted crops to establish deep root systems and irrigate deeply and infrequently to avoid excessive surface wetting. See above.

5. Delay irrigation following cultivation long enough to allow for weeds to desiccate. Certain weeds (e.g., purslane) may successfully re-root and grow after cultivation if irrigation reestablishes root-to-soil contact before the weeds die.

### **G. Fallow Period for Perennial Weed Control**

1. Use a fallow period to control problem perennials (e.g., Johnson grass, crab grass, bermuda grass)
  - a) Use a springtooth cultivator during fallow periods to bring perennial weed roots to surface for desiccation and/or freezing

### **H. Flame Weeding Techniques and Strategies**

1. Pre-irrigate “stale” beds (beds that have been formed but not planted) to germinate weeds and use flame weeder to kill newly germinated broadleaf weeds prior to planting crops
2. Use flame weeder on beds of slow-germinating crops such as garlic and carrots after irrigation and before crop emergence to kill newly germinated broadleaf weeds
3. Flame weeders are only effective on very small newly germinated broadleaf weeds with no surface moisture (dew) on leaves

### **I. Soil Solarization**

1. How to solarize
  - a) Soil must be irrigated and saturated to at least 70% of field capacity to a depth of 24 inches prior to tarping
  - b) Lay 2 ml clear plastic tarp as close to smooth soil surface as possible during warmest time of year
  - c) Plastic should be left in place for 4 to 6 weeks
  - d) Tillage deeper than 3 inches must be avoided after solarization
2. Results of solarization
  - a) Solarization controls many annual weeds, and is especially effective in controlling winter annuals
3. Limitations to soil solarization
  - a) Control of purslane, crabgrass and many perennials may be difficult to achieve
  - b) Soil solarization is most effective in very hot summer areas (90°F+ conditions)
  - c) Cost of soil solarization over large acreage may be prohibitive

### **J. Weed-Suppressive Mulches**

1. Dark plastic mulches can be used as a weed-suppressive mulch in many cropping systems
  - a) Example: Strawberries

### **K. Organic and “Living” Mulches**

1. Organic mulches
  - a) Straw, sawdust
2. Living mulches
  - a) Intercropping with a cover crop in main season crop, serving to prevent erosion and limit weed growth
  - b) Important in low- and no-till systems to suppress weed growth during season (see Unit 1.2, Garden and Field Tillage and Cultivation)



# Demonstration 1: Mechanical Weed Management

## *for the instructor*

### **OVERVIEW**

*For this field demonstration, the instructor should have access to a wide range of tractor-mounted or drawn tillage and cultivating implements and the appropriate tractors for each of the implements. It also requires access to tillable land and existing diverse cropping systems and/or formed fallow beds spaced to match the equipment.*

### **PREPARATION AND MATERIALS**

Implements and tractors used in the demonstration should be set up adjacent to the demonstration site and parked to allow fast hook up and drop off.

### **PREPARATION TIME**

0.5 hour

### **DEMONSTRATION TIME**

1 hour

### **DEMONSTRATION OUTLINE**

#### **A. Demonstration of Row Crop Cultivation Implements**

1. Examine lister bar, markers, and shovels
  - a) Explain the use of listers for bed formation
  - b) Discuss other options for forming beds
  - c) Explain the use of bed shapers
2. Do a field demonstration of a rolling cultivator
  - a) Run rolling cultivator down fallow beds
  - b) Discuss the various uses of the rolling cultivators for weed management in fallow and cropped systems.
3. Do a field demonstration of a row crop cultivator set up with sweeps and knives
  - a) Run cultivator down crop row
  - b) Discuss the various components of cultivator operation and set up



# Demonstration 2: Hand Weeding in the Garden and Small Farm

## *for the instructor*

### **OVERVIEW**

*This field demonstration provides a brief overview of the most common hand tools and techniques used to manage weeds on both a garden and small-farm scale. The instructor should have access to a wide range of hand tools for demonstrating field use and tool maintenance. The demonstration also requires access to tillable land and existing diverse cropping systems at various stages of development.*

### **PREPARATION AND MATERIALS**

- Hand tools
- Wheel hoe
- Reciprocating hoe
- Tined cultivators
- Glaser collinear hoe
- Sharpening tools (e.g., files) for hand tools
- Existing diverse cropping systems at various stages of crop development and soil moisture

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

2 hours

## DEMONSTRATION OUTLINE

### A. Tools and Techniques for Hand Weeding at the Garden and Small-Farm Scale

1. Briefly review weed prevention strategies (see Lecture 2 Outline)
2. Discuss and demonstrate why hand tools are used
  - a) Tractor-mounted/mechanical weed control devices aren't able to cultivate close enough to the stem of many irrigated crops
    - i. Show students bed of crops where mechanical implements are ineffective and hand tools necessary
    - ii. Review and discuss crops and cropping strategies where hand cultivation is less necessary or is needed infrequently (e.g., dry-farmed crops or large-seeded crops planted to moisture)
  - b) Exclusive hand tool use in garden settings
3. Discuss and demonstrate the use of various hand tools
  - a) Discuss the importance of timing weed cultivation to prevent reseeding and competition for nutrients, sunlight, and water
  - b) Discuss the importance of sharp hand tools
  - c) Discuss and demonstrate the importance of cultivating weeds and soil at proper soil moisture
  - d) Discuss the importance of cultivating weeds and soil at proper times of day to encourage weed desiccation
  - e) Demonstrate commonly used hand tools (see appendix 1, Hand Tools for Weed Management)
    - i. Wheel hoe
    - ii. Reciprocating hoe ("hula hoe" or "stirrup hoe")
    - iii. Tined cultivators
    - iv. Glaser Colinear hoe
4. Discuss and demonstrate maintenance and care of hand tools
  - a) Proper storage of hand tools for longevity
  - b) Sharpening of hand tools

# Demonstration 3: Identification of Common Weeds

## *for the instructor*

### **OVERVIEW**

*This demonstration introduces students to weed plant identification skills through field collection and the use of written and web-based resources for identification (see Resources section). Student will also be asked to research and share weed management information relative to the specimens collected. The instructor is encouraged to share his or her experience in managing the weed species identified.*

### **PREPARATION AND MATERIALS**

1. Gather multiple copies of printed identification guides (see Resources section).
2. Organize lab room with multiple computer stations for accessing web-based identification resources (see Resources section).
3. Ask students to gather as many unknown weedy plants as possible from gardens or fields.
4. Have students work in pairs to identify the common name of each of the weeds as well as gather cultural information regarding the management of each species. Cultural information on each specimen should include the following: Genus and species; life habit classification; soil indications; reproductive strategy; cultural controls for organic systems.

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION/LAB TIME**

2 hours



## **DEMONSTRATION OUTLINE**

### **A. Review the Identification Process**

1. Ask student to share the name of the plant and the identifying characteristics
2. Identification is confirmed with other students and instructor
3. Instructor reviews identifying characteristics, if necessary

### **B. Ask Students to Share Additional Cultural Information**

1. Where weed was found/habitat
2. Genus and species of weed
3. Life habit classification of weed
4. Soil physical or chemical properties as indicated by presence of particular weed species
5. Reproductive strategy and dispersal of weed
6. Cultural controls for organic systems

### **C. Instructor Shares His or Her Experience in Managing the Weed Species Identified**

# Assessment Questions

- 1) Describe common problems associated with the unmanaged growth of weedy plant species in the garden or farm.
  
  
  
  
  
  
  
  
  
  
- 2) What are five ways by which weed seeds are dispersed? Describe five preventive measures that may be used to avoid the dispersal of weed seeds in the garden and farm.
  
  
  
  
  
  
  
  
  
  
- 3) Describe two ways that crop rotation may be used to control weeds in organic farming systems.
  
  
  
  
  
  
  
  
  
  
- 4) Describe five planting and/or cultivation techniques used to minimize weed pressure.
  
  
  
  
  
  
  
  
  
  
- 5) Describe three irrigation techniques that may be used to minimize weed pressure in organic farming systems.
  
  
  
  
  
  
  
  
  
  
- 6) Describe three additional weed management techniques, how they function, and how they may be used in organic farming systems.

# Assessment Questions Key

- 1) Describe common problems associated with the unmanaged growth of weedy plant species in the garden or farm.
  - *Crop competition for nutrients, water, and light*
  - *Interference with harvesting operations*
  - *Allelopathic effects on crop*
  - *Ability of weeds to rapidly reproduce in cropping systems*
  - *Weeds can harbor diseases and pests*
- 2) What are five ways through which weed seeds are dispersed? Describe five preventive measures that may be used to avoid the dispersal of weed seeds in the garden and farm.
  - *Wind: Manage vegetation prior to seed maturation; work with neighbors to minimize weed seed sources*
  - *Irrigation water: Water filter on irrigation equipment*
  - *Importation on farm equipment: Clean equipment before transporting to new fields*
  - *Compost and animal manure: Thoroughly aerobically compost all manure at high temperatures*
  - *Facilitated by birds, gophers, and other animals*
  - *Contaminated crop seed: Select certified seed with low weed seed content*
- 3) Describe two ways that crop rotation may be used to control weeds in organic farming systems.
  - *Smother crops and crops that compete well with weeds, e.g., corn, winter squash, potatoes*
  - *Weed-suppressive annual cover crops*
  - *Weed-suppressive perennial cover crops in rotation*
  - *Optimize timing of cover crop planting to insure strong uniform growth and a weed suppressive cover*
- 4) Describe five planting and/or cultivation techniques used to minimize weed pressure.
  - *Plant large-seeded crops to moisture*
  - *Plant straight, perfectly spaced seed lines on straight, firm, uniform beds to facilitate cultivation*
  - *Use sleds or other guidance systems on all tractor mounted planters and cultivators to assure uniform spacing, ease of close cultivation and “dirting”*
  - *Use transplants, where practical, to get a jump on weeds*
  - *Keep weed cultivations (tractor mounted or hand held) shallow to avoid bringing up new weed seeds*
  - *Timing of cultivation: Soil moisture, tilth, and weed growth. Cultivation should precede irrigation by enough time to assure desiccation of weeds. Good tilth allows for ease of weed removal; compacted soils encourage the growth of certain noxious weeds. Cultivation should precede weed seed maturity.*
- 5) Describe three irrigation techniques that may be used to minimize weed pressure in organic farming systems.
  - *Pre-irrigate beds and lightly cultivate prior to planting*
  - *Use drip tape to avoid wetting the entire soil surface*
  - *Allow deep-rooted crops to establish deep root systems and irrigate deep and infrequently to avoid excessive surface wetting*

6) Describe three additional weed management techniques, how they function, and how they may be used in organic farming systems.

- *Irrigate stale beds (beds that have been formed but not planted) to germinate weeds and use flame weeder to kill newly germinated broadleaf weeds prior to planting crops*
- *Use flamer on beds of slow-germinating crops such as garlic and carrots after irrigation and before crop emergence to kill newly germinated broadleaf weeds*
- *Soil solarization suppresses weeds by elevating soil temperatures high enough to kill weed seeds*
- *Dark plastic mulches suppress weeds by blocking light and as a physical barrier*

# Resources

## PRINT RESOURCES

Bowman, Gregg, ed. 1997. *Steel in the Field: A Farmer's Guide to Weed Management Tools*. Handbook Series Book 2. Burlington, VT: Sustainable Agriculture Network.

*Includes drawings and explanations of numerous tractor implements used for mechanical weed management in sustainable cropping systems. Grower narratives give information on specific applications.*

Fischer, Bill, ed. 1998. *Grower's Weed Identification Handbook*. Publication 4030. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Detailed identification plates of over 272 California weed species.*

Gershuny, Grace. 1993. *Start with the Soil*. Emmaus, PA: Rodale Press.

*Includes a discussion of weeds as indicators of soil physical and chemical properties.*

Smith, Richard, W. Thomas Lanini, Mark Gaskell, Jeff Mitchell, Steven Koike, and Calvin Fouche. 2000. *Weed Management for Organic Crops*. Publication 7250. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*Information on cultural practices, cultivation, flammables, soil sterilization, mulches, beneficial organisms, and chemical control of weeds.*

Whitson, Tom, ed. 2000. *Weeds of the West, Fifth Edition*. Laramie, WY: Western Society of Weed Science and the University of Wyoming Cooperative Extension Service.

*900 photographs of over 350 weed species of Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming.*

## WEB RESOURCES

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

California Weed Science Society (CWSS)

[www.cwss.org](http://www.cwss.org)

*CWSS promotes environmentally sound proactive research and develops educational programs in weed science, as well as educational activities to promote integrated weed management systems.*

UC Integrated Pest Management Program

[www.ipm.ucdavis.edu](http://www.ipm.ucdavis.edu)

*Contains extensive information on IPM, including weed identification and management.*

Western Society of Weed Science (WSWS)

[www.wsweedsociety.org](http://www.wsweedsociety.org)

*WSWS works to promote weed science research and education; site includes job announcements, upcoming meetings, and links to additional weed management information.*

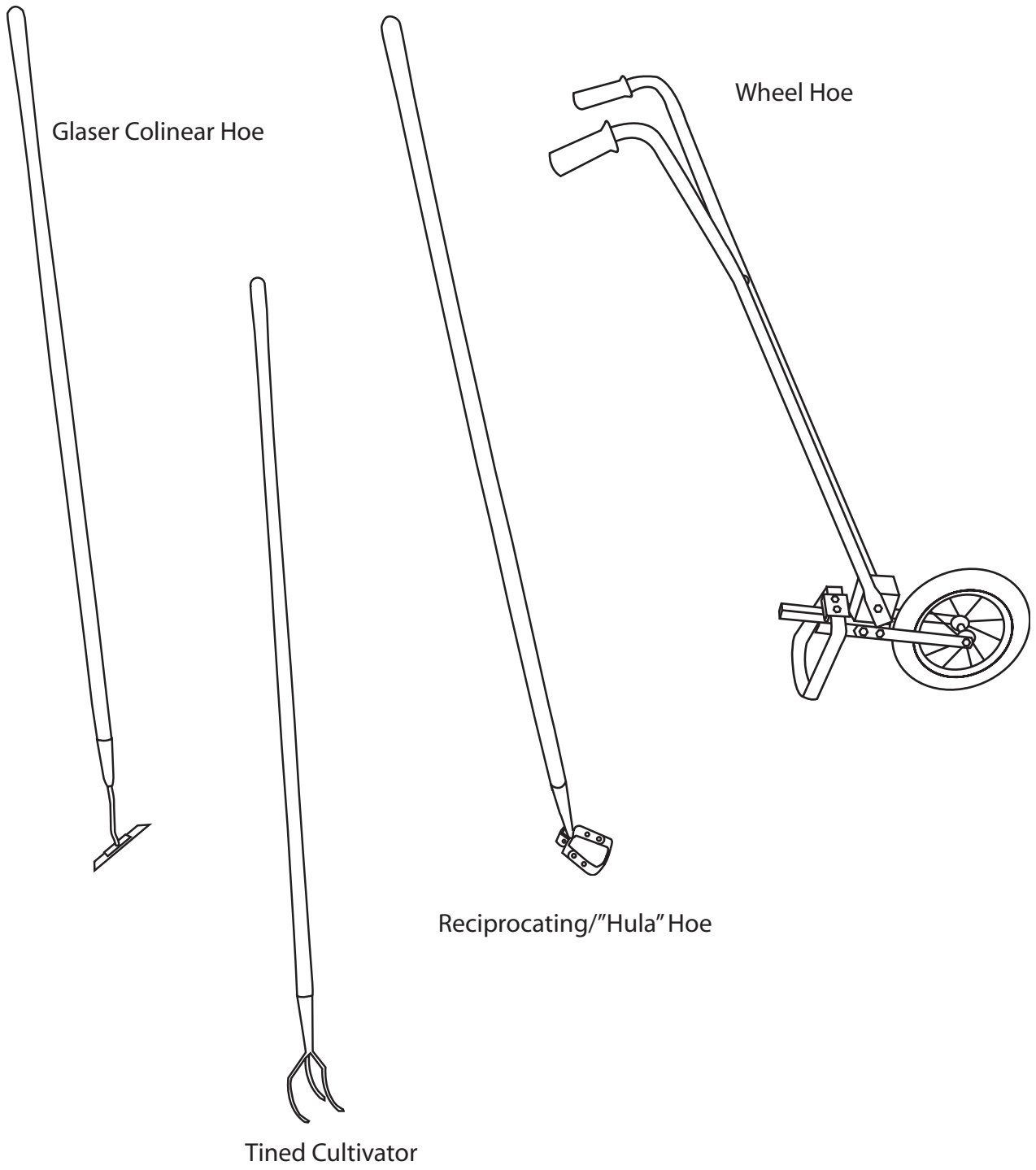
## VIDEOS

Cultural Weed Control in Vegetables. 1993. By Lanini, T. Program V93-E. Davis, CA. Oakland, CA: University of California Division of Agriculture and Natural Resources.

New Tools for Mechanical Weed Control in Vegetables. 1998. By Bellinder, R. and J. Colquhoun. 1998. Ithaca, NY: Cornell University

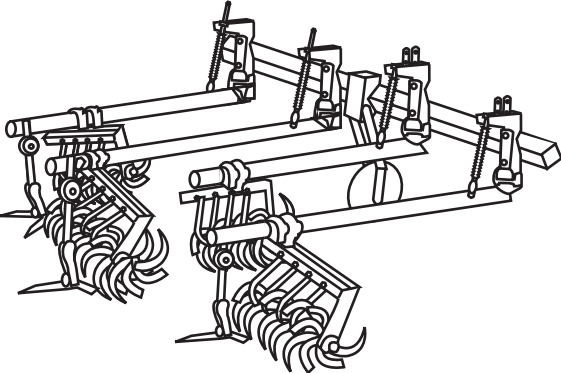
Vegetable Farmers and Their Weed Control Machines. 1997. By Grubinger, V. and M.J. Else 1997. Burlington, VT: University of Vermont and University of Massachusetts Extension.

# Appendix 1: Hand Tools for Weed Management

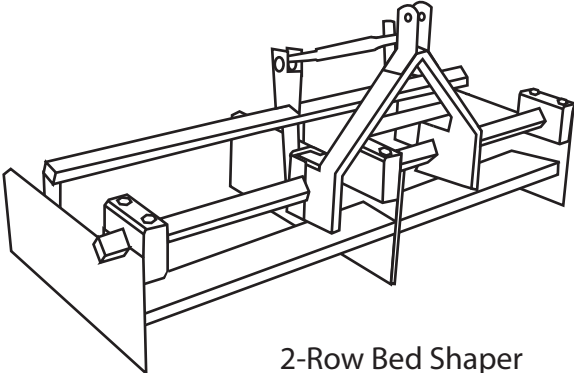


*illustrations by Cathy Genetti Reinhard; not to scale*

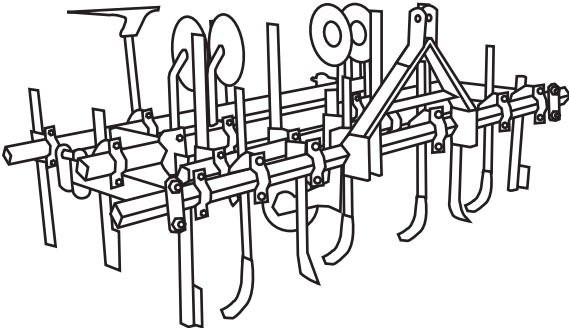
# Appendix 2: Tools for Mechanical Weed Management



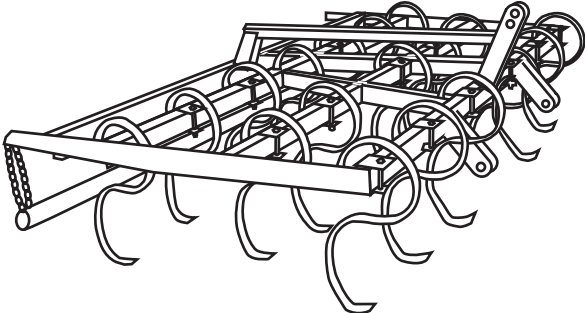
Lilliston Cultivator



2-Row Bed Shaper



3-Bar Cultivator



Spring-toothed Harrow

*illustrations by Cathy Genetti Reinhard; not to scale*

# 1.11 Reading and Interpreting Soil Test Reports

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# Introduction: Reading and Interpreting Soil Test Reports

## UNIT OVERVIEW

*Soil analyses can help form the basis of a sound soil fertility and plant nutrition program. In this unit, students will learn how to collect soil samples for laboratory analysis, and interpret and use soil analysis report data as a tool for soil quality assessment. Lectures and demonstrations will present the way that soil analysis results can be incorporated into an overall soil management plan. The unit emphasizes the role of soil analyses in developing efficient nutrient budgets and selecting soil amendments and fertilizers for certified organic production systems.*

Note: Before introducing the material in this unit, Part 2 of this manual on applied soil science (Units 2.1–2.3) should be presented to students who do not have a background in basic soil physical properties, chemistry, and biology. In addition, Unit 1.1, Managing Soil Fertility, should be presented prior to this unit.

## MODES OF INSTRUCTION

- > LECTURES (3 LECTURES, 2 HOURS)  
Lectures will cover the role of soil analysis in sustainable agriculture, the soil properties measured in a comprehensive soil analysis, and basic considerations in applications of soil amendments and fertilizers.
- > DEMONSTRATION 1: TAKING A REPRESENTATIVE SOIL SAMPLE (1.5 HOURS)  
Demonstration 1 illustrates the basic procedures involved in taking a representative soil sample for laboratory analysis.
- > DEMONSTRATION 2: READING SOIL TEST REPORTS (1.5 HOURS)  
In Demonstration 2, students will learn how to read and interpret soil analysis reports and select mineral and organic matter amendments and fertilizers.
- > DEMONSTRATION 3: NITROGEN BUDGETING (1 HOUR)  
Demonstration 3 offers an example of how a simple nitrogen budget can be calculated for an organic farm or garden.
- > DEMONSTRATION 4: FIELD OBSERVATIONS (1.5 HOURS)  
Demonstration 4 provides an outline to use in visiting a farm or garden operation for which a soil report has been prepared. This outline will direct students in how to observe the relationship between soil fertility management practices and plant nutrient levels (identified in the soil test) to plant growth and pest responses found in the field.
- > HANDS-ON EXERCISE: READING A SOIL TEST AND SELECTING AMENDMENTS (2 HOURS)  
Students will be assigned a sample soil analysis report to practice interpretation, conversion to user-friendly form, and formulation of basic fertility programs for short- and long-term goals. The hands-on exercise also includes the development of a simple nitrogen budget.
- > ASSESSMENT QUESTIONS (0.5 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- The role of soil analysis in providing current assessments of soil fertility/quality for crop growth
- The necessity of soil analysis in the formulation of accurate amendment recommendations for soil fertility and plant nutrition programs
- The importance of soil fertility in yields, crop health, crop quality, and the resistance and resilience of crop plants to pests and pathogens
- Fertilization trends in modern agriculture and the correlation with pest and disease susceptibility
- Factors involved in nitrogen budgeting and soil organic matter management

### SKILLS

- How to access regional soils information
- How to take a representative soil sample
- How to read and interpret soil analysis report data
- How to estimate nutrient needs of several crops
- How to develop amendment and fertilizer recommendations for certified organic production systems
- How to develop an estimated nitrogen budget for your crop(s)
- How to relate observed crop problems to fertility programs

# Lecture 1 Outline: Using a Soil Test to Assess Soil Quality

## *for the instructor*

### **A. Pre-Assessment Questions**

1. Characterize the physical, chemical, and biological components of soil fertility.
2. Which soil and plant nutrients affect the physical, chemical, and biological aspects of soil fertility?
3. Which soil and plant nutrients influence crop productivity and the susceptibility of crops to pests and diseases?
4. What negative consequences may result from excess nitrate nitrogen in the soil and in crops?
5. Explain the difference between well-decomposed, stabilized compost and other sources of raw organic matter (e.g., cover crops, manure) in terms of its utility as a soil amendment or fertilizer
6. In order to sustain crop production, what quantity of nutrients must be applied each year?
7. What materials would you use to supply plant available forms of nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients to your crops in a certified organic farming system?
8. How might one assure that adequate quantities of plant available nitrogen (N) are made accessible to crops without excessive fertilization?

### **B. Critical Terms in Soil Fertility Management of Organic Systems**

1. Amendment
2. Fertilizer

### **C. The Role of Soil Analysis in Sustainable Agriculture: Reducing Fertilizer Use and Improving Soil Quality and Human and Environmental Health**

1. Soil fertility, plant health, and the resistance and resilience of crop plants to pests and pathogens
  - a) The soil conditions created by an optimal balance of available plant nutrients
2. Review of soil nutrients as limiting factors in plant growth
  - a) Leibig's Law of the Minimum
    - i. Example: Barrel analogy
3. Fertilizer, fertilizer use, and soil testing trends in modern agriculture (see Unit 3.1, The Development of U.S. Agriculture)
  - a) Leibig oversimplified: Subsequent reductionist interpretations of Leibig's Law
  - b) Increased reliance on synthetic nitrogen fertilizer in the U.S. (see Gliessman 1998; U.S. Geological Survey 1998 )
  - c) An increased intensity of nitrogen fertilizer use (see Young 1999)
  - d) The historically low, but increasing use of soil testing in developing amendment and fertilizer plans
4. Excess fertilizer use, pest and disease susceptibility
  - a) Over 60 studies have shown that crops grown in soils with excess or deficient nutrients or poor soil physical properties yield less, are more susceptible to pests and pathogens and produce crops with poor post-harvest quality (see Young 1999)

5. Excess fertilizer use and fertilizer pollution (see Unit 3.3, Environmental Issues in Modern Agriculture)
  - a) Nitrogen and phosphorus deposition in surface and sub surface water, leading to eutrophication
  - b) Nitrate leaching and groundwater contamination
  - c) Question: Is there greater efficiency or reduced nutrient runoff from “organic” farms?
6. Summary

#### **D. Soil Testing as a Soil Fertility Management Tool**

1. A soil test provides current quantitative information on the nutrient content and the nutrient supplying capacity of a soil
2. Soil analyses can provide an accurate determination of a soil’s textural classification
3. A soil analysis provides quantitative data allowing for the comparison of a given soil’s nutrient and chemical profile with established agronomic benchmarks of soil fertility
4. Soil analysis also helps to identify nutrients that exists at very low levels—“limiting nutrients”—that may result in acute plant nutrient deficiencies
5. Soil testing provides essential information that may be used in developing nutrient budgets
6. The use of soil tests for periodic monitoring of soil nutrient levels allows a grower to gauge nutrient depletion or accumulation
7. Specialized testing: E.g., toxics, pesticides, heavy metals, nutrient profiles of compost
8. Summary

#### **E. Soil Testing and Recommendation Philosophies**

1. Sufficient Levels of Available Nutrients (SLAN) approach
2. Cation Saturation Ratio (CSR) approach
3. Nutrient Build-Up and Maintenance approach
4. Most testing services have established optimal ratios for general soil fertility that are a combination of SLAN, CSR, and Nutrient Build-Up and Maintenance approaches. As different testing services use different extraction techniques, it is import to consult with your local testing service on the system they use in developing recommendations. Always request “best practices” benchmarks from the testing service in order to maintain the highest yield and soil quality.

# Detailed Lecture 1 Outline: Using a Soil Test to Assess Soil Quality

## *for students*

### **A. Pre-Assessment Questions**

1. Characterize the physical, chemical, and biological components of soil fertility.
2. Which soil and plant nutrients affect the physical, chemical and biological aspects of soil fertility?
3. Which soil and plant nutrients influence crop productivity and the susceptibility of crops to pests and diseases?
4. What negative consequences may result from excess nitrate nitrogen in the soil and in crops?
5. Explain the difference between well-decomposed, stabilized compost and other sources of raw organic matter (e.g., cover crops, manure) in terms of its utility as a soil amendment or fertilizer.
6. In order to sustain crop production, what quantity of nutrients must be applied?
7. What materials would you use to supply plant available forms of nitrogen, phosphorous, potassium, calcium, magnesium, and micronutrients to your crops in a certified organic farming system?
8. How might one assure that adequate quantities of plant available nitrogen (N) are made accessible to crops without excessive fertilization?

### **B. Critical Terms in Soil Fertility Management**

1. Amendment: An organic matter or mineral material applied to the soil to improve or maintain the physical, chemical, and/or biological properties of the soil. (Contrast to fertilizer, below.)
2. Fertilizer: A readily available and concentrated source of plant nutrients used to supply limiting nutrients to growing plants in order to prevent short-term nutrient deficiencies

### **C. The Role of Soil Analysis in Sustainable Agriculture: Reducing Fertilizer Use and Improving Soil Quality and Human and Environmental Health**

1. Soil fertility, plant health, and the resistance and resilience of crop plants to pests and pathogens
  - a) Much like the importance of nutrition to the health of humans, an optimal balance of available plant nutrients will maintain desirable physical, chemical and biological properties of agricultural soils. Proper nutrition will also help prevent nutrient-related plant stress and crop losses through pests, diseases, and poor post-harvest quality.
2. Review of soil nutrients as potential limiting factors in plant growth
  - a) Leibig's Law of the Minimum: "Plant production can be no greater than the level allowed by the growth factor present in the least amount to the optimum amount for that factor"
    - i. Example: Barrel analogy with staves of varying lengths. The shortest stave (the limiting nutrient) will determine the total volume of water (yield) that can be held.
3. Fertilizer, fertilizer use, and soil testing trends in modern agriculture (see unit 3.1, The Development of U.S. Agriculture)

- a) Leibig oversimplified: Subsequent reductionist interpretations of Leibig's Law have tended to focus research and development in soil fertility on defining sufficient levels of individual plant nutrients (see below) and the development of synthetic forms of nutrients in order to maximize crop yields while minimizing input costs. Such an approach to soil fertility management has led to the development and widespread use of synthetic N-P-K; however, overuse of these inputs often results in compromises in soil quality. This approach does not replace soil organic matter nor does it consider the optimal nutrient requirements needed to sustain the desirable physical, chemical, and biological properties of agricultural soils.
  - b) Increased reliance on synthetic N-P-K fertilizer in the U.S.: From 1940–1980 domestic synthetic nitrogen fertilizer use increased from 9 to 47 million tons/year (see Gliessman 1998; U.S. Geological Survey 1998). Trends show steady increase in use of synthetic fertilizers (1983–1996) after steep decline in early 1980s (See [www.ers.usda.gov/publications/sb969/sb969b.pdf](http://www.ers.usda.gov/publications/sb969/sb969b.pdf))
  - c) An 18% increase in the concentration of nitrogen in fertilizer formulations from 1960–1995, resulting in increased intensity of nitrogen fertilizer use per acre (see Young 1999)
  - d) The use of soil testing in developing amendment and fertilizer plans: Many U.S. farmers have historically fertilized routinely using concentrated N-P-K fertilizers without determining the actual nutrient needs of the crops through soil analysis and nutrient budgeting. This has led in some instances to the overapplication of N-P-K fertilizers, while other limiting plant nutrients for soil chemical and physical properties have been overlooked.
4. Excess fertilizer use, pest and disease susceptibility
- a) Over 60 studies have indicated that crops grown in soils with excess or deficient nutrients or poor soil physical properties yield less, are more susceptible to pests and pathogens, and produce crops with poor post-harvest quality (see Young 1999)
5. Excess fertilizer use and fertilizer pollution (see Unit 3.3, Environmental Issues in Modern Agriculture)
- a) Nitrate enters streams and lakes mainly via leaching and subsurface flow; some organic N and ammonium are also deposited via runoff and erosion. Runoff and erosion are also major route for phosphorus. These nutrients may pollute surface waters, leading to eutrophication and the degradation of aquatic ecosystems
  - b) Excess nitrate may also leach into groundwater, increasing the incidence of nitrate poisoning of infants and children. Subsurface flow down slopes is a major route for nitrate entering rivers and other waterways.
  - c) Is there greater efficiency or reduced nutrient runoff from "organic" farms? Without proper nutrient budgeting and efficient amending, excessive organic matter-based fertilizer inputs into "organic" farms may also contribute to nutrient runoff resulting in similar environmental problems. It is therefore critical that both short- and long-term nutrient budgets be established in order to assure a balance of nutrient inputs (amendments, fertilizers) with outputs (harvest) and crop demand, and avoid excessive fertilization.
6. Summary: Soil nutrient deficiencies decrease soil quality and increase the risks of plant stress, poor yields, and susceptibility of crop plants to both pests and pathogens. Equally so, the overuse of synthetic or organic matter-based fertilizers may increase disease and pests incidences, reduce crop quality, and lead to environmental pollution and human health risks due to dietary exposure to nitrate. Without the replacement of soil organic matter, synthetic fertilizers pose the additional risks of soil degradation and eventual yield decreases. Soil analysis is therefore the foundation of a rational and efficient use of soil amendments and fertilizers that may help develop productive agricultural soil and at the same time avoid the problems associated with the overuse of fertilizers.

#### **D. Soil Testing as a Soil Fertility Management Tool**

1. A soil test provides current quantitative information on the nutrient content and the nutrient-supplying capacity of a soil (e.g., a quantitative measurement of the cation exchange capacity, or ppm N, P, K, Mg, etc.)
2. Soil analyses can provide an accurate determination of a soil's textural classification, which may help a grower anticipate how a soil will respond to cultivation as well as the soil's nutrient- and water-holding capacity
3. A soil analysis provides quantitative data allowing for the comparison of a given soil's nutrient and chemical profile with established benchmarks for each property. This helps to identify nutrient levels (or soil chemical properties such as pH) that are above or below optimal benchmarks. This may be remedied over the long term with annual soil amending.
4. Soil analysis also helps to identify nutrients that exist at very low (limiting nutrients) or very high (potentially toxic) levels that may result in acute plant nutrient deficiencies or toxicity. Once identified, these soil nutrient imbalances may be addressed through amending and/or a supplemental fertilizing program.
5. Soil testing provides essential information (e.g., estimated nitrogen release) that may be used in developing efficient nutrient budgets for your crops (see nitrogen budgeting, below)
6. Soil testing allows for periodic monitoring of soil chemical properties in order to maintain the soil nutrient levels (and chemical properties such as pH) within the established optimal ranges and may serve as an accurate indicator of nutrient depletion or accumulation
7. Specialized testing may be used for specific soil nutrients of concern, to test the nutrient content of composts, as well as to determine the presence of pesticides, heavy metals, or other potentially toxic compounds in a soil. See Resources section for testing services.
8. Summary: Soil analysis is the foundation of a rational and efficient use of soil amendments and fertilizers. When properly applied, these inputs—along with other sound agricultural practices—will help develop productive agricultural soil and avoid the environmental and pest management problems associated with nutrient deficiencies and the overuse of fertilizers.

#### **E. Soil Testing and Recommendation Philosophies**

1. Sufficient Levels of Available Nutrients (SLAN): The SLAN approach states that there are definable levels of individual nutrients in the soil below which crops will respond to fertilizers, and above which they likely will not respond through changes in measurable yield or reduction of deficiency symptoms. Building levels of soil nutrients above the point at which a yield increase is observed is considered inefficient.
2. Cation Saturation Ratio (CSR): The CSR approach states that there are optimal ratios of certain cation soil nutrients (e.g., calcium, magnesium, potassium, and sodium) that when present in agricultural soils lead to greater soil quality (physical, chemical, and biological properties), crop and animal health, an increased resistance to pests and pathogens (pre- and post harvest), and increased crop productivity.
3. Nutrient Build-Up and Maintenance: This approach calls for initial application(s) of given deficient nutrients in quantities that will raise the soil level of those nutrients to the point where crop yields are maximized. This is followed by annual amendment applications that will maintain a non-limiting soil nutrient level. It is often suggested that such build-up be done over a 2- to 4-year period. This approach emphasizes the major nutrients (nitrogen, phosphorus, and potassium) and does not focus equally on all 13 essential plant nutrients.
4. Most testing services have established optimal ratios for general soil fertility that are a combination of SLAN, CSR, and Nutrient Build-Up and Maintenance approaches. As different testing services use different extraction techniques, it is important to consult with your local testing service on the system they use in developing amendment recommendations. Always request "best practices" benchmarks for maintaining soil quality if different than above.



Note that different soils can require different nutrient extraction techniques, e.g., some are developed for soils with a given pH range and will give misleading results for soils outside of that range. Also, the presence of high levels of certain compounds in the soil may distort soil tests and require different extraction techniques.

The specific nutrient levels listed in this unit are based on the extraction techniques used at specific laboratories. Although over 90% of U.S. agricultural testing services use the same extraction techniques, some variation exists.

NOTE: It is **critical** that one confirms the specific “optimal” levels used in this unit with those used by your local testing service. The optimal levels presented in this unit are examples of those used by many A & L National Agricultural Laboratories.

# Lecture 2: Properties Measured in a Soil Analysis

## *for the instructor*

### A. Review of the Soil Properties Measured in a Comprehensive Soil Analysis (see appendix 1, Sample [Blank] Soil Analysis Report)

1. Percent (%) Organic Matter
  - a) Defined
  - b) Desirable range for percent organic matter for one's climate
2. Estimated Nitrogen Release (ENR)
  - a) ENR defined
  - b) The accuracy of ENR figures, an estimate of the ENR of one year
  - c) How to use ENR figures (discussed in Demonstration 3, Nitrogen Budgeting)
    - i. ENR and annual crops: Use 60% of the ENR figure in nitrogen budgeting
    - ii. ENR and perennial crops: Use 80% of the ENR figure in nitrogen budgeting
3. Extractable phosphorus (P): Two types of tests are commonly used to illustrate the phosphorus availability at different pH levels. Soil phosphorus availability is highly dependent on soil pH (see phosphorus section in Unit 2.2, Soil Chemistry and Fertility).
  - a) Available phosphorus (P1) Weak Bray method for soils with pH below 6.2
    - i. Optimal levels of more readily available phosphorus (P1): 30–40 ppm
  - b) Olsen sodium bicarbonate extraction for soil with pH above 7.5
    - i. Optimal levels of phosphorus: 55–65 ppm at pH of 6.2; 12–15 ppm at pH of 7.0
4. Extractable potassium/Potash (K)
  - a) Optimal levels of available K
    - i. The optimal level of K in a given soil is 2–5% of the cation saturation (may be higher in sandy soils)
    - ii. Total amount (in ppm) to achieve this based on the CEC of the soil (discussed in greater detail in Demonstration 2, Reading and Interpreting a Soil Analysis Report)
    - iii. Optimal levels for course-textured (sandy) soils range from 150–175 ppm; for heavy-textured (clay) soils, 175–250 ppm
5. Extractable magnesium (Mg)
  - a) Optimal levels of available Mg
    - i. The total amount (in ppm) to achieve this is based on the CEC of the soil (discussed in greater detail in Demonstration 2)
    - ii. Optimal range of Mg: 100–250 ppm. Soils with Mg levels over 25% of cation saturation often exhibit drainage problems and require attention.
    - iii. The optimal level of Mg in a given soil is 10–20% of the cation saturation (10% on clay soils, 20% on sandy soils)
6. Extractable calcium (Ca)
  - a) Optimal levels of available Ca
    - i. The optimal level of Ca in a given soil is 65–75% of the cation saturation
    - ii. The total amount (in ppm) to achieve this based on the CEC of the soil (discussed in greater detail in Demonstration 2)

7. Sodium (Na) (not a necessary plant nutrient)
  - a) Optimal levels of available Na
    - i. The optimal level of Na in a given soil is 0–5% of the cation saturation
    - ii. Sodium levels exceeding 5% of cation saturation may result in adverse physical and or chemical conditions. The total amount (in ppm) to achieve this based on the CEC of the soil (discussed in greater detail in Demonstration 2)
8. pH defined
  - a) Example: A pH of 7.0 is neutral (e.g., pure water). Low pH is acid (e.g., lemon juice or vinegar pH ~4.0). A high pH is referred to as basic or alkaline (e.g., lye pH ~9.0).
  - b) Optimal pH range: ~6.0–7.0 for a mineral soil; 5.5–6.0 for an organic soil
9. Buffer index: An index based on the soil pH that is used to estimate the amount of agricultural lime needed to raise a soil with a pH of 6.5 or less to several higher pH levels (6.0 and 6.5)
10. Hydrogen (H) ion concentration
11. Cation Exchange Capacity (CEC)
12. Percent cation saturation
  - a) % Potassium (K): 2–5% (may be slightly higher in sandy soils)
  - b) % Magnesium (Mg): 10–20% (10% in clay soils, 20% in sandy soils)
  - c) % Calcium (Ca): 65–75%
  - d) % Hydrogen (H): 0–20%
  - e) % Sodium (Na): 0–5%
13. Nitrate nitrogen ( $\text{NO}_3^-$ )
14. Sulfate ( $\text{SO}_4^-$ ), Sulfur (S)
  - a) Optimal levels of available S: 25–35 ppm
15. Micronutrients/trace elements
  - a) Zinc (Zn)
    - i. Optimal levels of available Zn: 1.1–3.0 ppm (DTPA extraction)
  - b) Manganese (Mn)
    - i. Optimal levels of available Mn: 9–12 ppm (DTPA extraction)
  - c) Iron (Fe)
    - i. Optimal levels of available Fe: 11–16 ppm (DTPA extraction)
  - d) Copper (Cu)
    - i. Optimal levels of available Cu: 0.9–1.2 ppm (DTPA extraction)
  - e) Boron (B)
    - i. Optimal levels of available B: 0.6–1.2 ppm (hot water extraction)
  - f) Plant tissue analysis is the most reliable way to monitor for adequate levels of micronutrients. See *A & L Agronomy Handbook* in Resources section.
16. Excess lime defined
17. Soluble salts defined
  - a) Optimal levels of available soluble salts: Less than 2.0 mmhos/cm
18. Chloride (Cl)
19. Soil texture

## **B. Reading and Interpreting a Soil Analysis Report (Demonstration 2); Developing a Nitrogen Budget (Demonstration 3)**

Following Lecture 2, students should be introduced to reading and interpreting a soil analysis report (refer to Demonstration 2) and be shown how to develop a simple nitrogen budget (Demonstration 3).

# Detailed Lecture 2 Outline: Properties Measured in a Soil Analysis

## *for students*

### **A. Review of the Soil Properties Measured in a Comprehensive Soil Analysis**

(see appendix 1, Sample [Blank] Soil Analysis Report)

1. Percent (%) Organic Matter
  - a) Defined: The measurement of the percent organic matter content of a soil. Includes raw and soil organic matter. Not a measure of the quality of organic matter.
  - b) Desirable range for percent organic matter: As climate influences the ability of organic matter to accumulate, no benchmarks for soil organic matter (SOM) can be broadly applied. A 3–5% organic matter content in cool temperate climates is desirable.
2. Estimated Nitrogen Release (ENR)
  - a) ENR defined: The amount of plant available nitrogen in lbs/acre estimated to be released through the mineralization of the currently existing soil organic matter during a single growing season
  - b) The accuracy of ENR figures: The amount of nitrogen liberated from the decomposition of organic matter is dependent upon soil biological activity. This activity is influenced by soil and environmental conditions such as climatic conditions; soil pH; the chemical composition of the organic matter; soil aeration; and soil moisture, among others. Therefore, the ENR figure listed in the soil analysis report is strictly an estimate.
  - c) How to use ENR figures: ENR data are one set of figures (added to the nitrogen contributions of compost and cover crops) that are used in calculating a nitrogen budget for your crop(s). (See nitrogen budgeting exercise, appendix 3 and appendix 4)
    - i. ENR and annual crops: Use 60% of the ENR figure listed on the soil test for annual crop production
    - ii. ENR and perennial crops: Use 80% of the ENR figure listed on the soil test for perennial crop production
3. Extractable phosphorus (P): Two types of tests are commonly used to illustrate the phosphorus availability at different pH levels
  - a) Available phosphorus (P1) Weak Bray method for soils with pH below 6.2
    - i. Optimal levels of more readily available phosphorus (P1): 30–40 ppm
  - b) Olsen sodium bicarbonate extraction for soil with pH above 7.5
    - i. Optimal levels of phosphorus: 55–65 ppm at pH of 6.2
4. Extractable potassium/potash (K): The amount of exchangeable K in ppm found in a given soil sample
  - a) Optimal levels of available K
    - i. The optimal level of K in a given soil is 2–5% of the cation saturation.
    - ii. Total amount (in ppm) to achieve this is based on the CEC of the soil (see Demonstration 2 for greater detail)
    - iii. Optimal levels for coarse-textured soils range from 150–175 ppm; for heavy-textured soils, 175–250 ppm
5. Extractable magnesium (Mg): The amount of exchangeable Mg in ppm found in a given soil sample
  - a) Optimal levels of available Mg
    - i. The total amount (in ppm) to achieve this is based on the CEC of the soil (see Demonstration 2 for greater detail)

- ii. Optimal range of Mg: 100–250 ppm. Soils with Mg levels over 23% of cation saturation often exhibit drainage problems and require attention.
  - iii. The optimal level of Mg in a given soil is 10–20% of the cation saturation
- 6. Extractable calcium (Ca): The amount of exchangeable calcium in ppm found in a given soil sample
  - a) Optimal levels of available Ca
    - i. The optimal level of Ca in a given soil is 65–75% of the cation saturation
    - ii. The total amount (in ppm) to achieve this is based on the CEC of the soil (see Demonstration 2 for greater detail)
- 7. Sodium (Na): The amount of exchangeable sodium in ppm found in a given soil sample
  - a) Optimal levels of available Na
    - i. The optimal level of Na in a given soil is 0–5% of the cation saturation. Sodium levels exceeding 5% of cation saturation may result in adverse physical and/or chemical conditions. The total amount (in ppm) to achieve this is based on the CEC of the soil (see Demonstration 2 for greater detail).
- 8. pH: The measurement of the acidity or alkalinity of a given soil (determined by the concentration of hydrogen ions)
  - a) Example: A pH of 7.0 is neutral (e.g., pure water). Low pH is acid (e.g., lemon juice or vinegar pH ~4.0). A high pH is referred to as basic or alkaline (e.g., lye pH ~9.0).
  - b) Optimal pH range: 6.3–6.8 for a mineral soil; 5.5–6.0 for an organic soil (see Unit 2.2, Soil Chemistry and Fertility)
- 9. Buffer index: An index based on the soil pH that is used to estimate the amount of agricultural lime needed to raise a soil with a pH of 6.5 or less to several higher pH levels (6.0 and 6.5)
- 10. Hydrogen: A measurement of the hydrogen ion concentration in meq/100g of soil in a given soil sample. As the hydrogen ion concentration increases, soil acidity will correspondingly increase, represented by a decrease in pH.
- 11. Cation Exchange Capacity: A measurement of the soil's ability to hold and exchange cation nutrients (e.g., Ca, Mg, Na, K, hydrogen) with growing plants. The sum of the exchangeable cations. The CEC of a soil is influenced by the amount and types of clays and organic matter in the soils; soils with higher clay and organic matter content usually have higher CECs, and are therefore the most fertile (see Unit 2.2, Soil Chemistry and Fertility).
- 12. Percent (%) saturation: The relative percentages of the major cation nutrients found occupying cation exchange sites in a given soil. (Balances recommended by most agronomists are given below. Totals of these percentages should add up to 100.)
  - a) % Potassium (K): 2–5%
  - b) % Magnesium (Mg): 10–15%
  - c) % Calcium (Ca): 65–75%
  - d) % Hydrogen (H): 0–20%
  - e) % Sodium (Na): 0–5%
- 13. Nitrate nitrogen ( $\text{NO}_3^-$ ): The amount of water-soluble nitrogen (nitrate) in ppm found in a given soil sample. Not a reliable test in organic farming systems for determining the need for nitrogen inputs.
- 14. Sulfate ( $\text{SO}_4^{2-}$ ) sulfur (S): The total amount of sulfur in ppm found in a given soil sample
  - a) Optimal levels of available S: 25–35 ppm
- 15. Micronutrients/trace elements
  - a) Zinc (Zn): The extractable amount of zinc (in ppm) found in a given soil sample
    - i. Optimal levels of available Zn: 1.1–3.0 ppm (DTPA extraction)
  - b) Manganese (Mn): The extractable amount of Mn (in ppm) found in a given soil sample
    - i. Optimal levels of available Mn: 9–12 ppm (DTPA extraction)

- c) Iron (Fe): The extractable amount of Fe (in ppm) found in a given soil sample
    - i. Optimal levels of available Fe: 11–16 ppm (DTPA extraction)
  - d) Copper (Cu): The extractable amount of Cu (in ppm) found in a given soil sample
    - i. Optimal levels of available Cu: 0.9–1.2 ppm (DTPA extraction)
  - e) Boron (B): The extractable amount of B (in ppm) found in a given soil sample
    - i. Optimal levels of available B: 0.6–1.2 ppm (hot water extraction)
  - f) Plant tissue testing is the most accurate way to gauge adequate micronutrient levels.  
See *A & L Agronomy Handbook* in Resources section.
16. Excess lime: A visual observation and rating of carbonates in a soil sample. High levels of free lime present may interfere with nutrient availability.
  17. Soluble salts: Total measurement of soluble salts by electrical conductivity. High levels indicate higher risk of plant toxicity due to salt accumulation from fertilizers, poor irrigation water, or chemical contamination.
    - a) Optimal levels of available soluble salts: Less than 2.0 mmhos/cm
  18. Chloride
  19. Soil texture: The relative proportions (percentage) of sand, silt, and clay particles measured in the soil analysis



# Lecture 3 Outline: Applying Soil Amendments and Fertilizers

## *for the instructor*

### **A. Applying Soil Amendments and Fertilizers**

(see [www.groworganic.com](http://www.groworganic.com) for more information on materials, and equipment for amending and fertilizing)

1. Soil amendments
  - a) Timing of amending
  - b) Quantities to apply in a given year
    - i. Example: Agricultural lime and micronutrients
  - c) Depth of incorporation of soil amendments
  - d) Tools and techniques used for incorporating soil amendments

### **B. Supplemental Fertilizing**

- a) Timing of fertilizing
- b) Quantities to apply in a given year
- c) Application of supplemental fertilizers
  - i. Foliar application
  - ii. Soil-based application
- d) Tools used for incorporating fertilizers
  - i. Spray rigs or backpack sprayers
  - ii. Fertigation
  - iii. Others

### **C. Hands-On Exercise: Reading and Interpreting Soil Analysis Reports, Nutrient Budgeting, and Selecting Mineral and Organic Matter Demonstration 4: Field Observations**

Following Lecture 3, students should practice reading and interpreting soil analysis reports, nutrient budgeting, and selecting soil amendments (refer to the Hands-On Exercise). Students should also visit a working farm or garden operation for which a soil test has been done (refer to Demonstration 4, Field Observations for a discussion of soil fertility and nutrient management practices on a working farm).





# Detailed Lecture 3 Outline: Applying Soil Amendments and Fertilizers

## *for students*

### **A. Applying Soil Amendments and Fertilizers**

(see [www.groworganic.com](http://www.groworganic.com) for more information, materials and equipment for amending and fertilizing)

#### 1. Soil Amendments

- a) Timing of amending: Early fall is a preferred time for soil amending with mineral amendments as it allows for several months of winter to elapse during which mineral amendments break down, making the nutrients more available in the spring
- b) Quantities to apply in a given year: Total quantities of amendments to be applied will depend on the levels of soil nutrients reported in a soil analysis report and determined necessary through nutrient budgeting. If soil tests indicate the need for large quantities of amendments, growers should follow the manufacturers' and agronomists' recommendations for application rates, as the potential toxicity of different soil amendments to the soil and crops is highly variable.
  - i. Example: Agricultural gypsum with a low potential toxicity may be applied when indicated by a soil test to the soil at an annual rate of 2+ tons/acre, whereas most micro-/trace elements have a high potential toxicity and should be applied sparingly, often at 0.5–2 gallons/acre
- c) Depth of incorporation of soil amendments: Soil amendments should be evenly incorporated into the depth of tillage, or banded down rows in the case of acute nutrient deficiencies
- d) Tools and techniques used for incorporating soil amendments: Soil amendments may best be incorporated with cover crops seed in the fall using similar equipment

### **B. Supplemental Fertilizing**

- a) Timing of fertilizing: The timing of supplemental fertilizing is determined by need based on plant tissue testing and/or growth response observations
- b) Quantities to apply in a given year: The concentration of nutrients varies in various supplemental fertilizers; follow the manufacturer's and agronomists' recommendations for application rates
- c) Application of supplemental fertilizers
  - i. Foliar application: Foliar fertilizers are sprayed directly on the growing plants and are absorbed through the stomata. Foliar fertilizers should be applied during cool parts of the day (when the greatest number of stomata are most open) and to the underside of the leaves (where the greatest concentration of stomata are located).
  - ii. Soil-based application: Supplemental fertilizers may be injected into the irrigation system (requires filtration) or applied directly to the soil surface around the root systems of the crops. If applied directly to the soil surface it is generally recommended to apply the fertilizer prior to irrigation.
- d) Tools used for incorporating fertilizers
  - i. Spray rigs or backpack sprayers may be used on a field and garden scale to apply mist and liquid fertilizers
  - ii. Fertigation (injecting fertilizer through irrigation equipment): See equipment suppliers for specialized equipment and formulations
  - iii. Others



# Demonstration 1: Taking a Soil Sample for Laboratory Analysis

*for the instructor*

## OVERVIEW

*Collecting a representative sample of a given soil is critical to receiving accurate soil analysis information. In this demonstration, the instructor should discuss the sampling considerations given in the Demonstration Outline, and demonstrate the tools and techniques used to take soil samples and prepare a suitable sub-sample for laboratory analysis.*

## RESOURCES AND REFERENCES

- *Agronomy Handbook: Soil and Plant Analysis*. A & L Western Agricultural Laboratories, Inc. 1311 Woodland Ave., #1. Modesto, California 95351. (209) 529-4736
- Magdoff, Fred and Harold Van Es. *Building Soils for Better Crops, Second Edition*. Handbook Series Book 4, Sustainable Agriculture Network. Ch. 19: Getting The Most Out of Soil Tests. Available from [www.sare.org](http://www.sare.org).

## PREPARATION AND MATERIALS

- Stainless steel or chrome soil auger or stainless steel trowel
- Plastic buckets
- Sample bags from laboratory
- County soil survey maps
- Laboratory forms for submitting sample and request for analysis
- Notebook, pen, and folder for documenting
- Student preparatory reading: A & L Reference Guide—“Soil Sampling”

## PREPARATION TIME

1.5 hours

## DEMONSTRATION TIME

1.5 hours

## DEMONSTRATION OUTLINE

### A. Sampling Procedures

1. Sample area
  - a) First discuss the use of County soil maps to help delineate regional variations in soil textural classifications
  - b) Different soil types (texture and color), distinct crop growth response areas, or soil treatment areas are sampled separately
  - c) Each sample should be from a plot no larger than 40 acres
  - d) Avoid: Corners of fields, poorly drained areas, and 50 feet from structures and roads
  - e) Problem areas: Sample “problem” areas (e.g., poor drainage, poor plant growth responses) and “good” areas for comparison; include surface and subsoil sample for problem areas
  - f) Varying terrain: Sample bottom land and hills separately
2. Time of year to sample
  - a) Samples may be taken at any time (though fall is often recommended)
  - b) Be consistent from year to year with sampling time and testing service
  - c) Combining soil samples and plant tissue samples with plant growth observations
  - d) Frequency
    - i. Initial stages of soil development and intensive cropping systems: 1x/year
    - ii. Once chemical benchmarks have been reached: 1x/2-3 years
3. Demonstrate tools used in sampling
  - a) Stainless steel soil auger, steel trowel, or spade/shovel
  - b) Plastic buckets
  - c) Sample bags from lab
4. Demonstrate sampling depth (should be consistent from year to year)
  - a) Initial sampling
    - i. Remove plant residues from surface (do not include this or other distinguishable forms of organic matter in sample)
    - ii. Sample distinct soil horizons separately (e.g., A and B horizons), if within the depth tillage, noting depth to each horizon
  - b) Subsequent sampling
    - i. Remove plant residues from surface (do not include in sample)
    - ii. Sample to 12 inches or depth of tillage unless problem soil (see below)
    - iii. Include entire soil profile from auger core or soil slice
  - c) “Problem” soils
    - i. Include separate surface and sub-soil sample (inquire with testing service)
  - d) Orchard systems
    - i. Pre-plant depth: Sample to depth of tillage
    - ii. In established no-till orchards: Sample to 6 inches in depth
5. Demonstrate sample size
  - a) 2 cups of soil sub-sampled from well-mixed composite of 10–20 random samples, including for textural classification
  - b) 2 cups each for nematodes, pesticide residues, or other specialized sampling
6. Demonstrate sample preparation
  - a) Mix cores or slices together
  - b) Fill sample bag provided with sub-sample (no need for further processing)

7. Completing lab forms and personal documenting
  - a) Location of sample/field
  - b) Date
  - c) Previously grown crops and/or crops to be grown
  - d) Sample depth
  - e) Specific type of analysis to request
    - i. Initial soil analysis
    - ii. Problem soils/trouble shooting
  - f) Plant growth responses
8. Specialized sampling (separate test for each)
  - a) Pesticides (inquire with testing service)
  - b) Nematodes (inquire with testing service)
  - c) Problem soils (inquire with testing service)
  - d) Compost analysis (inquire with testing service regarding organic amendment sampling)



# Demonstration 1: Taking A Representative Soil Sample For Laboratory Analysis

## *step-by-step instructions for students*

### **INTRODUCTION**

*The key to receiving accurate soil analyses information is to properly collect and submit a representative sub-sample of a given soil. Follow the steps outlined in these instructions when taking a soil sample for laboratory analysis.*

### **PREPARATION AND MATERIALS**

- Stainless steel or chrome plated soil auger or stainless steel trowel
- Plastic buckets
- Sample bags from soil testing laboratory
- County soil survey maps

### **RESOURCES AND REFERENCES**

- For a review of plant analysis techniques see: *Agronomy Handbook: Soil and Plant Analysis*. Chapter II. A & L Western Agricultural Laboratories, Inc. 1311 Woodland Ave., No. 1. Modesto, California 95351. (209) 529-4736
- Illustrated soil sampling techniques: [www.back-to-basics.net/efu/pdfs/sampling.pdf](http://www.back-to-basics.net/efu/pdfs/sampling.pdf)
- Magdoff, Fred, and Harold Van Es. *Building Soils for Better Crops, Second Edition*. Chapter 19, Getting the Most Out of Soil Tests

### **STUDENT OUTLINE**

#### **A. Sampling Procedures**

1. Sample area
  - a) County soil maps may help delineate regional variations in soil textural classifications and land uses for that soil type
  - b) Different soil types, including texture, color, distinct crop growth response areas and/or soil treatment areas should be sampled separately
  - c) Sample from areas of 40 acres or less
  - d) Avoid: Corners of fields, poorly drained areas and 50 feet from structures and roads
  - e) Problem areas: Sample “problem” areas (e.g., poor drainage or poor plant growth responses) and “good” areas for comparison; include surface and subsoil sample
  - f) Varying terrain: Sample bottom land and hills separately



2. Time of year to sample
  - a) Samples may be taken at any time (though fall is often recommended)
  - b) Be consistent from year to year with sampling time, locations, and testing service
3. Frequency of sampling
  - a) Initial stages of soil development and intensive cropping systems: 1x/year
  - b) Once chemical benchmarks have been reached: 1x/2–3 years
4. Tools to use when taking soil samples
  - a) Stainless steel soil auger, stainless steel trowel or stainless spade/shovel
  - b) 5-gallon plastic buckets (to hold 15–30 cups of soil total)
  - c) Sample bags from testing agency
5. Sampling depth (should be consistent from year to year)
  - a) Initial sampling
    - i. Remove plant residues from surface (do not include in sample)
    - ii. Sample distinct soil horizons separately (e.g., A and B horizons), if within the depth of tillage, noting depth to each horizon
  - b) Subsequent sampling
    - i. Remove plant residues from surface (do not include in sample)
    - ii. Sample to 12 inches unless problem soil (see below)
    - iii. Include entire soil profile from auger core or soil slice
  - c) Problem soils
    - i. Include separate surface and sub-soil sample (inquire with testing service)
  - d) Orchard systems
    - i. Pre-plant depth: Sample to depth of tillage
    - ii. In established no-till orchards: Sample to 6 inches in depth
6. Sample size
  - a) 2 cups of soil sub-sampled from well-mixed composite of 10–20 random samples, including for textural classification
  - b) 2 cups each for nematodes, pesticide residues, or other specialized sampling
7. Sample preparation
  - a) Mix cores or slices together from 10–20 random samples
  - b) Fill sample bag provided with 1.5 cups of soil sub-sampled from well mixed composite
  - c) No need for further processing
  - d) For problem soils, submit soil sample with a plant tissue sample and description of plant growth observations when trouble shooting poor crop growth responses (see sample depth, above)
8. Completing lab forms and personal documenting
  - a) Location of sample/field
  - b) Date
  - c) Crop previously grown and/or those to be grown
  - d) Sample depth
  - e) Specific type of analysis requested (inquire with testing service)
  - f) Observations of plant growth responses, if problems
9. Specialized sampling
  - a) Pesticides (inquire with testing service for specific sampling procedures and sample volumes)
  - b) Nematodes (inquire with testing service)
  - c) Problem soils (inquire with testing service)
  - d) Compost analysis (inquire with testing service about organic matter amendment sampling)

# Demonstration 2: Interpreting a Soil Test Report

## *for the instructor*

### **OVERVIEW**

*This demonstration introduces students to reading and interpreting sample soil analysis reports. Based on these reports, students will learn to select the appropriate types and amounts of soil amendments and fertilizers for use in certified organic production systems. Such interpretation skills will provide students with the ability to develop both amendment recommendations for long-term soil fertility management plans and address acute soil and plant nutrient deficiencies through proper supplemental fertilization.*

Following the outline below, demonstrate and discuss each step in the interpretation process, beginning with a description of the Nutrient Budgeting Worksheets (appendix 2) used to track calculations. Using the appendices listed below, demonstrate and discuss the following: Reviewing the accuracy of sampling information; use of the analysis report to describe the general characteristics of the sampled soil; how to transfer data to the nutrient budgeting worksheets and convert figures from ppm tested to lbs/acre of soil nutrients; the contrasting of soil nutrient levels with defined optimal levels to define limiting and/or excess soil nutrients; selecting the type and quantities of soil amendments to address limited or imbalanced soil nutrients or soil chemical properties.

The instructor should explain amendment options, including the advantages and disadvantages of each option and their relative environmental and financial costs. An example of a nitrogen budget should be calculated using the nitrogen budgeting worksheets, factoring ENR from compost, cover crops, and existing soil organic matter (see Demonstration 3, Nitrogen Budgeting). This pair of demonstrations should be followed by the Hands-On Exercise in which students are asked to read and interpret a sample soil analysis report, select amendments and fertilizers, and develop a simple nitrogen budget for a hypothetical farm or garden operation.

### **PREPARATION AND MATERIALS**

- Sample lab analyses report reproduced on overhead transparency (OHT)

The following appendices on (OHT):

- Appendix 1, Blank Sample Test
- Appendix 2, Nutrient Budgeting Worksheets
- Appendix 5, Supplemental Fertilizers Worksheet
- Appendix 6, Optimum Nutrient Levels of Major Cations Based on CEC
- Appendix 7, Nutrient Profiles of Common Fertilizers and Amendments
- Appendix 8, Fertilizer Solutions Chart
- Agricultural supply catalogues for National Organic Program-approved amendments and fertilizers: Peaceful Valley Farm Supply, [www.groworganic.com/](http://www.groworganic.com/)
- Overhead projector
- Pen for writing on OHT

### **PREPARATION TIME**

1 hour

### **DEMONSTRATION TIME**

1.5 hours

## **DEMONSTRATION OUTLINE**

### **A. Goals of the Session**

- To teach students how to read and interpret sample soil analysis reports and how to calculate the proper amounts of mineral and organic matter soil amendments needed to make the necessary soil adjustments using the Nutrient Budgeting Worksheets
- To teach students how to determine the need for supplemental fertilizers
- To teach students how to develop an estimated Nitrogen Budget for crops

### **B. The Role of Nutrient Budgeting Worksheets**

Nutrient Budgeting Worksheets are a format for tracking calculations to determine the type and quantities of soil amendments and fertilizers, if any, to use in adjusting the chemical properties of a given soil. Will also demonstrate if you are adding more nutrients than are removed in the crop harvests. Any excess will either accumulate in the soil (soil tests over number of years should show this) or be lost to the environment.

### **C. Using a sample soil test report and the Nutrient Budgeting Worksheets (Appendix 2), demonstrate reviewing the accuracy of sampling report information**

1. Name
2. Field identification name/number
3. Date sampled
4. Crop
5. Soil depth from which sample was taken

### **D. Demonstrate transcribing the following data from the soil report to the Nutrient Budgeting Worksheets to help isolate the general agronomic characteristics of the soil**

1. Soil textural classification
2. Soil pH
3. Organic matter
4. Excess carbonates/lime
5. CEC
6. Buffer pH
7. Soluble salts
8. Describe and discuss the general agronomic characteristics of the soil based on the lab report

### **E. Demonstrate transcribing all of the nutrient levels tested in ppm from the lab report to the “ppm tested” (Row A) of the Nutrient Budgeting Worksheets**

1. Soil cations
  - a) Calcium (Ca):
  - b) Magnesium (Mg):
  - c) Potassium/Potash (K):
  - d) Sodium (Na):
  - e) Hydrogen (H) ion concentration:
2. Macronutrients
  - a) Available phosphorus (P1) Weak Bray method:
  - b) Olsen method phosphorus (P2) extraction:
  - c) Nitrate nitrogen ( $\text{NO}_3^-$ ):
  - d) Sulfate ( $\text{SO}_4^-$ ) Sulfur (S):

3. Micronutrients/trace elements:
  - a) Zinc (Zn)
  - b) Manganese (Mn)
  - c) Iron (Fe)
  - d) Copper (Cu)
  - e) Boron (B)
  
- F. Demonstrate transcribing all of the qualitative descriptors (High, Med, Low, etc.) of the nutrient levels into Row G of Nutrient Budgeting Worksheets**
  
- G. Demonstrate transcribing the “Percent Cation Saturation” ratios from the soil test to the %CSR (Row H) of the Nutrient Budgeting Worksheets**
  1. % Potassium (K)
  2. % Magnesium (Mg)
  3. % Calcium (Ca)
  4. % Hydrogen (H)
  5. % Sodium (Na)
  
- H. Demonstrate converting all the nutrient levels tested in ppm to lbs/ac (listed in E, above )**
  1. Demonstrate multiplying nutrient levels tested in ppm (Row A) by conversion factors (Row C) and placing the sum in Row E
  2. Explain the conversion factors used in converting ppm to lbs/acre
  
- I. Demonstrate determining the ppm optimal range (Row B) for the major cation (Ca, Mg, K) nutrients using the CSR (Row H), the CEC of the tested soil, and Appendix 6**
  1. Ca
  2. Mg
  3. K
  
- J. Demonstrate determining lbs/ac optimal range for major cations**
  1. Multiply Row B by Row C = Row D
  
- K. Demonstrate calculating lbs/ac of actual nutrient required for all nutrients**
  1. Demonstrate subtracting “lbs/acre tested” (Row E) from “lbs/ac optimal range” (Row D) = “lbs/acre of actual nutrient required” (Row D - Row E = Row F)
  
- L. Demonstrate selecting appropriate mineral amendments to supply needed nutrients**
  1. Review Row G of Nutrient Budgeting Worksheets for “Very High” nutrient levels in order to avoid selecting amendments that would add nutrients that already exist at a very high level
  2. Select soil amendment using appendix 8, the Fertilizer Solutions Chart and/or agricultural supply catalogues (see Resources section)
  
- M. Demonstrate determining the nutrient content (by percentage) of amendments using appendix 7 and/or agricultural supply catalogues (see Resources section)**
  1. Transcribe nutrient percentages into Row K, “Nutrient content by %,” of the Nutrient Budgeting Worksheets (convert % to decimal, e.g., 39% = 0.39)

**N. Demonstrate calculating lbs/acre of the amendment required to increase the nutrient level to the optimal range**

1. Divide the “lbs/acre of nutrient required” (Row F) by the “Nutrient content by percentage/%” (Row K) of the soil amendment to be used = “lbs/acre of amendment required” (Row L). ( $\text{Row F}/\text{Row K} = \text{Row L}$ ).

**O. Demonstrate calculating tons/acre or lbs/100 square ft of amendment needed**

1. Divide “lb/acre amendment required” (Row L) by 2000 lbs (1 ton) = tons/acre of amendment needed
2. To calculate lbs/100 square ft amendment required: Divide the lbs/ac-ft amendment required (L) by 440. Enter this value into Row M. ( $L/440 = M$ ).

**P. Demonstrate calculating costs of amendments**

1. Multiply tonnage or lbs of amendment needed (Row L) by price/ton or lb (see agricultural supply catalogues in Resources section)

**Q. Demonstrate identifying nutrient deficiencies to address through supplemental fertilizing**

1. Review soil report for “Low” and “Very Low” nutrient levels
2. Transfer this information to appendix 5, Supplemental Fertilizers Worksheet

**R. Demonstrate selecting fertilizers to alleviate stress and prevent acute nutrient deficiencies (see appendices 5 and 8)**

**S. Discuss timeline and application rates for applying amendments and fertilizers identified as necessary based on interpretation process**

1. Current season
  - a) Timing
  - b) Application rates
2. Subsequent years
  - a) Timing
  - b) Application rates
3. Discuss frequency of subsequent soil sampling

**T. Discuss and demonstrate writing a summary of findings and specific amendment recommendations**

1. Qualitative description of the agronomic characteristics of the soil
2. Defined nutrient excesses, imbalances, and/or deficiencies
3. Amendments selected to address excesses, imbalances and/or deficiencies
4. Associated costs
5. Timeline for implementation and application rates to be used
6. Defined acute nutrient deficiencies
7. Supplemental fertilization to address acute nutrient deficiencies
8. Timeline for implementation and application rates to be used
9. Nitrogen requirements of crop(s)
10. Estimated nitrogen contributions of soil organic matter (ENR), compost and cover crops
11. Timeline, application rates of compost, cover crop species and seeding rates used to meet N needs

Follow up this demonstration with Demonstration 3, Nitrogen Budgeting.

# Demonstration 2: Interpreting Soil Test Reports

## *step-by-step instructions for students*

*These instructions will help you read and interpret soil analysis reports and select soil amendments and fertilizers. This information will help you interpret soil analysis lab results, develop amendment recommendations for long-term soil fertility management plans, and address acute soil and plant nutrient deficiencies through proper supplemental fertilization. This sheet, along with Appendix 2: Nutrient Budgeting Worksheets, will help you with the following: review the accuracy of sampling information on your soil test; describe the relevant agronomic characteristics of your soil; assist you in the necessary conversions from parts/per million (ppm) nutrients tested to lbs/acre of soil nutrients; contrast soil nutrient levels with defined optimal benchmarks in order to define limiting and/or excess soil nutrients; and select the type and quantities of soil amendments and/or fertilizers that may be used to address limited or imbalanced soil nutrient levels. This form and the associated appendices will also help you develop a nitrogen budget for your crop(s) through calculating the nitrogen contributions from compost, cover crops and existing S.O.M. and contrasting this with estimates of nitrogen removal through cropping.*

### **PREPARATION AND MATERIALS**

- Lab analyses report

The following appendices on overhead transparencies (OHT):

- Appendix 2, Nutrient Budgeting Worksheets
- Appendix 4, Nitrogen Budgeting Worksheet Exercise
- Appendix 5, Supplemental Fertilizer Worksheet
- Appendix 6, Optimal Nutrient Levels of Major Cations Based on CEC
- Appendix 7, Nutrient Content of Common Fertilizers and Amendments
- Appendix 8, Fertilizer Solutions Chart
- Appendix 9, Approximate Pounds/Acre of Nutrients Removed by Common Crops
- Calculator
- Pencil
- Agricultural supply catalogues for National Organic Program-approved amendments and fertilizers

### **REFERENCE**

- *Agronomy Handbook: Soil and Plant Analysis*. A & L Western Agricultural Laboratories, Inc. 1311 Woodland Ave., #1. Modesto, California 95351. (209) 529-4736

**A. Collect and organize the materials listed above**

**B. Review and confirm the accuracy of sampling information using the Soil Test Report and Appendix 2, Nutrient Budgeting Worksheets)**

1. Name
2. Field identification name/number
3. Date sampled
4. Crop
5. Soil depth sampled
6. Soil textural classification

**C. Transcribe the general agronomic characteristics of the soil from the lab report to the nutrient budgeting worksheets**

1. Soil textural classification
2. Soil pH
3. Organic matter
4. Excess carbonates/lime
5. CEC
6. Buffer pH
7. Soluble salts

**D. Transcribe tested nutrient levels and ratios from the lab report to the nutrient budgeting worksheets**

1. Transcribe the nutrient levels tested in ppm from the lab report to Row A of the Nutrient Budgeting Worksheets
2. Transcribe the Percent Cation Saturation Ratios (%CSR) from the lab report to Row H of Nutrient Budgeting Worksheets

**E. Convert the nutrient levels tested to lbs/ac**

1. Convert all nutrients tested from ppm to lbs/ac by multiplying ppm tested (Row A) by the conversion factor in Row C. Write the answer for each in Row E. ( $A \times C = E$ ).
2. Define the optimal range in ppm for Ca, Mg, K required to achieve optimal Cation Saturation Ratios using the cation exchange capacity (CEC) of the tested soil and appendix 6). Write the optimal range for each nutrient in Row B. Optimal ranges for all other nutrients have been included in the Nutrient Budgeting Worksheets.
3. Now convert the ppm optimal range for Ca, Mg, and K to the optimal range in lbs/ac for each nutrient by multiplying ppm optimal range (B) by the conversion factor in Row C. Write the answer for each in Row D. ( $B \times C = D$ )

**F. Calculate lbs/ac of actual nutrient required**

1. Calculate lbs/ac of actual nutrient required by subtracting lb/ac-ft optimal range (Row D) from lb/ac tested (Row E). Write the answer for each in Row F. ( $D - E = F$ ).

**G. Characterize each of the soil nutrient levels with a qualitative description**

1. Contrast the nutrient levels tested in lbs/ac (Row E) with the lbs/ac optimal range (Row D)
2. Document a qualitative description (Row G) for each of the nutrient levels using the following: Very Low (VL) = well below the optimal range; Low (L) = just outside or the low end of the optimal range; Medium (M) = close to average of the optimal range; High (H) = just above or the high end of the optimal range; Very High (VH) = well above the optimal range. Confirm with soil test descriptions.



## H. Select appropriate mineral amendments to supply needed nutrients

1. Select amendment using the Fertilizer Solutions Chart (appendix 8). Avoid selecting any amendment that contains a nutrient known to already exist at “High” or “Very High” levels in the soil.
2. Determine the nutrient content (by percentage) of amendments using appendix 8 or agricultural supply catalogues. Enter this value into Row K.

## I. Calculate lbs/ac amendment required

1. Calculate lbs/ac amendment required by dividing lbs/ac of nutrient required (Row F) by the percentage of actual nutrient contained in the amendment (Row K). Enter this value into column L. ( $F/K = L$ ).

## J. Calculate tons/acre (or lbs/100 square ft) of amendment required

1. To calculate tons/acre of amendment required: Divide lbs/ac amendment required (Row L) by 2000 lbs. Enter this value into column M. ( $L/2000 = M$ ).
2. To calculate lbs/100 square ft amendment required: Divide the lbs/ac amendment required (Row L) by 440. Enter this value into Row M. ( $L/440 = M$ ).

## K. Calculate the cost of amendments/acre and total cost of amending all acreage for each amendment

1. Enter the price/unit volume of each selected amendment selected in Row N. See agricultural supply catalogues in Resources section.
2. Define total surface area (acres or square feet) in needed amendment. Enter this value into Row O.
3. Multiply tons/ac (or lbs/sq-ft) of amendment needed (Row M) by the price/unit volume of amendment (Row N). This is the cost of amendment per acre. Multiply this figure by the total acreage or total square footage in need of amending (Row O). This is the total cost of amendment for all acreage. Enter this value into Row P. ( $M \times N \times O = P$ )

## L. Calculate total costs of all amendments over all acreage

1. Add all the total costs of each amendment in Row P. This is the total cost of all amendments over all acreage. Enter this value into the far right side of the bottom row total cost of Row P.

## M. Nitrogen budgeting: Meeting the nitrogen requirements of crops (see appendix 4)

1. Determine amount of nitrogen removed in lbs N/acre
  - a) Line 1: Using appendix 9, Approximate Pounds/Acre Of Nutrients Removed By Common Crops, determine the amount of nitrogen removed in lbs N/acre for a specific crop or crops. Enter this value into line 1.
2. Calculate the estimated nitrogen contributions from the following sources:
  - a) Soil organic matter (SOM) – Line 2: Multiply the total Estimated Nitrogen Release (ENR) figure from your soil report x 60% (for annual cropping systems) or x 80% (for perennial/ no- or low-till systems). Enter this value into line 2. This is an estimate of the lbs N/acre mineralized from SOM in one year’s time.
  - b) Compost – Line 3: First enter the application rate of compost in tons/acre. Next enter the percent nitrogen content of your compost (use average or test results). Multiply total wet weight of compost by 0.35 and subtract this figure from total application rate (tons/acre). This gives you dry weight. Multiply total pounds of dry weight compost applied by the percent nitrogen of the compost. This is the total pounds of actual nitrogen applied/acre. Next, multiply the average amount of nitrogen made available in the first year (~50%) by the total pounds of actual N applied. This is the estimated nitrogen released in the first 3–6 months of the growing season from well-decomposed compost. Enter this value in line 3.



- c) Nitrogen fixing cover crops – Line 4: Using the UC Davis Cover Crop Data Base: [www.sarep.ucdavis.edu/cgi-bin/ccrop.EXE/show\\_crop\\_5](http://www.sarep.ucdavis.edu/cgi-bin/ccrop.EXE/show_crop_5), or the calculations from Unit 1.6, *Selecting and Using Cover Crops*, enter the estimated pounds of nitrogen/acre fixed by a legume cover crop into the blank space in line 4. This is the estimated nitrogen contribution of a legume cover crop when directly incorporated into the soil at the optimal stage of development (~75% of full bloom). Next multiply the average amount of nitrogen made available in the first year (~50%) by the total pounds of actual N fixed. This is the estimated nitrogen released in the first 3–6 months of the growing season from a nitrogen fixing cover crop. Enter this figure into line 4.
3. Calculate the total available nitrogen from all of the above sources
  - a) Line 5 – Add up lines 2-4. Enter this figure into line 5. This is the total available nitrogen from all sources.
4. Determine the need for supplemental nitrogen
  - a) Line 6 – Subtract line 5 from line 1. Enter this figure into line 6. \*If this figure is a negative number it is estimated that the crops should not need any additional sources of nitrogen. If this figure is a positive number, then one should increase the application rate of compost, adjust the species or seeding rate of cover crops, and/or select the proper supplemental fertilizer (below) to supply the needed nitrogen. If number is large and negative or remains negative from year to year, it may indicate N loss to environment.

#### **N. Identify potential acute nutrient deficiencies**

1. Review soil report for “Very Low” and “Low” nutrient levels (Row G). Enter all nutrients found to exist in the soil at “Very Low” and “Low” into the first column of the Supplemental Fertilizers Worksheet (appendix 5) under “Potential Limiting Nutrients”.

#### **O. Select a supplemental fertilizer to prevent acute nutrient deficiencies**

1. Select a proper supplemental fertilizer(s) using appendix 8, the Fertilizer Solutions Chart. Using an agricultural supply catalogue, record all relevant information for the use of the needed supplemental fertilizer in the subsequent columns. Calculate total volume of supplemental fertilizers needed and their associated costs.

#### **P. Write a summary of your findings and specific amendment recommendations**

1. Qualitative description of the agronomic characteristics of the soil
2. Defined nutrient excesses, imbalances, and/or deficiencies
3. Amendments selected to address excesses, imbalances, and/or deficiencies
4. Associated costs
5. Timeline for implementation and application rates of amendments to be used
6. Defined acute nutrient deficiencies
7. Supplemental fertilization to address acute nutrient deficiencies
8. Timeline for implementation and application rates of fertilizers to be used
9. Nitrogen requirements of crop(s)
10. Estimated nitrogen contributions of soil organic matter (ENR), compost, and cover crops
11. Time line, application rates, and cover crop species to be used to meet N needs in future
12. Frequency and date of subsequent soil sampling

\* Note: Seasonal environmental conditions may create growing conditions (e.g., cool and wet soils) that may depress mineralization and N availability, thereby creating a demand for supplemental fertilizer despite the presence of adequate quantities of N in the soil.

# Demonstration 3: Nitrogen Budgeting

## *for the instructor*

### **OVERVIEW**

*This demonstration offers an example of how a simple nitrogen budget can be calculated for an organic farm or garden. Using the nitrogen budgeting worksheets and the Demonstration Outline below, discuss and demonstrate the process of calculating an estimated nitrogen budget for a farm, factoring estimated nitrogen release (ENR) from compost, cover crops, and existing soil organic matter. For this exercise, appendix 3 (Nitrogen Budgeting Exercise) includes an example of the steps involved in calculating a basic nitrogen budget. Following this demonstration, students should be given the Hands-On Exercise.*

### **PREPARATION AND MATERIALS**

- Appendix 3, Example of a Nitrogen Budget
- Appendix 9, Approximate Pounds/Acre of Nutrients Removed by Common Crops
- Sample soil test report
- Overhead projector
- Pen for writing on overhead transparency film

### **PREPARATION TIME**

0.5 hour

### **DEMONSTRATION TIME**

1 hour

## **DEMONSTRATION OUTLINE**

### **A. Discuss rationale and goals of nitrogen budgeting**

1. Meeting but not exceeding crop nitrogen requirements of crops

### **B. Discuss factors to consider in N-budgeting for organic farming and gardening systems**

1. Crop removal estimates and nutrient contributions of inputs (cover crops, compost, and ENR from SOM)

### **C. Demonstrate how to use the crop removal estimates in appendix 9 to provide an approximation of the amount of plant nutrients that are removed from the soil in a year by a specific crop or crops**

1. This figure is placed on Line 1 of the Nitrogen Budgeting Worksheet Exercise (appendix 4)

### **D. Discuss nitrogen contributions from three major sources in organic farming systems: ENR from SOM, compost, and cover crops**

1. Demonstrate how to transcribe the estimated nitrogen release (ENR) figures from the soil test to the Nitrogen Budgeting Worksheet for calculating the nitrogen contribution of ENR (see Line 2 of the Nitrogen Budgeting Worksheet)
  - a) Discuss the use of estimated nitrogen release in an annual and perennial cropping system
  - b) Demonstrate calculations
2. Demonstrate how to factor in the nitrogen contribution of compost using Line 3 of the Nitrogen Budgeting Worksheet
  - a) Discuss application rate
  - b) Discuss nitrogen content derived from analysis, and that nitrogen content is based on dry weight
  - c) Discuss wet weight of compost and how to calculate dry weight
  - d) Demonstrate multiplying dry weight by %N
  - e) Discuss and demonstrate %N available
3. Demonstrate how to determine the nitrogen contribution of nitrogen-fixing cover crops (see [www.sarep.ucdavis.edu/](http://www.sarep.ucdavis.edu/) and Unit 1.6, Selecting and Using Cover Crops, for more information). These data should be included in Line 4 of the Nitrogen Budgeting Worksheet
  - a) Demonstrate calculations
4. Discuss factoring in the nitrogen concentration in irrigation water.
5. Discuss the accuracy of this type of nitrogen budgeting (see F, below)

### **E. Demonstrate how to calculate the balance of nitrogen inputs and outputs**

1. Demonstrate totaling the nitrogen inputs by adding Lines 2–4 of the Nitrogen Budgeting Worksheet. This figure should be placed on Line 5 of the Nitrogen Budgeting Worksheet.
2. Demonstrate how the nitrogen contributions of all inputs should be subtracted from the crop removal estimates to determine the need for additional nitrogen inputs (e.g., increased application of compost, increased seeding rate of nitrogen-fixing cover crops, or supplemental fertilizing). This figure should be placed on Line 6 of the Nitrogen Budgeting Worksheet.

**F. The challenges of accurate nitrogen budgeting in organic farming systems:**

**Factors influencing the release of nitrogen from organic matter**

1. 99% of the N in most soil is tied up in soil organic matter (SOM), the release of which is dependent on soil conditions such as temperature, aeration, and moisture, which are in turn dependent on weather/air temperature, tillage, rainfall, and irrigation practices
2. The quality and quantity of existing soil organic matter and organic matter inputs. The C:N ratio, the presence of lignins and tannins, soil biological activity, and the placement of organic matter amendments in the soil profile all influence the mineralization rate of organic matter. The accuracy of the mineralization rates listed in the Nitrogen Budgeting Worksheet must be understood in this light and represent only a rough estimate.
3. Discuss long-term budgeting and nutrient management. The use of this nitrogen budgeting exercise, combined with annual soil analysis report data, can give a grower an indication of either the accumulation or depletion of soil nutrients. With such information, the grower may make adjustments to the system in order to balance nutrient inputs with outputs, thereby both assuring nutrient availability and avoiding the problems associated with excess soil nutrients.



# Demonstration 4: Field Visit to A Working Agricultural Operation — Relating Crop Growth Observations to Fertility Programs

## *for the instructor*

### **OVERVIEW**

*Visit a local garden or farm for which a soil analysis report has been prepared and reviewed by the class. Request from the grower an overview of the current soil fertility and pest and disease management plans and practices used in the operation. The overview should include the following components: soil textural classification; hydrology of fields; history of cultivation; history of soil testing and amending; the use of cover crops, compost, and crop rotation; the use of supplemental fertilization; primary tillage practices used; any persistent pest, disease, plant growth response and/or crop quality concerns occurring in the production of the crop(s).*

Following the presentation, tour the fields/gardens looking for any nutrient deficiency symptoms that may be correlated with known physical or chemical properties of the soil (refer to soil analysis), and that may be associated with specific cultural practices. With the permission of the grower, samples of crop vegetation can also be taken for later comparison with photographs of crops with known nutrient deficiencies.

### **PREPARATION AND MATERIALS**

- Sample lab analyses report
- Crop deficiency and toxicity reference charts (see below)

### **RESOURCES AND REFERENCES**

- *Agronomy Handbook: Soil and Plant Analysis*. A & L Western Agricultural Laboratories, Inc. 1311 Woodland Ave., #1. Modesto, California 95351. (209) 529-4736. (For crop deficiency symptoms see pp. 87-92.)
- Unit 2.2 of this manual, Introduction to Soil Chemistry and Fertility. (For crop deficiency symptoms see Detailed Lecture Outline; for web sites containing photographs of specific crops with specific nutrient deficiencies see Resources section.)

## DEMONSTRATION OUTLINE

### A. Soil Fertility and Pest and Disease Management Plans and Practices: Grower Overview

1. Soil textural classification
2. Soil quality/soil tilth
3. Hydrology of fields
4. History of cultivation
5. History of soil testing, amending, and plant growth responses
6. The use of cover crops: Timing, application rate, and type
7. The use of composts: Timing, application rate, and type
8. The use crop rotation: Timing and type
9. How they budget for nitrogen
10. The use of plant tissue testing: Timing and type
11. The use of supplemental fertilization: Timing, application rate, and type
12. Primary tillage practices used
13. Irrigation practices
14. Any persistent and economically significant problems
  - a) Pests
  - b) Diseases
  - c) Plant growth responses
  - d) Crop quality concerns

### B. Field Observations

1. Deficiencies: Are there major or micro-nutrient deficiencies evident from the soil analysis? Are they also evident in the field?
2. Excesses: Are there major or micronutrient imbalances evident from the soil analysis (including those that cause poor soil physical conditions or toxicity such as...)? Are they also evident in the field?
3. Soil physical condition: How is the tilth of the soil? Is it cloddy or cracked, does it take tillage to achieve loose soil? Is there a compacted plow or disc pan 6 to 12 inches below the surface? Is the soil well aggregated?
4. Organic matter: Is there evidence of raw OM, an active humus layer, healthy bioactivity?
5. Crop health: Do the plants look healthy and deep green? Do they appear to be overfertilized with nitrogen?
6. Pests and disease: Is there evidence of pests, diseases, or damage from either? Does it appear that the plants are resilient to the damage, or do the crops appear stressed?
7. Water relations: Does the soil appear to have standing water, does it drain well, or have poor water retention? Does the soil stick to shoes when you walk through it? Are farm operations ever performed when it is wet?

# Hands-on Exercise 1: Reading and Interpreting Soil Analysis Reports, Nutrient Budgeting, and Selecting Mineral and Organic Matter Soil Amendments

*for the student*

## INTRODUCTION

*In this exercise you will be asked to read and interpret a sample soil analysis report and practice formulating a basic fertility program for meeting short- and long-term soil fertility and plant nutrition goals. Using the Step-by-Step Instructions from Demonstration 2 and the reference materials listed below, you will generate a basic soil fertility management plan in which you will: define any potential limiting nutrients and/or soil chemical imbalances; calculate application rates of needed soil amendments to make necessary adjustments to soil chemical properties; select any needed supplemental fertilizers, and; develop a basic nitrogen budget for a hypothetical organic production system.*

NOTE: It is **CRITICAL** that one confirms the specific “optimal” levels used in this unit with those used by your local testing service. The optimal levels presented in this unit are examples of those used by many A & L National Agricultural Laboratories.

## PLEASE INCLUDE THESE COMPONENTS IN YOUR SOIL FERTILITY MANAGEMENT PLAN:

- A description of the relevant agronomic characteristics of the sampled soil
- The identification of any potentially limiting and/or excess nutrients found in the soil
- The selection of the type, quantities and costs of soil amendments that may be used to address limited or imbalanced soil nutrient levels
- The selection of the type, quantities and costs of supplemental fertilizers that may be used to address limited or imbalanced soil nutrient levels
- Development of a nitrogen budget for your crop(s) including suggested application rates of compost, selected cover crop species and their seeding rates (see appendix 4, Nitrogen Budgeting Worksheet)
- A summary of your findings including a timeline for the implementation of both short- and long-term elements of your soil fertility management plan

## PREPARATIONS AND MATERIALS

- Sample soil analysis report
- Step-by-Step Instructions from Demonstration 2 (pp. 31–34)
- Calculator
- Appendix 2, Nutrient Budgeting Worksheets
- Appendix 4, Nitrogen Budgeting Worksheet Exercise
- Appendix 5, Supplemental Fertilizer Worksheet
- Appendix 6, Optimal Nutrient Levels of Major Cations Based on CEC
- Appendix 7, Nutrient Content of Common Fertilizers and Amendments
- Appendix 8, Fertilizer Solutions Chart
- Appendix 9, Approximate Pounds/Acre of Nutrients Removed by Common Crops
- Agricultural supply catalogues with listing of soil amendments (see Resources section)





# Assessment Questions

1. What are the effects of excess nitrogen on crops and in the environment?
2. Give examples of raw organic matter.
3. Explain the difference between compost and other sources of organic matter.
4. Which nutrients affect pest and disease susceptibility?
5. In general, what is the minimum fertility program for sustainable production?



# Assessment Questions Key

1. What are the effects of excess nitrogen on crops and in the environment?

*Elongated cells with thinner cell walls, excess growth and vigor, increased susceptibility to pests and diseases, poor storage quality. Excess nitrogen released into the environment may lead to the eutrophication of aquatic ecosystems and the contamination of ground water.*

2. Give examples of raw organic matter.

*Leaves and leaf litter, crop stubble, manures, sawdust, plant and animal remains, cover crops and other undigested/undecomposed organic matter*

3. Explain the difference between compost and other sources of organic matter.

*Compost is aerobically decomposed organic matter; most other sources are raw organic materials that require digestion in the soil medium. Raw organic matter may take 3–6 weeks+ to break down and release nutrients, resulting in the temporary depression of soil nitrogen levels and the possibility of plant nitrogen deficiencies.*

4. Which nutrients affect pest and disease susceptibility?

*They all do. Excess nitrogen and imbalances of phosphorus, potassium, and/or calcium are generally more suspect in pest and disease problems.*

5. In general, what is the minimum fertility program for sustainable production?

*Replacement of nutrients removed by the crop.*

6. Explain the concepts of Cation Exchange Capacity and Cation Saturation Ratios (CSR).

*The clay and humus particles in the soil have a negative charge. Positively charged ions (e.g., of Ca, Mg, K, Na, H, etc.) are adsorbed to the surfaces of clay and humus, where they can be exchanged with other cations in the soil solution, on plant roots or held tightly, depending on conditions. CSR is the ratio of Ca, Mg, K, and Na on the exchange sites, and is a major factor in soil fertility and structure.*

7. What are several advantages of optimum soil cation balance?

*Optimum soil tilth, aeration, drainage, nutrient availability, biological activity, organic matter breakdown, and minimized toxic elements*

8. What are the three primary sources of nitrogen factored into a nitrogen budget for an organic farming system?

*Compost, the estimated nitrogen release (ENR) from soil organic matter, and the nitrogen contributed by nitrogen-fixing cover crops*

# Resources

## SUGGESTED READINGS

A and L Western Agricultural Laboratories, Inc. Reference Guides: “Soil Sampling” and “Soil Analysis” 1311 Woodland Ave. #1 Modesto, CA 95351. 209.529-4080.

*The two four-page pamphlets above provide an overview of basic soil sampling procedures and the soil properties measured in an A and L soil analysis report. Available from [www.al-labs-west.com/index.html](http://www.al-labs-west.com/index.html).*

Gaskell, Mark, Jeff Mitchell, Richard Smith, Steven Koike, and Calvin Fouche. 2000. *Soil Fertility Management for Organic Crops*. Publication 7249. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A brief four-page overview of soil fertility for organic production systems. Available on-line in PDF format from [anrcatalog.ucdavis.edu](http://anrcatalog.ucdavis.edu).*

## PRINT RESOURCES

A and L Western Agricultural Laboratories, Inc. *Agronomy Handbook: Soil And Plant Analysis*. Modesto, CA: California Laboratory.

*A concise and practical handbook designed to be used in association with A and L soil analysis testing services. Provides an overview of general properties of soils and recommendations on the management of all essential soil and plant nutrients. Includes useful tables on crop removal estimates, crop deficiency symptoms, nutrient composition of common fertilizers and amendments comprehensive section on plant analysis.*

Albrecht, William A., and C. Walters (editors). 1975. *The Albrecht Papers, I, II and III*. Raytown, MO: Acres USA.

*Provides an overview of William Albrecht’s agronomic research and outlines the rationale behind his suggestions of base cation saturation ratios.*

California Fertilizer Association. 2001. *The Western Fertilizer Handbook, Ninth Edition*. Thomson publications.

*This handbook presents fertilization, nutrient management, and related topics based on the fundamentals of biological and physical sciences.*

Magdoff, Fred, and Harold Van Es. 2000. *Building Soils for Better Crops. Second Edition*. Handbook Series Book 4, Sustainable Agriculture Network. Beltsville, MD: National Agricultural Library.

*An introductory overview of organic management of soil fertility covering the basics of soil organic matter, physical, and chemical properties of soil, ecological soil and crop management. Practical and accessible information. Available from [www.sare.org](http://www.sare.org).*

Miller, P. R., W.L. Graves. et al. 1989. *Cover Crops for California Agriculture*. Leaflet 21471. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A concise overview of the common cover crops use in California agriculture. Addresses annual and perennial cropping systems.*

Sprague, H., ed. 1964. *Hunger Signs in Crops*. New York: David Mckay Company.

*Discusses the visual signs of nutrient deficiencies in various crops.*

Traynor, J. 1980. *Ideas in Soil and Plant Nutrition*. Bakersfield, CA: Kovak Books.

UC Division of Agriculture and Natural Resources. 1998. *Cover Cropping in Vineyards*. Publication 3338. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*A technical introduction to the use of cover crops in California vineyards. Covers agronomic and economic aspects of cover crop use.*

Young, G. 1999. "Training Manual for Soil Analysis Interpretation in Northern California." Master's Thesis, California State University, Sonoma.

*A thesis project developed for teaching farmers and extension agents how to read and interpret soil analysis reports. Includes summaries of studies of fertilizer use trends in northern California and those linking over fertilization with pest and disease problems. Emphasizes the research and recommendations of William Albrecht.*

#### WEB RESOURCES

Alternative Farming Systems Information Center, USDA

[www.nal.usda.gov/afsic/](http://www.nal.usda.gov/afsic/)

*Technical information on organic farming, sustainable agriculture, community supported agriculture. Access to National Agricultural Library to research journal article abstracts and order articles.*

Appropriate Technology Transfer for Rural Areas  
[www.attra.org/](http://www.attra.org/)

*A national sustainable farming information center. Information on sustainable farming production practices, alternative crop and livestock enterprises, innovative marketing. List of web sites on soil quality, with over 50 links and references on soil fertility*

Bob Lippert's Frequently Asked Questions Regarding Soil Testing, Plant Analysis, and Fertilizers, Department of Crop and Soil Environmental Science, Clemson University

[hubcap.clemson.edu/~blpprt/bobweb/bobweb.html](http://hubcap.clemson.edu/~blpprt/bobweb/bobweb.html)

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*Contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Commercial Organic Nutrient Recommendations, University of Maine Soil Testing Service and Analytical Lab

[anlab.umesci.maine.edu/handout/organ01.HTM](http://anlab.umesci.maine.edu/handout/organ01.HTM)

Evaluating Microbiology of Compost (Vicki Bess, *BioCycle*, May 1999; Vol. 40, Issue 5)

[www.jgpress.com](http://www.jgpress.com)

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This sustainable agriculture education resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

Fertilizer Recommendations for Horticultural Crops  
[www.hortnet.co.nz/publications/guides/fertmanual/dguide1.htm](http://www.hortnet.co.nz/publications/guides/fertmanual/dguide1.htm)

*Information and photos of specific crop nutrient deficiencies*

Interpreting Missouri Soil Test Reports, University of Missouri-Columbia

[muextension.missouri.edu/xplor/agguides/soils/g09112.htm](http://muextension.missouri.edu/xplor/agguides/soils/g09112.htm)

Interpreting Soil Test Results for Commercial Crops, University of Maine Soil Testing Service and Analytical Lab

[anlab.umesci.maine.edu/combk/comm0.HTM](http://anlab.umesci.maine.edu/combk/comm0.HTM)

Nutrient Management for Commercial Fruit and Vegetable Crops in Minnesota, University of Minnesota

[www.extension.umn.edu/Documents/D/C/DC5886.html](http://www.extension.umn.edu/Documents/D/C/DC5886.html)

Ohio Agronomy Guide, Bulletin 472: Soil Fertility  
[www.ag.ohio-state.edu/~ohioline/b472/fertile.html](http://www.ag.ohio-state.edu/~ohioline/b472/fertile.html)

Organic Materials Review Institute  
[www.omri.org](http://www.omri.org)

*A list of materials compatible in organic farming, brand name review, technical information.*

Peaceful Valley Farm Supply  
[www.groworganic.com](http://www.groworganic.com)  
*A catalogue of tools and supplies and technical support for organic farmers and gardeners.*

Philosophy of Soil Testing, National Corn Handbook, Purdue University  
[www.agcom.purdue.edu/AgCom/Pubs/](http://www.agcom.purdue.edu/AgCom/Pubs/)

Selecting an Analytical Laboratory, Colorado State University  
[www.ext.colostate.edu/pubs/crops/00520.html](http://www.ext.colostate.edu/pubs/crops/00520.html)

Soil Fertility Test Interpretation: Phosphorus, Potassium, Calcium, Magnesium, Rutgers Cooperative Extension Service  
[www.rce.rutgers.edu:80/ag/](http://www.rce.rutgers.edu:80/ag/)

Soil Sampling for High Yield Agriculture  
[www.back-to-basics.net/efu/pdfs/sampling.pdf](http://www.back-to-basics.net/efu/pdfs/sampling.pdf)  
*An illustrated overview of basic soil sampling techniques.*

Soil Test Explanation, Colorado State University  
[www.ext.colostate.edu/pubs/crops/00502.html](http://www.ext.colostate.edu/pubs/crops/00502.html)

Soil Test Interpretations, New Mexico State University  
[www.cahe.nmsu.edu/pubs/\\_a/ /a-122.html](http://www.cahe.nmsu.edu/pubs/_a/ /a-122.html)

Soil Testing and Nutrient Management, A Basic Guide for Interpreting Soil Test Values, Woods End Agricultural Laboratory  
[www.woodsend.org/brinton2.pdf](http://www.woodsend.org/brinton2.pdf)

Soil Testing Handbook for Professionals in Agriculture, Horticulture, Nutrient and Residuals Management, 3rd Edition. University of Maine Soil Testing Service and Analytical Lab  
[anlab.umesci.maine.edu/handbk/part0.htm](http://anlab.umesci.maine.edu/handbk/part0.htm)

Something to Grow On: Nutrient Management, the Key to Successful Nursery Crop Production, Cornell University

[www.hort.cornell.edu/department/faculty/good/growon/index.html](http://www.hort.cornell.edu/department/faculty/good/growon/index.html)

UC Sustainable Agriculture Research and Education Program (UC SAREP)  
[www.sarep.ucdavis.edu/soil/websites.htm](http://www.sarep.ucdavis.edu/soil/websites.htm)

*Sustainable agriculture news, technical information, grant programs, Biologically Integrated Farming Systems (BIFS) program.*

Understanding the Numbers on Your Soil Test Report, University of Arkansas  
[www.uaex.edu/Other\\_Areas/publications/](http://www.uaex.edu/Other_Areas/publications/)

Understand Your Soil Test: Calcium, Magnesium, Boron, Copper, Chlorine, Molybdenum, University of Nebraska  
[www.ianr.unl.edu/pubs/Soil/g165.htm](http://www.ianr.unl.edu/pubs/Soil/g165.htm)

USDA National Organic Program.

[www.ams.usda.gov/nop/](http://www.ams.usda.gov/nop/)  
*Regulations on certification, materials, and labeling for organic producers and processors.*

# Appendix 1: Sample (blank) Soil Analysis Report

(Numbers refer to headings in Lecture 2 Outline)

ACME Agricultural Laboratories, Inc. Sample/Lab Number: \_\_\_\_\_

- |                               |                                     |                              |                     |
|-------------------------------|-------------------------------------|------------------------------|---------------------|
| 1                             | % Organic Matter                    |                              | _____ %             |
| 2                             | ENR                                 |                              | _____               |
| PHOSPHORUS                    |                                     |                              |                     |
| 3a                            | P1                                  |                              | _____ ppm Weak Bray |
| 3b                            | P2                                  |                              | _____ ppm Reserve   |
| 4                             | Potassium                           | K                            | _____ ppm           |
| 5                             | Magnesium                           | Mg                           | _____ ppm           |
| 6                             | Calcium                             | Ca                           | _____ ppm           |
| 7                             | Sodium                              | Na                           | _____ ppm           |
| 8                             | pH                                  |                              | _____ Soil          |
| 9                             | pH                                  |                              | _____ Buffer Index  |
| 10                            | Hydrogen                            | H                            | _____ meq/100 g     |
| 11                            | CEC                                 |                              | _____ meq/100 g     |
| PERCENT BASE SATURATION       |                                     |                              |                     |
| 12a                           | Potassium                           | K                            | _____ % K           |
| 12b                           | Magnesium                           | Mg                           | _____ % Mg          |
| 12c                           | Calcium                             | Ca                           | _____ % Ca          |
| 12d                           | Hydrogen                            | H                            | _____ % H           |
| 12e                           | Sodium                              | Na                           | _____ % Na          |
| 13                            | Nitrate Nitrogen                    | NO <sub>3</sub> <sup>-</sup> | _____ ppm           |
| 14                            | Sulfate Sulfur                      | SO <sub>4</sub> <sup>-</sup> | _____ ppm           |
| MICRONUTRIENTS/TRACE ELEMENTS |                                     |                              |                     |
| 15a                           | Zinc                                | Zn                           | _____ ppm           |
| 15b                           | Manganese                           | Mn                           | _____ ppm           |
| 15c                           | Iron                                | Fe                           | _____ ppm           |
| 15d                           | Copper                              | Cu                           | _____ ppm           |
| 15e                           | Boron                               | B                            | _____ ppm           |
| 16                            | Excess Lime Rate                    |                              | _____               |
| 17                            | Soluble Salts                       |                              | _____ mmhos/cm      |
| 18                            | Chloride                            | Cl                           | _____ ppm           |
| 19                            | Particle Size Analysis              |                              | _____               |
|                               | (Soil Texture: %Sand, %Silt, %Clay) |                              |                     |





# Appendix 2: Nutrient Budgeting Worksheets

REPORT NO. \_\_\_\_\_

NAME \_\_\_\_\_ DATE SAMPLED \_\_\_\_\_ SOIL DEPTH SAMPLED: 0 - 12" \_\_\_\_\_

FIELD I.D. \_\_\_\_\_ CROP \_\_\_\_\_ SOIL TEXTURE \_\_\_\_\_

% ORGANIC MATTER \_\_\_\_\_ PH \_\_\_\_\_ CO<sub>3</sub> \_\_\_\_\_ HCO<sub>3</sub> \_\_\_\_\_ CATION EXCHANGE CAPACITY (CEC) \_\_\_\_\_

**SOIL CATIONS**

	CALCIUM (Ca)	MAGNESIUM (Mg)	POTASSIUM (K)	SODIUM (Na)	HYDROGEN (H)	
<b>A</b> ppm tested						
<b>B</b> ppm optimal range				na	na	
<b>C</b> Conversion factor ppm to lbs/acre (to 13-14")	x 4	x 4	x 4.8	na	na	
<b>D = B x C</b> lbs/acre optimal range				na	na	
<b>E = A x C</b> lbs/acre tested				na	na	
<b>F = D - E</b> lbs/acre of nutrient required				na	na	
<b>G</b> VL Low Med Hi VH						
<b>H</b> % CSR tested (cation saturation ratio)						
<b>I</b> % CSR optimal	65 – 75%	5 – 10%	3 – 5%	0 – 5%	0 – 20%	
<b>J</b> Soil amendment to be used				na	na	
<b>K</b> Nutrient content by %				na	na	
<b>L = F/K</b> lbs/acre amendment required				na	na	
<b>M = L/2000 or M = L/440</b> tons/acre or lbs/100 sq-ft of amendment needed				na	na	
<b>N</b> Price per unit				na	na	
<b>O</b> acre or sq ft				na	na	
<b>P</b> Total cost/amendment						<b>Total cost of amendments</b>



## Appendix 2 (cont'd): Nutrient Budgeting Worksheets – Macronutrients

MACRONUTRIENTS	P1 (P <sub>2</sub> O <sub>5</sub> -P) Available	P2 (NaHCO <sub>3</sub> -P) (Olsen method)	SULFUR (SO <sub>4</sub> -S)	NITROGEN (NO <sub>3</sub> -N)	
<b>A</b> ppm tested					
<b>B</b> ppm optimal range	30 – 40	12 – 15 (at pH of 7.0)	15 – 20		
<b>C</b> conversion factor ppm to lbs/acre (to 13–14")	x 9.2	x 9.2	x 12		
<b>D = B x C</b> lbs/acre optimal range	150 – 250	110 – 138	135 – 185		
<b>E = A x C</b> lbs/acre total present					
<b>F = D - E</b> pounds/acre of nutrient required					
<b>G</b> VL Low Med Hi VH					
<b>H</b> % CSR tested	na		na		
<b>I</b> % CSR optimal	na		na		
<b>J</b> Soil amendment to be used					
<b>K</b> Nutrient content by %					
<b>L = F/K</b> lbs/acre amendment required					
<b>M</b> tons/acre or lbs/100 sq ft of amendment needed					
<b>N</b> Price per unit					
<b>O</b> acres or sq ft					
<b>P</b> Total cost /amendment					<b>Total cost of amendments</b>



## Appendix 2 (cont'd): Nutrient Budgeting Worksheets – Micronutrients

MICRONUTRIENTS	ZINC (Zn)	MANGANESE (Mn)	IRON (Fe)	COPPER (Cu)	BORON (B)	
<b>A</b> ppm tested						
<b>B</b> ppm optimal range	1.1 – 3.0	9 – 12	11 – 16	0.9– 1.2	0.6– 1.2	
<b>C</b> conversion factor ppm to lbs/acre (to 13–14")	x 4	x 4	x 4	x 4	x 4	
<b>D = B x C</b> lbs/acre optimal range	4 – 12	36 – 48	44 – 64	3.6 – 4.8	2 – 4	
<b>E = A x C</b> lbs/acre total present						
<b>F = D - E</b> pounds/acre of nutrient required						
<b>G</b> VL Low Med Hi VH						
<b>H</b> % CSR tested	na	na	na	na	na	
<b>I</b> % CSR optimal	na	na	na	na	na	
<b>J</b> Soil amendment to be used						
<b>K</b> Nutrient content by %						
<b>L = F/K</b> lbs/acre amendment required						
<b>M = L/2000 or M = L/440</b> tons/acre or lbs/100 sq ft of amendment needed						
<b>N</b> Price per unit						
<b>O</b> acres or sq ft						
<b>P</b> Total cost/amendment						<b>Total cost of amendments</b>



# Appendix 3: Example of a Nitrogen Budget

NITROGEN REMOVAL		1) 150 lbs N/acre (spinach) (Estimated total N lost to crop removal)
NITROGEN CONTRIBUTIONS		
Soil Organic Matter Estimated Nitrogen Release (ENR) Example ENR: 110 lbs/ac	<ul style="list-style-type: none"> <li>Use 60–80% of Estimated Nitrogen Release (ENR) on Soil Test for annual and perennial crops, respectively.</li> <li>110 lbs/acre (110 x .60) = 66 lbs/acre of actual N</li> </ul>	2) 66 lbs N/acre (Estimated nitrogen released in the first year from soil organic matter)
Compost  * Moist compost is ~35% moisture by weight. This needs to be subtracted from the total compost weight. (0.35 x total compost weight = amount to subtract from total to get dry weight)	<ul style="list-style-type: none"> <li>Average application rate: 5–7 tons/acre/year of compost</li> <li>~1 % nitrogen content</li> <li>10,000–14,000* lbs x .01 = 65–91 lbs actual N</li> <li>with ~50% available in the first year = 32.5–45 lbs N</li> </ul>	3) 32.5–45 lbs N/acre (Estimated nitrogen released N released in the first year from compost)
Legume Cover Crops	<ul style="list-style-type: none"> <li>Estimated N fixation by Bell Beans = 100 lbs/ acre</li> <li>Estimated % N Available in first season after incorporation = 50%</li> <li>100 lbs X .50 = 50 lbs estimated lbs of actual N available in first season after incorporation</li> </ul>	4) 50 lbs. N/acre (Estimated N contribution of fabaceous cover crops)
Total Available Nitrogen	<ul style="list-style-type: none"> <li>66 lbs + 45 lbs + 50 lbs = 161 total lbs of actual N/acre</li> </ul>	5) 161 lbs N/acre (Estimated total available nitrogen/acre)
Calculating Additional Nitrogen Needs	<ul style="list-style-type: none"> <li>Line 1 (Total N lost to crop removal) – Line 5 (Total Available Nitrogen)</li> <li>150 lbs – 161 lbs = 11 lbs N/acre surplus. No supplemental N needed</li> </ul> <p>Note: Seasonal environmental conditions (e.g., cool and wet soils) may create growing conditions that may depress mineralization and N availability, thereby creating a demand for supplemental fertilizer despite the presence of adequate quantities of N in the soil. This relatively low excess should not lead to losses to the environment if nutrient release is properly timed with crop demand.</p>	





# Appendix 4: Nitrogen Budgeting Worksheet

<p>NITROGEN REMOVAL</p> <p><i>(See appendix 5 for crop removal estimates)</i></p>		<p>1) _____ lbs.N/acre (Estimated average total N lost to crop removal)</p>
<p>NITROGEN CONTRIBUTIONS</p>		
<p>Soil Organic Matter Estimated Nitrogen Release (ENR) <i>(See soil analysis report for ENR figures)</i></p>	<ul style="list-style-type: none"> <li>• Estimated Nitrogen Release (ENR) on Soil Test _____ x 60–80% (for annual and perennial crops, respectively)</li> </ul>	<p>2) _____ lbs.N/acre (Estimated nitrogen released in the first year from soil organic matter)</p>
<p>Compost</p> <p>* Moist compost is ~35% moisture by weight. This needs to be subtracted from the total compost weight. (0.35 x total compost weight = amount to subtract from total to get dry weight)</p>	<ul style="list-style-type: none"> <li>• Application rate: _____ tons/acre/year of compost</li> <li>• Average N content of compost = _____%</li> <li>• _____ lbs. compost* x %N of compost = _____ lbs. actual N applied</li> <li>• Average N available in the first year = 50%</li> <li>• _____ lbs. actual N applied x .050 = ENR of compost</li> </ul>	<p>3) _____ lbs N/acre (Estimated nitrogen released N released in the first year from compost)</p>
<p>Legume Cover Crops <i>(See Unit 1.6 for estimating N contribution of cover crops)</i></p>	<ul style="list-style-type: none"> <li>• Estimated N fixation by cover crop = _____ lbs/ acre</li> <li>• Estimated % N Available in first season after incorporation = 50%</li> <li>• _____ lbs. X .50 = _____ lbs. estimated lbs of actual N available in first season after incorporation</li> </ul>	<p>4) _____ lbs. N/acre (Estimated N contribution of fabaceous cover crops)</p>
<p>Total Available Nitrogen</p>	<ul style="list-style-type: none"> <li>• _____ lbs. + _____ lbs. + _____ lbs. = _____ total lbs of actual N/acre</li> </ul>	<p>5) _____ lbs. N/acre (Estimated total available nitrogen/acre)</p>
<p>Calculating Additional Nitrogen Needs</p>	<ul style="list-style-type: none"> <li>• Line 1 _____ (Total N lost to crop removal) – Line 5 _____ (Total Available Nitrogen)</li> </ul>	<p>6) _____ lbs. N/acre (Total needed supplemental nitrogen in lbs./acre)</p>

\* Note on the accuracy of the above mineralization figures: The C:N ratio of organic matter, climate and weather patterns, the presence of lignins and tannins on the organic matter, soil biological activity, soil moisture, and the placement of the organic matter amendments in the soil profile are all influential factors in determining the mineralization rate of organic matter. Therefore, the accuracy of the mineralization rates listed in the Nitrogen Budgeting Worksheet above must be understood in this light and represent only rough estimates.



# Appendix 5: Supplemental Fertilizers Worksheet

POTENTIAL LIMITING NUTRIENTS	FERTILIZER	APPLICATION METHOD	APPLICATION RATE	FREQUENCY OF APPLICATION	TOTAL VOLUME NEEDED	COST/ACRE
TOTAL						



## Appendix 6: Optimum Nutrient Levels (in ppm) of Major Cations Based on CEC

CEC of Soil	Ca 65%	Ca 75%	Mg 10%	Mg 15%	K 3%	K 5%	Na <5%
2	260	300	24	37	23	39	23
3	390	450	37	55	35	59	35
4	520	600	49	73	47	78	46
5	650	750	61	92	59	98	58
6	780	900	73	110	70	118	69
7	910	1050	85	128	82	137	81
8	1040	1200	98	146	94	157	92
9	1170	1350	110	165	105	176	104
10	1300	1500	122	183	117	196	115
11	1430	1650	134	201	129	216	127
12	1560	1800	146	220	140	235	138
13	1690	1950	159	238	152	255	150
14	1820	2100	171	256	164	274	161
15	1950	2250	183	275	176	294	173
16	2080	2400	195	293	187	314	184
17	2210	2550	207	311	199	333	196
18	2340	2700	220	329	211	353	207
19	2470	2850	232	348	222	372	219
20	2600	3000	244	366	234	392	230
25	3250	3750	305	458	293	490	288
30	3900	4500	366	549	351	588	345
35	4550	5250	427	641	410	686	403
40	5200	6000	488	732	468	784	460
TOTAL EXCHANGE CAPACITY	CALCIUM LEVEL should be between these levels		MAGNESIM LEVEL should be between these levels		POTASSIUM LEVEL should be above first and near or below second		SODIUM LEVEL should be below this

Sample calculations:

FOR ANY CEC:	PPM OPTIMUM	MINUS	PPM TESTED	EQUALS	PPM NEEDED
CEC 11	ppm Ca (optimum) 1430 – 1650	-	ppm Ca (tested) 950	=	ppm needed 480 – 700
CEC 11	ppm Mg (optimum) 134 – 201	-	ppm Mg (tested) 287	=	ppm needed 0

To calculate pounds or tons of amendments, multiply amount needed (ppm) by 4 to get pounds per acre-foot. Then divide amount needed in pounds by percent of element in the amendment. Ex:ample: Limestone, 32% Ca; 700 ppm needed x 4 = 2800 pounds/acre foot divided by .32 = 8,750 pounds divided by 2000 pounds = 4.4 tons/ac ft.. To calculate pounds per 1000 square feet (1 foot deep), divide pounds needed (8,750) by 44 = 200 pounds/1000 sq feet.



# Appendix 7: Nutrient Content of Common Fertilizers and Amendments

MATERIAL	% N-P-K	% Ca-Mg-S	MICRO-NUTRIENT	TOTAL LBS NUTRIENTS per 100 lbs	COST per 100 lbs	COST PER LB. OF NUTRIENT	COMMENTS
<b>SYNTHETIC MINERALS</b>							
Ammonium sulfate	21-0-0	0-0-24		45			SOL-AC
Urea	46-0-0	—		46			SOL-AC
Calcium nitrate	15-0-0	19-0-0		34			SOL
Ammonium nitrate	34-0-0	—		34			SOL-AC
Super phosphate	0-20-0	25-0-0		50			SOL
Diammonium phosphate	18-48-0	—		66			SOL-AC
Nutricote	14-14-14	—		34			SOL-AC
Osmacote	14-14-14	—		34			SOL-AC
N-P-K Blend	—						SOL
Potassium sulfate	0-0-50	0-0-18		68			SOL
<b>MINED MINERALS</b>							
Rock Phosphate	0-25-0	25-0-0	+	50			SR
Sulfate of potash	0-0-50	0-0-18	+	68			SR
Greensand	0-2-7	—	+	9			SR
Sulfur	0-0-0	0-0-90	+	90			SR-AC
<b>CALCIUM AMENDMENTS</b>							
Shell limestone	—	39-1-0	+	40			SR
Dolomite	—	20-10-0	+	30			SR
Gypsum	—	22-0-16	+	38			SR
Hydrated (Ag) lime	—	70-0-0		70			SOL
Mined limestone	—	36-1-0	+	37			SR
Hardwood ash	0-2-5	20-2-0	+	29			SOL
<b>ORGANIC MATTER FERTILIZERS &amp; AMENDMENTS</b>							
Fish emulsion	4-2-2	1-0-0	+	9			SOL-RAW
Fish powder	12-1-1	1-0-0	+	15			SOL-RAW
Blood meal	13-0-0	—	+	13			SR-RAW
Cottonseed meal	7-2-2	—	+	11			SR-RAW
Bat guano	10-4-1	1-0-0	+	16			SR-RAW
Chicken manure	3-2-1	3-0-0	+	9			SR-RAW
Steer manure	1-1-1	—	+	3			SR-RAW
Bonemeal	2-15-0	20-0-0	+	37			SR
Mushroom waste	1.5-1-1.5	3-0-0	+	7			SR-RAW
Agricultural compost	1.5-1-1.5	2-0-0	+	6			SR
N-P-K Organic Blend	7-5-7	1-0-0	+	20			SR

SOL Soluble, quick acting, leaches out easily RAW Requires digestion before plant uptake SR Slow release, less leaching AC Acidifies soil





# Appendix 8: Fertilizer Solutions Chart

	** Nitrogen Source, at least 4%	** Phosphorus Source, at least 4%	** Potassium Source, at least 3%	Solution Grade, at least 3%	Foliar / Injectable	Significant Magnesium	Significant Sulfur	Significant Calcium minerals	Contains multiple trace Corrects specific mineral deficiencies	Pelleted or Granulated	* Fast Release = Immediate to 1 month	* Mid release = 1 to 4 months	* Long term release = 4+ months	For correcting low pH	For correcting high pH	Contains significant amounts of humus or humic acids	Used where nematodes are a problem	Contributes to microbial activity
Alfalfa Meal																		
Azomite																		
Bat Guano, High N	•				•	•				•								•
Blood Meal	•							•										•
Bone Meal		•					•											
Brix Mix					•			•			•							
4-4-2	•	•																•
6-6-6	•	•	•								•							•
7-5-7	•		•								•							•
8-5-1	•	•					•				•							•
7-7-2 BioGro Fish Pellets	•	•						•			•							•
9-3-5 BioGro Fish Pellets	•	•	•					•			•							•
Calcium 25					•		•	•			•							
Chicken Manure, Composted		•						•			•					•		•
Compost, New Era, Grover's, Cranford's			•					•				•	•	•	•	•	•	•
Corn Gluten Meal	•										•							•
Cottonseed Meal	•										•							•
Feather Meal	•										•							•
Fish Powder	•				•	•		•			•							•
Fish Meal	•	•									•							•
Fish Emulsion	•							•			•							•
Fish, Eco-Hydrolyzed Liquid	•				•	•		•			•							•
Fish & Kelp, Eco-Growth Liquid					•	•		•			•				•			•
Greensand			•					•				•						•
Kelp, Acadian Liquid			•		•	•		•			•							•
Kelp, Algit								•			•							•
Kelp, Soil Min			•					•				•						•
Kelp, Eco Cold-Processed Liquid					•	•		•			•				•			•
Kelp, Algamin					•	•		•			•							•
Kelp, Maxicrop			•		•	•		•			•							•
Gypsum, Solution Grade					•	•					•				•			•
Gypsum, Mined						•	•					•			•			•
Humate, Activate 80								•				•			•			•
Lime, Oystershell								•				•	•					•
Lime, Solution Grade					•	•		•			•		•					•
Micronized-Cranfords Compost					•	•		•			•				•			•
Micronized Humate-Micro-Hume					•	•		•			•				•			•
Micronized Nutri Min					•	•		•			•							•
Micronized Soft Rock Phosphate		•			•	•		•			•							•
Micronized Shrimp Shell Meal		•			•	•		•			•					•		•
Neem cake	•										•					•		•
Omega 6-6-6	•	•	•		•	•					•							•
Omega 1-5-5		•	•		•	•					•							•
Phytamin 800	•				•	•					•							•
Soft Rock Phosphate		•					•	•				•						•
Seabird Guano, High N	•	•			•	•					•							•
Seabird Guano, High P		•			•	•					•							•
Shrimp Shell Meal	•	•					•	•				•				•		•
Sulfate of Potash, Soluble			•		•	•					•							•
Sulfate of Potash, Standard			•			•						•						•
Sul Po Mag			•			•						•						•
Sul Po Mag, Soluble			•		•	•						•						•
WestBridge BioLink 5-5-5	•	•	•		•	•					•							•
Worm Castings								•				•			•			•

Use Appendix 8 (previous page) as a reference to help you choose fertilizers. Remember, though, that this type of chart has inherent limitations. This chart will be updated with each catalog publication, as new information becomes available. \* The time period mentioned in these categories represents the approximate length of time these fertilizers will last in your soil. Release period will vary, depending upon soil temperatures and biology. \*\*Please note: Fertilizers that do not show a dot for a particular analysis (N-P-K) may still contain smaller amounts of these. ©2003 Peaceful Valley Farm Supply, Inc. Reprinted with permission. Check the following web site for updates: (in the current catalogue) <https://secure.groworganic.com/catalog.html>

## Appendix 9: Approximate Pounds/Acre of Nutrients Removed by Common Crops

CROP	YIELD	NITROGEN	PHOSPHATE	POTASH	CALCIUM	MAGNESIUM	SULFUR
<b>GRAINS</b>							
Corn	200 bu	300	120	260	42	30	32
Rice	150 bu	150	60	160	24	17	18
Soybeans	60 bu	330	72	144	102	14	27
Wheat	74 bu	158	54	120	20	18	17
<b>HAY - LEGUMES</b>							
Alfalfa	10 tons	600	140	500	280	50	50
Vetch	5 tons	275	75	225	120	25	25
<b>HAY - GRASSES</b>							
Coastal Bermuda	10 tons	500	120	350	75	45	60
Timothy	5 tons	180	68	220	40	24	14
<b>FRUITS AND VEGETABLES</b>							
Apples	21 tons	175	75	320	100	40	40
Cabbage	30 tons	195	72	240	72	30	66
Celery	50 tons	260	110	500	130	40	70
Cucumbers	20 tons	180	60	300	160	40	32
Grapes	10 tons	55	20	100	10	7	11
Lettuce	20 tons	140	46	200	56	14	16
Onions	15 tons	90	41	80	24	9	36
Oranges	30 tons	270	60	270	210	52	30
Peaches	15 tons	116	30	150	101	24	21
Pears	20 tons	118	48	174	102	28	25
Potatoes	25 tons	150	75	250	10	12	8
Spinach	15 tons	150	45	90	36	15	12
Tomatoes	30 tons	120	36	210	15	15	21
Turnips	12 tons	154	34	168	65	12	22
Mixed Vegetable Average		130	54	218	78	21	29

From Soil and Plant Analysis, A&L Western Laboratories, 1974; Western Fertilizer Handbook, 1980; Nutrient Deficiencies & Toxicities in Crop Plants, 1993.



# Part 2 Applied Soil Science

Unit 2.1 Soils and Soil Physical Properties

Unit 2.2 Soil Chemistry and Fertility

Unit 2.3 Soil Biology and Ecology



# 2.1 Soils and Soil Physical Properties

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# Introduction: Soils and Soil Physical Properties

## UNIT OVERVIEW

*This unit introduces students to the components of soil and soil physical properties, and how each affect soil use and management. The lecture introduces the components of soil and different concepts of soil and soil physical properties, with special attention to those properties that affect farming and gardening. Through a series of demonstrations and hands-on exercises, students are taught how to determine soil texture by feel and are given the opportunity to examine other soil physical properties such as soil structure, color, depth, and pH. The demonstrations offer an opportunity to discuss how the observed soil properties might affect the use of the soil for farming and gardening.*

## MODES OF INSTRUCTION

- > LECTURE (1 LECTURE, 3.0 HOURS)  
The lecture outline introduces students to the components of soil, and different concepts of soil and soil physical properties, with special attention to those properties that affect farming and gardening.
- > DEMONSTRATION 1: SOIL TEXTURE DETERMINATION (1.0 HOUR)  
Demonstration 1 teaches students how to determine soil texture by feel. Samples of many different soil textures are used to help them practice.
- > DEMONSTRATION 2: SOIL PIT EXAMINATION (1.0 HOUR)  
In Demonstration 2, students examine soil horizons, texture, structure, color, depth, pH, etc. in a large soil pit. Students and the instructor should discuss how the soil properties observed affect the use of the soil for farming, gardening, and other purposes.
- > SUPPLEMENTAL DEMONSTRATIONS AND EXAMPLES (1 HOUR)  
These simple demonstrations offer ideas for using objects, samples, or models to illustrate by way of analogy various soil physical properties.
- > ASSESSMENT QUESTIONS (1.0 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- Components of soil
- Soil physical properties: What are they?
- How soil physical properties affect use

### SKILLS

- How to determine soil texture
- How to recognize different types of soil structure

**REQUIRED READINGS (SEE RESOURCES SECTION)**

Gershuny, Grace. 1993. *Start With the Soil*, Chapter 1; Chapter 2, pp. 27–38; Chapter 8, pp. 187–195; Chapter 9, pp. 200–205

Brady, Nyle C., and R. R. Weil. 1999. *The Nature and Properties of Soils*. Chapter 1, 1.1–1.14 (pp. 1–22)

**RECOMMENDED READINGS**

Stell, Elizabeth P. 1998. *Secrets to Great Soil*. Chapter 1

# Lecture Outline: Soils and Soil Physical Properties

## *for the instructor*

### A. Introduction

1. What is soil?
  - a) Definitions
    - i. Different concepts = Different definitions
      - Edaphological (in relation to plant growth)
      - Engineering
      - Pedological (sees soil as a distinct entity)
  - b) Functions of soil
    - i. Support growth of higher plants
    - ii. Primary factor controlling fate of water in hydrologic system
    - iii. Nature's recycling system
    - iv. Habitat for organisms
    - v. Engineering medium

### B. How Soil Is Made

1. Soil-forming factors
  - a) Time: How long the soil has been forming
  - b) Parent material: E.g., rock, alluvium
  - c) Biotic factors: Plants, animals, microorganisms
  - d) Topography: Slope position, aspect, shape, and amount
  - e) Climate: Temperature, moisture, seasonal distribution
2. Soil profiles and soil development
  - a) Soil horizons
  - b) Soil horizonation
3. What is in soil?
  - a) 40–50% mineral
    - i. Gravel, cobbles, stones, boulders
    - ii. Sand (0.05–2.00 mm)
    - iii. Silt (0.002–0.05 mm)
    - iv. Clay (< 0.002 mm)
  - b) 0–10% biological (see tables 1 and 2 in Detailed Lecture Outline)
    - i. Flora and fauna
    - ii. Live and dead (organic matter)
    - iii. Macroscopic and microscopic
  - c) ~50% pore space
    - i. Air
    - ii. Water
4. Soil classification: 12 Orders

## C. Soil Properties

### 1. Texture

- a) Soil separates (mineral part of soil)
  - i. Sand: Gritty
  - ii. Silt: Floury when dry, greasy when wet
  - iii. Clay (see Baklava demonstration in Supplemental Demonstrations)
- b) Texture triangle
  - i. 12 soil textures

### 2. Structure

- a) What is it?
  - i. Arrangement of soil particles into aggregates
  - ii. Natural vs. man-made (peds vs. clods)
  - iii. Types (shape) (see figure 3, Soil Texture Triangle, in Detailed Lecture Outline)
  - iv. Size: very fine, fine, medium, coarse, very coarse, thick, thin
  - v. Grade
  - vi. Compound structure
    - One structure beside another
    - One structure within another (“parts to...”)
  - vii. Persistence upon wetting and drying—“Aggregate stability”
- b) What causes structure?
  - i. Biological factors/organic matter
  - ii. Clay (type and amount)
  - iii. Calcium and sodium effects
  - iv. Climate (wet/dry, freeze/thaw)

### 3. Pores

- a) What are they and why are they important?
- b) Types of pores
  - i. Interstitial pores: Spaces between mineral grains and peds
  - ii. Tubular pores: Pores made by root or animal activity that are or were at one time continuous
  - iii. Vesicular pores: Bubble-shaped pores
- c) Sizes of pores
  - i. Macropores: Allow free movement of air and water
  - ii. Micropores: Air movement is greatly impeded, water movement is restricted to capillary flow

### 4. Bulk density

- a) What is it?
- b) Importance

### 5. Organic matter

- a) Importance of organic matter
  - i. Structure
  - ii. AWC
  - iii. CEC
- b) Relationship to climate

6. Color
  - a) How it is measured
  - b) Significance of/indicator of:
    - i. Drainage and wetness (redoximorphic features) (show samples)
    - ii. Organic matter
7. Soil depth
  - a) Bedrock
  - b) Densely compacted material (tillage pan)
  - c) Natural hardpans (soil cemented by iron, lime, gypsum, silica, etc.) (show example)
  - d) Strongly contrasting textures (pot effect)
  - e) Water tables
8. Soil temperature
  - a) Factors influencing soil temperature
    - i. Local climate: Soil temperature is highly correlated to air temperature
    - ii. Slope steepness and aspect
    - iii. Topography: Topography influences microclimates
    - iv. Cover: Plants shade the soil, reducing the temperature
    - v. Soil color: Darker-colored soils absorb heat more readily than lighter-colored soils
    - vi. Horticultural practices: Influence of mulches
  - b) Soil temperature influences on soil properties
    - i. Biological activity
    - ii. Organic matter accumulation: Lower temperature, greater organic matter accumulation
    - iii. Weathering of parent materials: Fluctuating temperatures help break down mineral grains; warmer temperatures increase chemical weathering
9. Drainage
  - a) Excessively drained
  - b) Somewhat excessively drained
  - c) Well drained
  - d) Moderately well drained
  - e) Somewhat poorly drained
  - f) Poorly drained
  - g) Very poorly drained
10. Odor
  - a) Indicator of wetness
11. Permeability
  - a) Rate at which water moves through the soil
  - b) Measurement (inches/hour)
  - c) Properties influencing permeability
    - i. Texture (do permeability demonstration in Supplemental Demonstrations)
    - ii. Structure
      - Salts
      - Organic matter
      - Compaction and pores
      - Calcium
      - Soil organisms

- d) Additional properties influencing infiltration
    - i. Dryness
    - ii. Surface fragments
    - iii. Fire
    - iii. Slope
12. Available Water Capacity (AWC)
- a) Field capacity: The amount of water the soil can hold against the flow of gravity (1/3 bar or 33 kPa). (Also see Unit 1.5, Irrigation: Principles and Practices.)
  - b) Wilting point: The moisture level at which the soil can no longer provide moisture for plant growth. (15 bar or 1500 kPa)
  - c) Measurement (inches/inch or inches/foot)
  - d) Properties influencing water-holding capacity
    - i. Texture
    - ii. Salts
    - iii. Organic matter
    - iv. Compaction
    - v. Soil depth
    - vi. Coarse fragments
    - vii. Estimating AWC

# Detailed Lecture Outline: Soils and Soil Physical Properties

## *for students*

### **A. Introduction**

#### 1. What is soil?

##### a) Definitions

###### i. Different concepts = Different definitions

- Edaphological (in relation to plant growth)

A mixture of mineral and organic material that is capable of supporting plant life

- Engineering

Mixture of mineral material (sands, gravels and fines) used as a base for construction

- Pedological (sees soil as a distinct entity)

The unconsolidated mineral or organic material on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. Geosphere-Biosphere-Hydrosphere-Atmosphere interface.

##### b) Functions of soil

###### i. Support growth of higher plants

###### ii. Primary factor controlling fate of water in hydrologic system

###### iii. Nature's recycling system

###### iv. Habitat for organisms

###### v. Engineering medium

### **B. How Soil Is Made**

#### 1. Soil-forming factors

At one time it was felt that soils were static. In the late 1800s, Russian soil scientists introduced the concept that soils are dynamic—that they developed to the point where they are now and that they are evolving into what they will be. They came up with five soil-forming factors that influence how soils turn out the way they do. The idea is that if all five of the soil-forming factors are the same, then the soil will be the same. The technical term used for soil formation is pedogenesis.



Weathering is the term used to refer to the breakdown of rock into smaller and smaller pieces. Two types of weathering are recognized, chemical and mechanical (physical). Mechanical weathering has to do with the breakdown of rock due to physical factors such as temperature fluctuations and freeze/thaw cycles of water. An example would be quartz breaking down to fine sand size particles. (Since quartz is resistant to chemical weathering, it won't get much smaller than this.)

Chemical weathering refers to the breakdown of rock due to chemical reactions. For example, limestone ( $\text{CaCO}_3$ ) and gypsum ( $\text{CaSO}_4$ ) dissolve in water and become smaller and smaller. Micas can lose potassium ions and become vermiculite. Vermiculite, in turn, can lose more potassium and become smectite. Feldspars lose potassium and become kaolinite. In these cases, rock weathers to a microscopic or even elemental state.

- a) Time: How long the soil has been forming
  - b) Parent material: E.g., rock, alluvium
  - c) Biotic factors: Plants, animals, microorganisms
  - d) Topography: Slope position, aspect, shape and amount
  - e) Climate: Temperature, moisture, seasonal distribution
2. Soil profiles and soil development
- a) Soil horizons

Soils consist of one or more distinct layers called horizons. These layers are referred to as O, A, E, B, C and R depending on their position and nature

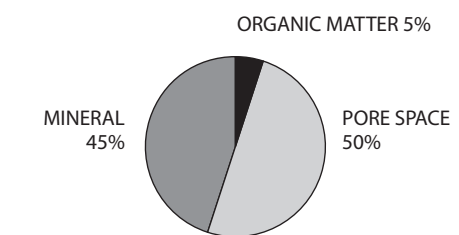
- O: Layers dominated by organic material. Usually not present under warm-dry conditions.
- A: The mineral soil horizon that is usually at the surface or below an O horizon. It usually has more organic carbon than underlying layers. Sometimes this layer is missing or truncated due to erosion or removal. Also, all surfaces resulting from plowing, pasturing, or similar disturbances are referred to as A horizons.
- E: Horizon characterized by eluviation (removal of materials such as silicate clay, iron, aluminum, or organic matter), if distinct from the A horizon. Frequently not present. Usually more pale colored than the A horizon.
- B: A horizon, formed below an A, E, or O horizon, which is dominated by obliteration of all or much of the original rock structure and which shows evidence of soil formation such as illuvial (moved down from an above horizon) concentration of silicate clay, iron, aluminum, humus, carbonates, gypsum, or silica; development of soil color or structure; or brittleness, etc.
- C: Horizons or layers, excluding hard bedrock, that are little affected by pedogenic (soil forming) processes and that lack properties of O, A, E or B horizons.
- R: Hard bedrock

- b) Soil horizonation  
(Talk through a possible scenario, use blackboard)
3. What is in soil? (See figure 2)

**FIGURE 1: THE 12 MOST COMMON ELEMENTS IN THE EARTH'S CRUST**

ELEMENT	% VOLUME	% WEIGHT
$\text{O}^{2-}$	90	47
$\text{Si}^{4+}$	2	27
$\text{Al}^{3+}$	1	7
$\text{Fe}^{2+}$	1	4
$\text{Mg}^{2+}$	1	2
$\text{Ca}^{2+}$	1	3
$\text{Na}^+$	1	2
$\text{K}^{2+}$	1	2
$\text{Ti}^{4+}$	trace	3
$\text{H}^+$	trace	1
$\text{Mn}^{4+}$	trace	1
$\text{P}^{5+}$	trace	1

**FIGURE 2. SOIL COMPOSITION: AN IDEALIZED SOIL**



- a) 40–50% mineral
  - i. Gravel, cobbles, stones, boulders
  - ii. Sand (0.05–2.00 mm)
  - iii. Silt (0.002–0.05 mm)
  - iv. Clay (< 0.002 mm)
- b) 0–10% biological (See tables 1 and 2)
  - i. Flora and fauna
  - ii. Live and dead (organic matter)
  - iii. Macroscopic and microscopic
- c) ~50% pore space
 

Pore space consists of the “empty” spaces in the soil. While this might seem to make the pore space unimportant, in reality it is a very important part of the soil. Pore space might be filled with one of two things:

  - i. Air
  - ii. Water

**TABLE 1. SOIL FAUNA AND THEIR EATING HABITS**

MICROPHYTIC FEEDERS		CARNIVORES SECONDARY CONSUMERS		CARNIVORES TERTIARY CONSUMERS	
ORGANISM	MICROFLORA CONSUMED	PREDATOR	PREY	PREDATOR	PREY
Springtails	Algae* Bacteria* Fungi*	Mites	Springtails* Nematodes* Enchytraeids	Ants	Spiders Centipedes Mites* Scorpions
Mites	Fungi Algae Lichens	Centipedes	Springtails Nematodes Snails* Slugs* Aphids* Flies		Centipedes
Protozoa	Bacteria and other microflora				Beetles
Nematodes	Bacteria Fungi	Moles	Earthworms* Insects		
Termites	Fungi				

\*feed on live plants/plant residues, and/or soil organic matter

**TABLE 2. COMMON POPULATIONS OF SOME SOIL MICROORGANISMS**

ORGANISM	NUMBER PER GRAM OF SOIL
Bacteria	$10^8 - 10^9$
Actinomycetes	$10^7 - 10^8$
Fungi	$10^5 - 10^6$
Algae	$10^4 - 10^5$
Protozoa	$10^4 - 10^5$
Nematoda	$10 - 10^2$

#### 4. Soil classification: 12 Orders

Soil scientists have come up with systems for classifying soils, much like plants and animals are classified. There are currently 4 main classification schemes: Russian, FAO, Canadian, and Soil Taxonomy (Euro-American in origin, but used worldwide). Soil Taxonomy is similar to plant and animal classification in that this classification is based on genesis—how it is thought the soil developed (plants and animals are also classified by how it is thought they originated—genetics). Also, like plant and animal classification systems, Soil Taxonomy is not static. As more is learned, the system changes somewhat.

The highest category of this system is called Orders. Currently there are 12 soil orders (see Table 3).

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**TABLE 3. 12 ORDERS IN SOIL TAXONOMY**

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Alfisols	high base saturation—areas with low rainfall, but wetter than deserts
Andisols	volcanic ash affected
Aridisols	deserts
Entisols	“young” soils (floodplains, mountains, deserts, etc.)
Gelisols	permafrost-affected soils
Histosols	organic soils, common in wet and cold areas (marshes, muskeg, etc.)
Inceptisols	fairly “young” soils—soil development more advanced than Entisols
Mollisols	thick, dark surfaces—humid and sub-humid grasslands (corn belt)
Oxisols	very low fertility, very “old” soils—humid tropics
Spodosols	humid temperate woodlands, acidic
Ultisols	low base saturation—humid warm-temperate, sub-tropics and tropics; low fertility, acidic
Vertisols	high shrink-swell

---

The other categories of the classification system are suborder, great group, subgroup, family, and series. The series corresponds to species in biological classification systems. Series names are usually taken from local geographic features or place names. There are over 20,000 recognized soil series in the U.S. This is an indicator of the tremendous amount of variability there is in soils.

### C. Soil Properties

#### 1. Texture

Non-technical definition: How the soil feels

Technical definition: An expression that characterizes the relative amounts of sand, silt and clay in the soil.

##### a) Soil separates (mineral part of soil)

- i. Sand: gritty
- ii. Silt: floury when dry, greasy when wet

##### iii. Clay

- Morphology

Most clay minerals consist of microscopic layers (see Baklava demonstration in Supplemental Demonstrations and Examples). These are called phyllosilicate minerals. (Phyllo- is from Greek for leaf, as in phyllo dough used to make baklava.)

Different types of clay have different kinds of layers and different properties  
 Some clay minerals are amorphous—without shape. Common in humid temperate woodlands (Spodosols) and volcanic soils (Andisols)

- Properties of clays
  - Sticky (adhesion—sticks to other things) (target demonstration)
  - Plastic (cohesion—sticks to itself) (ribbon demonstration)
  - Shrink-swell (slinky demonstration)
  - Large surface area, due to layers and to size (block demonstration)
  - Cation Exchange Capacity (CEC)
  - Clay has net negative charge, attracts cations (positive ions; ions are broken molecules. Certain ions serve as plant nutrients)
- Characteristics of some clay minerals
  - Kaolinite** 1:1, no shrink-swell, low CEC (3-15 meq/100g), low surface area (5-20 m<sup>2</sup>/g); prevalent in warm, humid areas such as the southeast US
  - Illite** (hydrous mica), 2:1, moderate shrink-swell, medium CEC (15-40 meq/100g); medium surface area (100-120 m<sup>2</sup>/g)
  - Smectite** (montmorillonite) 2:1 high shrink-swell, high CEC (80-110 meq/100g), high surface area (700-800 m<sup>2</sup>/g). Found in younger (less weathered) soils. Common in California.
  - Iron and Aluminum Oxides:** somewhat crystalline, very low CEC (pH dependent), prevalent in tropics and semi-tropics, fixes phosphorus
  - Allophane and Imogolite:** amorphous, moderate CEC (pH dependent, 10-30 meq/100g), prevalent in volcanic ash derived soils, fixes phosphorus

b) Texture Triangle (see Figure 3, next page)

i. 12 soil textures (see Table 4)

**TABLE 4.** 12 SOIL TEXTURES NAMES AND THEIR ABBREVIATIONS

clay	C	sandy loam	SL
sandy clay	SC	loam	L
silty clay	SIC	silt loam	SIL
clay loam	CL	loamy sand	LS
sandy clay loam	SCL	sand	S
silty clay loam	SICL	silt	SI

## 2. Structure

a) What is it?

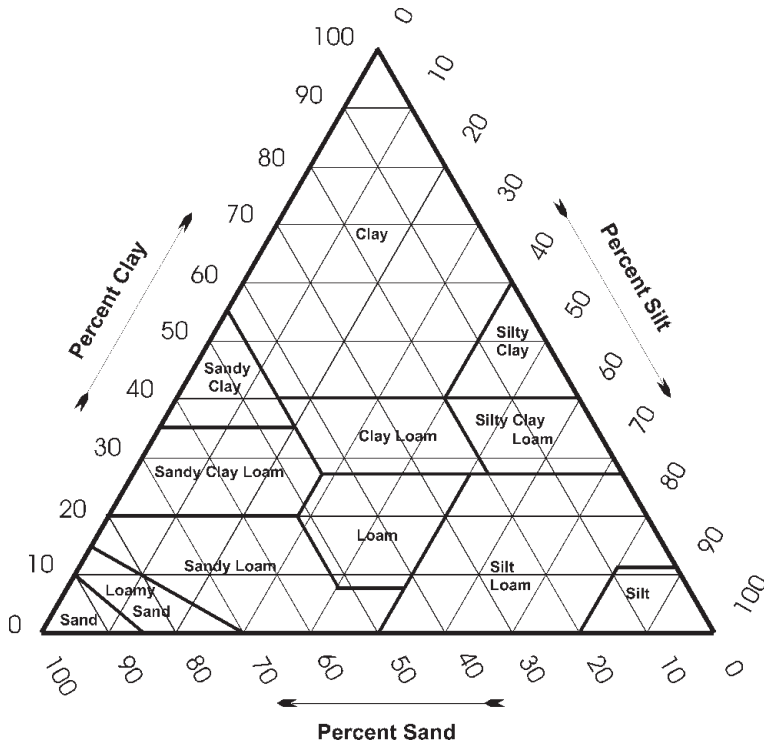
- i. Arrangement of soil particles into aggregates
- ii. Natural vs. man-made (peds vs. clods)
- iii. Types (shape) (See Figure 4, p. 15)
  - Granular
  - Blocky (angular and sub-angular)
  - Platy
  - Columnar and prismatic
  - Single grain (non-structure)
  - Massive (non-structure)

- iv. Size: very fine, fine, medium, coarse, very coarse, thick, thin
- v. Grade
  - Weak: Peds barely observable in place, difficult to distinguish from massive or single grain.
  - Moderate: Peds well formed and evident in undisturbed soil
  - Strong: Peds distinct in undisturbed soil. Peds have distinctive surface features.
- vi. Compound structure
  - One structure beside another
  - One structure within another (“parts to...”)
- vii. Persistence upon wetting and drying—“Aggregate stability”

**TABLE 5.** SIZE CLASSES OF SOIL STRUCTURAL UNITS. THIN AND THICK, RATHER THAN FINE AND COARSE, ARE USED FOR PLATY STRUCTURES.

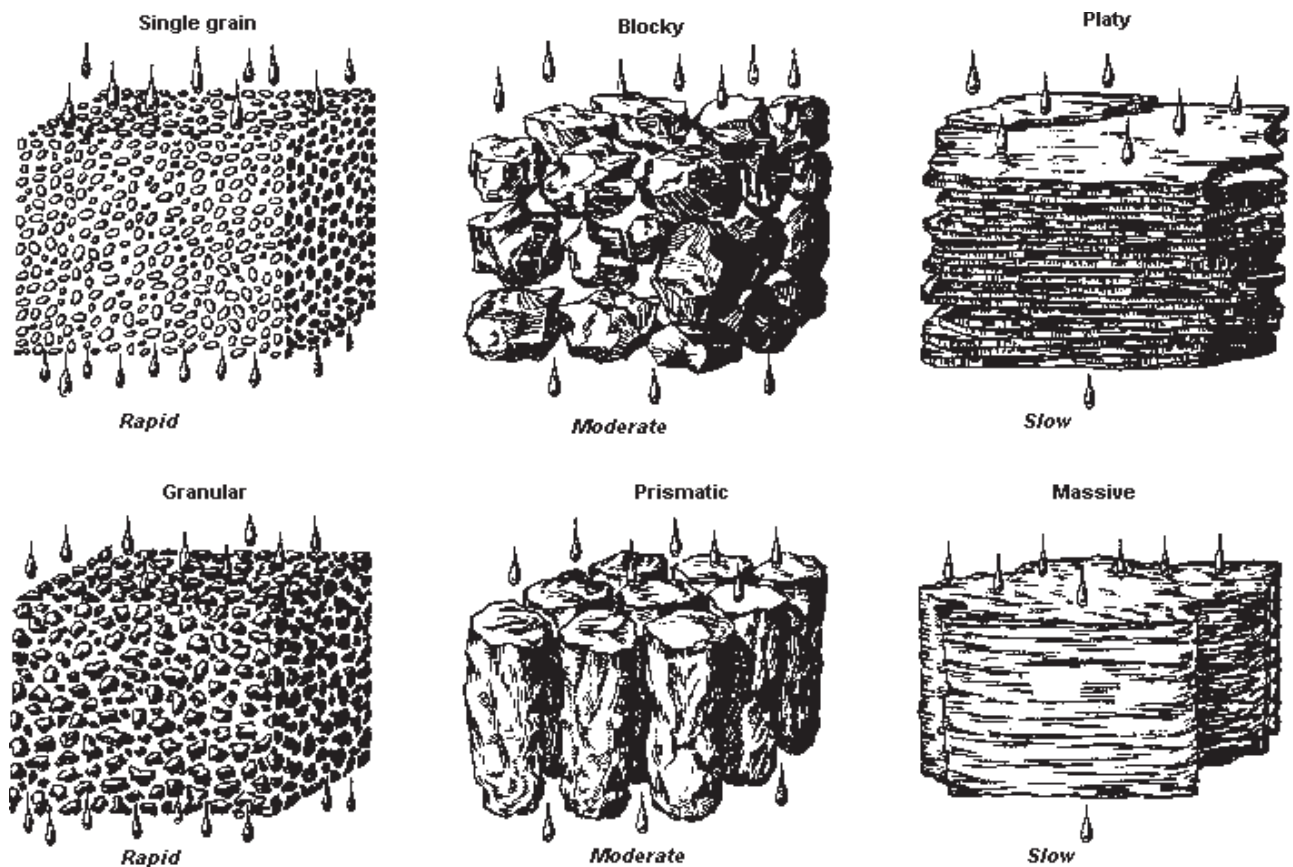
SIZE CLASS	PLATY	COLUMNAR/ PRISMATIC	BLOCKY	GRANULAR
very fine (thin)	<1 mm	<10 mm	<5 mm	<1 mm
fine (thin)	1 – 2 mm	10 – 20 mm	5 – 10 mm	1 – 2 mm
medium	2 – 5 mm	20 – 50 mm	10 – 20 mm	2 – 5 mm
coarse (thick)	5 – 10 mm	50 – 100 mm	20 – 50 mm	5 – 10 mm
very coarse (thick)	>10 mm	>100 mm	>50 mm	>10 mm

**FIGURE 3.** SOIL TEXTURE TRIANGLE



- b) What causes structure?
- i. Biological factors/organic matter
    - Bacterial exudates
    - Root activity and exudates
    - Macrofauna activity and waste
  - ii. Clay (type and amount)
  - iii. Calcium and sodium effects
  - iv. Climate (wet/dry, freeze/thaw)

**FIGURE 4. SOIL STRUCTURE AND ITS EFFECTS ON PERMEABILITY**



### 3. Pores

- a) What are they and why are they important?

Pores are the “holes” or voids in the soils. They are important because air and water move through and are stored in pores. Without air, roots cannot live nor can most microbes that are essential to the proper functioning of a healthy soil.

- b) Types of pores: Three types of pores are generally recognized

- i. Interstitial pores: Spaces between mineral grains and peds
- ii. Tubular pores: Pores made by root or animal activity that are or were at one time continuous
- iii. Vesicular pores: Bubble-shaped pores

- c) Sizes of pores—two basic size classes of pores are recognized, though there is not a particular size limit between them
  - i. Macropores: allow free movement of air and water
  - ii. Micropores: air movement is greatly impeded, water movement is restricted to capillary flow.

#### 4. Bulk Density

##### a) What is it?

The bulk density of the soil (or of anything else) is the (oven dry) weight of a given volume of soil divided by the volume. It is expressed in grams per cubic centimeter. The formula is usually written like this:

$$D_b = M_s/V_t$$

Where  $D_b$  = bulk density

$M_s$  = mass of solids

$V_t$  = total volume

Soil bulk density values range from 0.5 to 3.0 but most values are between 0.8 and 1.8.

Anything denser than about 1.8 is root limiting.

Bulk density is usually determined by coating a mass of soil with a thin layer of plastic; weighing the soil, correcting for moisture content; then determining the volume of that soil by water displacement.

The bulk density of the soil is a reflection of the amount of pore space in the soil. Other factors affecting the bulk density are the types of minerals present (some are heavier than others), the texture (clays are lighter than silts and sands) and the amount of organic matter (organic matter has a really low bulk density compared to mineral grains).

##### b) Importance

Compacted soils have higher bulk densities than non-compacted soils

#### 5. Organic matter

Organic matter consists of dead plant parts and animal and microbial waste products in various stages of decomposition. Eventually, these things break down into humus, which is relatively stable in the soil.

##### a) Importance of organic matter: Although organic matter makes up a minor part of the soil, it has a very strong impact on it

###### i. Structure

Organic matter acts like glue that helps hold soil aggregates together. This will even hold upon wetting.

###### ii. Available Water Capacity (AWC)

Organic matter helps bind water to the soil to keep it from being lost through percolation. This is especially important in sandy soils.

###### iii. Cation Exchange Capacity (CEC)

While the highest CEC you will find in a clay is 160 meq/100g (cmol/kg), humus has a CEC of 100 to 300 meq/100g (cmol/kg) or more

##### b) Relationship to climate

You cannot add large amounts of organic matter to the soil and expect it to persist. There is a maximum equilibrium amount any given soil can hold. This amount is inversely proportional to soil temperature and moisture. That is to say, wetter and colder soils can maintain higher equilibrium amounts of organic matter. Anything added beyond that amount will break down to carbon dioxide and water. The equilibrium amount can be raised to some degree by additions of organic matter, such as in organic gardening situations, but even then it will only go so high. Tropical soils, for example, tend to be nutrient- and organic-matter poor; the nutrient pool tends to be stored in the above-ground biomass (leaves and branches). The muskeg areas of northern Canada, however, contain large amounts of organic matter.

A new practice related to this is being employed to reduce greenhouse gas emissions. Carbon sequestration is the practice of burying organic matter deep in the soil to maximize the amount of organic carbon it contains. To the extent that the soil can hold the organic carbon in equilibrium, it will reduce emissions of CO<sub>2</sub> from the soil.

## 6. Color

### a) How it is measured

Munsell Color Notation (show color book)

### b) Significance of/indicator of:

#### i. Drainage and wetness (Redoximorphic features) (show samples)

Greenish, bluish, and gray colors in the soil indicate wetness. These colors may occur as the dominant color (matrix) or in patches (mottles). The colors are caused by the reduction of iron by bacteria in anaerobic conditions. (The bacteria get the electrons they need for energy from iron rather than from oxygen.) These colors will persist even if the area is drained, so they serve as indicators, not proof.

Bright colors (reds and yellows), on the other hand, indicate well-drained soils. You don't want to have free water (water in excess of the available water capacity) within the rooting depth of your plants during the growing season. It is possible for a soil with bright colors to still have wetness problems if the groundwater is moving fast enough and if it has sufficient oxygen or if it is too cold for biological activity.

#### ii. Organic matter

Dark colors in the soil usually indicate organic matter. They may also indicate wetness (remember, wetter soils can accumulate more organic matter). Sometimes, the color may be derived from the parent material. This is often the case in soils derived from basic (dark-colored) igneous rock.

## 7. Soil depth

It is important to know the depth of the soil. The depth determines how far the roots can grow and how much water the soil can hold. Depth is measured to the shallowest root-limiting layer. Some things that may limit depth are:

### a) Bedrock

### b) Densely compacted material (tillage pan)

Tillage pans are formed when farm implements repeatedly pass through the soil at the same depth. This action causes soil particles to be pressed closer together, reducing the amount of pore space and the size of the pores. Consequently, these pans have permeability rates lower than that of the soil above and below it.

A soil may be plowed or ripped to tear up natural or tillage pans and to increase the pore space in the soil. Also, deep-rooted cover crops might be used (see Unit 1.6, Selecting and Using Cover Crops). In a gardening context, double digging might be used (see Unit 1.2, Garden and Field Tillage and Cultivation).

The benefits of using some kind of tillage to break up soil compaction don't last forever. And while it is more difficult to break up compaction in a finer textured soil, the benefits will last longer than they will in a coarse textured soil. In a coarse textured soil, such as a sandy loam, most of the pore space added by plowing or ripping will be lost by the end of one cropping season.

### c) Natural hardpans (soil cemented by iron, lime, gypsum, silica, etc.) (Show example)

### d) Strongly contrasting textures (pot effect; usually found in floodplain soils)

### e) Water tables



## 8. Soil temperature

Soil temperature is important to gardeners, especially when it comes to spring planting. Many seeds need a certain minimum temperature before they will germinate.

### a) Factors influencing soil temperature

- i. Local climate: Soil temperature is highly correlated to air temperature
- ii. Slope steepness and aspect: In the Northern Hemisphere, north-facing aspects tend to be cooler than south-facing aspects. The effect is more pronounced with steeper slopes and lower relative humidity.
- iii. Topography: Topography influences microclimates. For example, cool air flows down from mountaintops along drainages and settles in low parts of valleys. Soil and air temperature in these drainages and low areas may be lower than the elevated areas adjacent to them. This is readily apparent in the "citrus belt" in the San Joaquin Valley.
- iv. Cover: Plants shade the soil, reducing the temperature. In addition, growing plants cool the temperature through transpiration.
- v. Soil color: Darker-colored soils absorb heat more readily than light-colored soils
- vi. Horticultural practices: Mulching reduces heat by reducing *insolation*—the absorption of heat when it's sunny and can also act as an *insulator*—holding in heat in extremely cold weather

### b) Soil temperature influences on soil properties

- i. Biological activity: Lower temperature = lower biological activity. Below about 40°F there is little biological activity.
- ii. Organic matter accumulation: Lower temperature = higher organic matter accumulation.
- iii. Weathering of parent materials: Fluctuating temperatures help break down mineral grains. Warmer temperatures increase chemical weathering.
- iv. Nutrient availability: Many nutrients are unavailable or poorly available at low temperatures, especially phosphorus. (This is primarily related to biological activity.)

## 9. Drainage

Soil drainage or drainage classes is a way of expressing the frequency and duration of periods in which the soil is saturated (has free water or water in excess of field capacity). Excess free water in the root zone can kill plants or keep them from becoming established. The U.S. Department of Agriculture recognizes seven natural drainage classes (from the Soil Survey Manual):

### a) Excessively drained

Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have very high hydraulic conductivity or are very shallow. These soils tend to be droughty.

### b) Somewhat excessively drained

Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have high saturated hydraulic conductivity or are very shallow.

### c) Well drained

Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.

d) Moderately well drained

Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m, periodically receive high rainfall, or both.

e) Somewhat poorly drained

Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.

f) Poorly drained

Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity or nearly continuous rainfall, or of a combination of these.

g) Very poorly drained

Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.

10. Odor

a) Indicator of wetness

When soils are waterlogged, bacteria will get their oxygen from sulfur. This will release hydrogen sulfide gas. This accounts for the sulfur smell prevalent around salt marshes.

11. Permeability

a) Rate at which water moves through the soil

Permeability is the rate at which water moves down through the soil. It is usually measured in inches per hour. Infiltration is the rate at which water enters the soil. It is similar to permeability, except that it also takes into account surface conditions such as soil crusting. Permeability and infiltration rates affect the rate at which you can safely apply water to the field. Applying water faster than the permeability and infiltration rates can lead to sealing of the soil surface, which further decreases infiltration rates; it can also cause ponding, which increases the possibility of diseases; and it can lead to runoff, which causes erosion and possible fertilizer loss.

The permeability of a soil can be no faster than the permeability of the slowest layer. For example, sandy loam has a permeability of 2.0 to 6.0 inches per hour. Sandy clay loam has a permeability of 0.2 to 0.6 inches per hour. A soil that has a sandy loam surface over a sandy clay loam subsoil will have a permeability of 0.2 to 0.6 inches per hour.

b) Measurement (inches/hour)

Permeability is normally measured in inches per hour. A newer expression you will see is Saturated Hydraulic Conductivity (Ksat). It is measured in  $\mu\text{m}/\text{sec}$  or  $\text{cm}/\text{hr}$ .

c) Properties influencing permeability

i. Texture

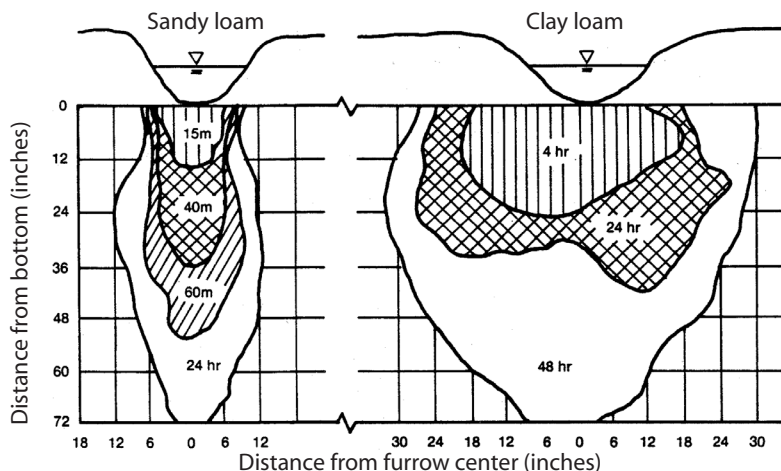
Soil texture is usually the dominant soil property affecting infiltration. Soils that are high in clay content tend to have a slower permeability. Soils that are high in sand content tend to have a faster permeability (see Table 6).

**TABLE 6. SOIL PERMEABILITY CHART**  
THESE ARE NORMAL VALUES FOR NON-COMPACTED SOILS, SUCH AS IN GRASSLAND SITUATIONS

TEXTURE CLASS	TEXTURE	PERMEABILITY RATE	PERMEABILITY CLASS
Coarse	gravel, coarse sand	> 20 inches/hour	very rapid
	sand, loamy sand	6 – 20 inches/hour	rapid
Moderately Coarse	coarse sandy loam	2 – 6 inches/hour	moderately rapid
	sandy loam		
	fine sandy loam		
Medium	very fine sandy loam	0.60 – 2 inches/hour	moderate
	loam		
	silt loam		
	silt		
Moderately fine	clay loam	0.20 – 0.60 inches/hour	moderately slow
	sandy clay loam		
	silty clay loam		
Fine	sandy clay	0.06 – 0.20 inches/hour	slow
	silty clay		
	clay (<60%)		
Very fine	clay (>60%)	< 0.06 inches/hour	very slow
	clay pan		

Soil texture not only affects how fast water moves through the soil, it also affects the pattern by which water moves through the soil. Water will move almost straight down through a sandy soil, whereas it will have more lateral movement in a heavier soil (one with more clay). (See figure 5)

**FIGURE 5. MOVEMENT OF WATER THROUGH SANDY AND CLAY SOILS**



## ii. Structure

Soil structure has perhaps the greatest effect on permeability. The cracks and pores between aggregates allow for the movement of air and water through the soil. Anything that improves structure improves permeability and vice versa. Tillage and irrigation affect soil structure. For example, heavy overhead irrigation or flood irrigation breaks down soil structure, which can lead to a sealing of the soil surface. This in turn makes it more difficult for any further water to enter the soil. Tillage can help break up a soil that has become sealed, providing it is not done while the soil is too wet or too dry.

All of the following properties relate to soil structure:

- Salts: Sodium salts cause soil particles to disperse and clog pores, which has a negative effect on soil structure. Such soils tend to seal when wet, which slows infiltration and permeability rates drastically.
- Organic matter: Organic matter (decayed plant material) is desirable in the soil, not only because it improves soil fertility, but it also improves soil structure, which has beneficial effects on permeability and infiltration.
- Compaction and pores: All soils contain pores. The pore spaces are occupied by either air or water (plant roots need both air and water). Fine-textured soils (soils with high clay content) contain more total pore space than coarse-textured soils (such as sandy loam and sand), however the pore spaces are smaller. Because of this, water moves more slowly through a fine-textured soil.
- Calcium: Calcium improves soil structure by encouraging aggregation and increasing pore size. As a result it improves permeability and infiltration.
- Soil organisms: Microorganisms (e.g., bacteria and fungi) and macroorganisms (e.g., insects and earthworms) in the soil contribute to improved permeability and infiltration. They have a beneficial effect on soil structure because they encourage the formation of soil aggregates and they make pores in the soil.

## d) Additional properties influencing infiltration

- i. Dryness: Frequently, dry soils will repel water until they become moistened to some degree. This is especially true of soils that have high amounts of organic matter. (Peat moss demonstration)
- ii. Surface fragments: A heavy cover of gravel and stones will prevent water from entering the soil and increase runoff. However, these types of soil are not usually cultivated.
- iii. Fire: A hot fire can produce resins and waxy materials that repel water
- iv. Slope: Slope may cause water to run off rather than enter the soil

## 12. Available Water Capacity (AWC)

Definition: Amount of water that the soil can hold that is available for plant growth

AWC is the difference between the amount of water in the soil at field capacity and the amount of water in the soil at wilting point. (Sponge demonstration)

- a) Field capacity: The amount of water the soil can hold against the flow of gravity. (1/3 bar or 33 kPa)
- b) Wilting point: The moisture level at which the soil can no longer provide moisture for growth of most agronomic plants. (15 bar or 1500 kPa)
- c) Measurement (inches/inch or inches/foot)

AWC is usually measured in inches per foot or inches per inch. If it takes the addition of two inches of water to wet a dry soil (at PWP) to a depth of 1 foot, then the AWC is 2 inches per foot (0.16 inches per inch). The available water capacity is then expanded to the number of inches of water the soil can hold within the rooting depth of the crop—usually ranging from 4–60 inches or a root-restricting layer, whichever is shallower.
- d) Properties influencing water holding capacity

i. Texture

Soils that are high in sand content tend to have a lower available water capacity. Soils that are high in clay content tend to have a higher available water capacity. However, if the clay content is too high or the clay particles are too fine, then the AWC might be reduced because the tiny pores may hold onto the water so tightly that the plants can't get it (see examples in Table 7).

**TABLE 7.** TYPICAL AVAILABLE WATER CAPACITY (AWC) FOR VARIOUS SOIL TEXTURES FOR SOILS HIGH IN 2:1 MINERALS (SOILS HIGH IN KAOLINITE OR GIBBSITE ARE ABOUT 20% LOWER)

SOIL TEXTURE	AVAILABLE MOISTURE	
	RANGE inches/foot	AVERAGE inches/foot
Very Coarse to Coarse Textured (sands and loamy sands)	0.50 – 1.25	0.90
Moderately Coarse Textured (coarse sandy loam, sandy loam and fine sandy loam)	1.25 – 1.75	1.50
Medium Textured (very fine sandy loam, silt, silt loam, loam, sandy clay loam, clay loam and silty clay loam)	1.50 – 2.30	1.90
Fine and Very Fine Textured (silty clay, sandy clay and clay)	1.60 – 2.50	2.10
Organic Soils (peats and mucks)	2.00 – 3.00	2.50

ii. Salts

Salts reduce the Available Water Capacity of the soil. A soil that is salty can be wet and yet not have any water available for plant growth. This is because the salts have such a strong attraction for the water that the roots cannot overcome it (see Table 8).

**TABLE 8.** REDUCTION IN AWC FOR SALTS

EC of soil	4	6	12	16	18	20	22	25	30
% Reduction AWC	10	20	30	40	50	60	70	80	90

iii. Organic matter: Organic matter is desirable in the soil, not only because it improves soil fertility, but because it can also improve the Available Water Capacity

iv. Compaction: When a soil is compacted, the soil particles are pressed together, which reduces the pore space. This means there is less space for the water to occupy.

v. Soil depth: Rooting depth is the depth to rock or other layer in the soil that restricts root depth. Natural hard pans as well as man-made pans may restrict root growth. The presence of a root-restricting layer reduces the available water capacity of the soil, since it reduces the amount of soil that is available for plant roots.

One also needs to consider the natural rooting depth of the plants. For example, if the plant roots will only go to a depth of two feet in a soil with no root restrictions, then soil below two feet should not be considered when calculating available water capacity for that crop.

- vi. Coarse fragments: “Coarse fragments” refers to gravel, cobbles, stones and boulders in the soil—anything larger than 2 mm. Since coarse fragments do not hold water, their presence in the soil reduces its water holding capacity. (See Table 9)

**TABLE 9.** REDUCTION IN AWC FOR COARSE FRAGMENTS

TEXTURE MODIFIER	% COARSE FRAGMENTS	% AWC REDUCTION
No modifier	0-15%	0-15%
Gravelly, cobbly, stony, bouldery	15-35%	15-35%
Very (gravelly, cobbly, stony, bouldery)	35-60%	35-60%
Extremely (gravelly, cobbly, stony, bouldery)	60-90%	60-90%

- vii. Estimating AWC: See Example 1

**EXAMPLE 1.** CALCULATION OF TOTAL AVAILABLE WATER CAPACITY IN THE ROOT ZONE

ESTIMATING AVAILABLE WATER CAPACITY

Determine AWC for each layer soil texture.

Reduce AWC for each layer for gravel.

Reduce AWC for each layer for salts.

Calculate AWC for entire soil.

(In this example we assume no salts or coarse fragments)

DEPTH	TEXTURE	LAYER THICKNESS (FOOT)		AWC PER FOOT (INCHES/FOOT)	=	AVAILABLE MOISTURE (INCHES)
0 to 8 inches	sandy loam	8/12	x	1.5	=	1.0
8 to 20 inches	sandy clay loam	12/12	x	1.9	=	1.9
20 to 48 inches	loamy sand	28/12	x	0.9	=	2.1
48 inches	rock (rooting depth)					
<b>TOTAL AVAILABLE MOISTURE</b>						<b>5.0 INCHES</b>

If you wanted to irrigate at 50% depletion, which is often the case, then in this case you would irrigate with 2.5 inches of water when the available water reached 2.5 inches (50% of 5 inches).



# Demonstration 1: Soil Texture Determination

## *for the instructor*

### **INSTRUCTOR OVERVIEW**

*The following demonstration outline covers the resources and skills used to determine the texture of a given soil sample by feel and to determine the approximate percent of sand, silt, and clay in that sample. First demonstrate how to use the Soil Texture Decision Chart to identify the texture of a given sample. Following this, give students the opportunity to identify the approximate soil textural classification of several additional soil samples. The Soil Texture Triangle is used to help students determine the approximate percent of sand, silt, and clay in their samples. The Soil Texture Descriptions are included to help confirm the accuracy of the determination by providing descriptions of how the soil feels and performs under several tests.*

### **MATERIALS**

- Multiple samples of different kinds of soil textures
- Handouts (see below)
  1. The Soil Texture Decision Chart: How soil texture is determined
  2. The Soil Texture Triangle: The percentages of sand, silt, and clay in each textural classification
  3. The Soil Texture Descriptions: How the soil feels and performs under several tests

### **DEMONSTRATION TIME**

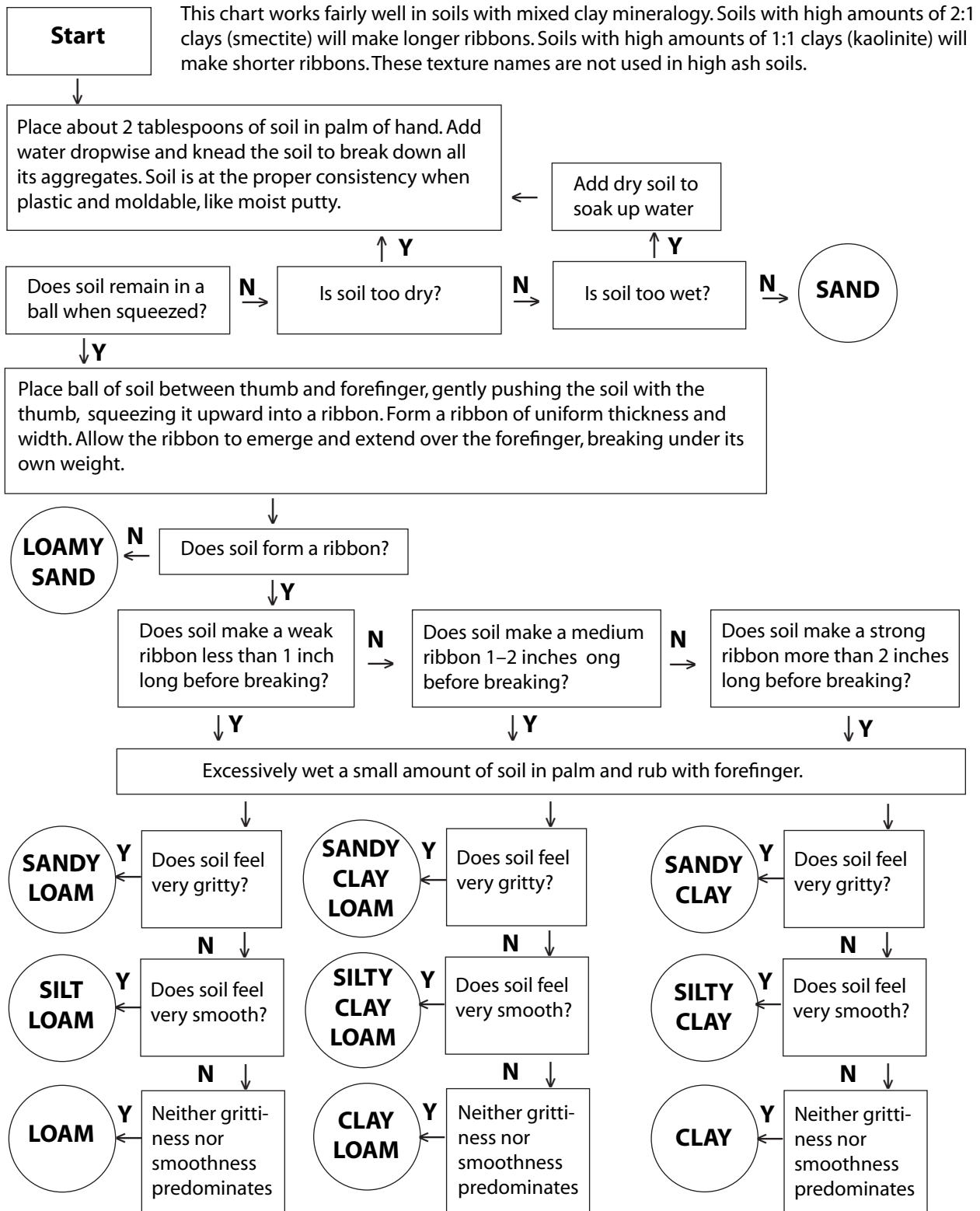
About 1 hour

### **DEMONSTRATION OUTLINE**

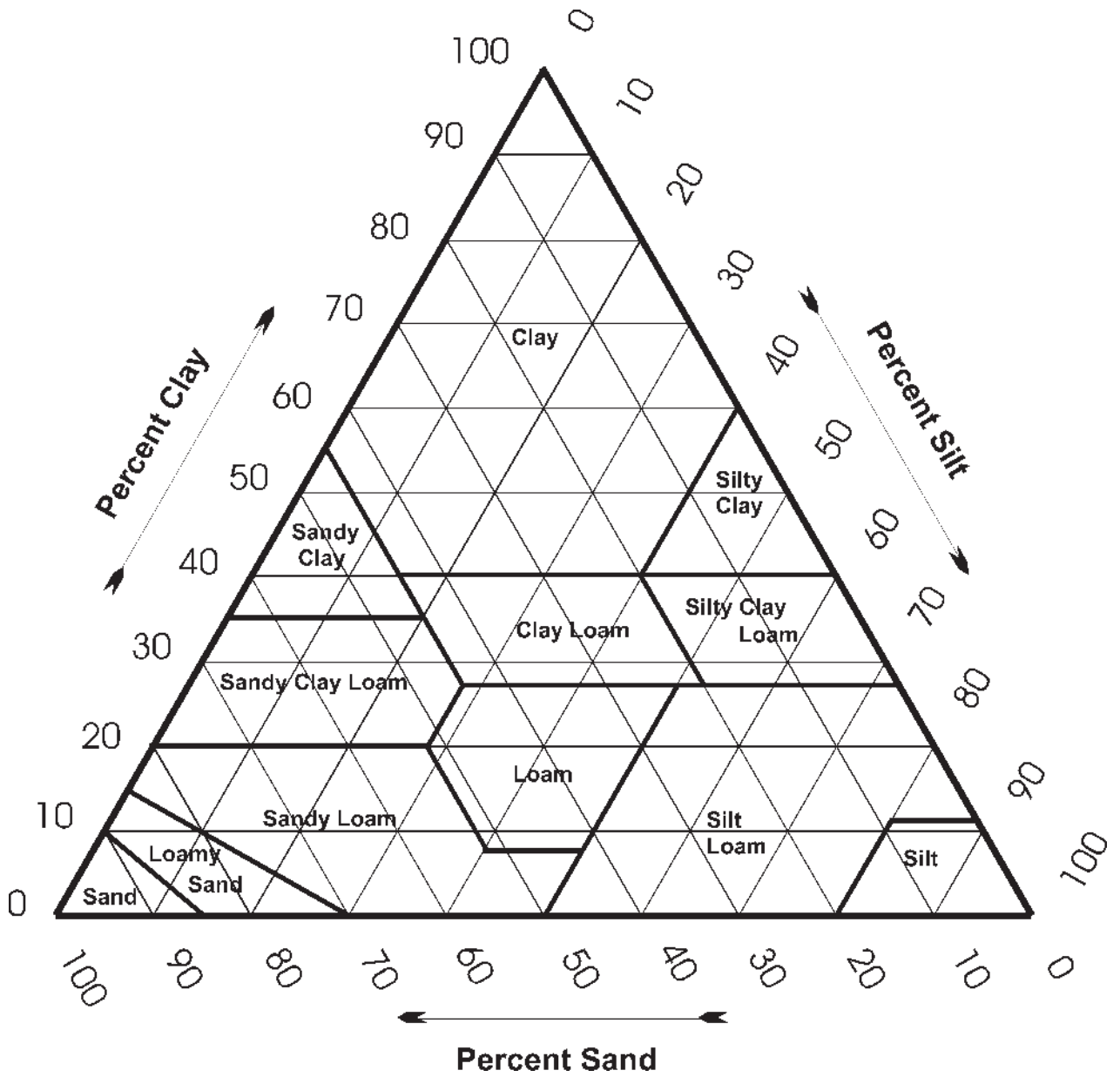
- A. Demonstrate how to determine the soil texture of a given sample by feel using the Soil Texture Decision Chart (next page)
- B. Determine the percentage of sand, silt, and clay in the soil sample using the Soil Texture Triangle (page 27)
- C. Use the Soil Texture Descriptions (pages 28–29) to confirm the accuracy of the textural determination
- D. Students practice determining soil texture following the same steps
- E. Once a texture has been determined, describe/discuss the characteristics of each of the soils
  1. Drainage
  2. Water-holding capacity/drainage
  3. Nutrient-holding capacity
  4. Describe/discuss how each of the example soils may be improved using organic farming practices



## Soil Texture Decision Chart



# Soil Texture Triangle



# Soil Texture Descriptions

*Edd Russell, Soil Scientist, USDA, Natural Resources Conservation Service*

The mineral particles in the soil are divided into the following size classes:

Coarse fragments (gravel, cobbles, stones)	larger than 2 mm
Sand	.05 to 2 mm
Silt	.002 to .05 mm
Clay	smaller than .002 mm

To put these in perspective, if a particle of clay were the size of a BB, then a particle of silt would be about the size of a golf ball, and a grain of sand would be about the size of a chair. Sand, silt, and clay are referred to as soil separates.

Sand is gritty when wet or dry. Sands are the smallest soil particles you can see with the naked eye. Silt is smooth and floury when dry and it is greasy feeling when wet. Clay is hard when dry and it is sticky and plastic when wet. Clay exhibits both cohesion (it sticks to itself) and adhesion (it sticks to other things).

Texture is a word used to describe how something feels. Soil texture refers to the relative proportion of each of the soil separates in a specific soil or horizon (layer) in the soil, because this determines how a soil feels. The texture triangle, shown on page 27, is used to determine which texture class a soil belongs to based on the specific amounts of sand, silt, and clay it contains.

Following is a description of some of the texture classes. There is also a chart at the back of this section that shows you how to determine soil texture.

## **SAND**

Sand is loose and single grained. The individual grains can readily be seen and felt. Squeezed in the hand when dry, it will fall apart when the pressure is released. Squeezed when moist, it will form a cast, but will crumble when touched.

## **LOAMY SAND**

When dry, loamy sand is loose and single grained. When wet it is gritty, it does not ribbon and lacks stickiness, but it may show faint clay stainings. Squeezed when moist, it forms a cast that does not break with very careful handling. Individual grains of sand can be readily seen or felt.

## **SANDY LOAM**

A sandy loam soil forms weak aggregates, it contains 45%–85% sand, but has enough silt and up to 20% clay which makes it somewhat coherent. Individual sand grains can be seen and felt. Squeezed when dry it will form a cast that will readily fall apart, but when moist it will form a cast that will bear careful handling without breaking. It will definitely stain fingers. When placed in water it turns the water cloudy.

## **LOAM**

Loam is a soil having a relatively even mixture of different grades of sand, silt, and clay. It is mellow with a somewhat gritty feel, yet fairly smooth and slightly sticky and slightly plastic. Dry aggregates are slightly hard or hard to break. When moist it will form a cast that can be handled without breaking. It stains fingers. When placed in water it turns the water cloudy.

## **SILT LOAM**

A silt loam is a soil having moderate amounts of the fine grades of sand and less than 27% clay; over half of the particles are silt sized. When dry, aggregates break with some difficulty. When moist it forms a firm ball and ribbons fairly well. Either dry or moist it will form casts that can be freely handled without breaking.

**SILT**

Silt is a rare textural class that is not easy to find in nature. Silt feels quite floury and soft when dry. When moist it is greasy feeling and is neither sticky nor plastic.

**SANDY CLAY LOAM**

A sandy clay loam is a soil with 45%–80% sand, 20%–35% clay, and 0%–28% silt. Dry aggregates are hard and break with difficulty. When moist it forms a firm ball and can be squeezed into a ribbon and may show a fingerprint. It is sticky and plastic; it stains fingers and it turns water cloudy.

**CLAY LOAM**

A clay loam is a moderately fine-textured soil that usually breaks into aggregates or lumps that are hard when dry and friable or firm when moist. The soil ribbons well when moist and shows a good fingerprint; is sticky and plastic and will form a cast that can bear much handling. It stains fingers.

**SILTY CLAY LOAM**

A silty clay loam handles like silt loam but it is sticky, plastic and friable or firm when moist. Also, when moist the soil shows a good fingerprint and, like clay loam, will form a cast that can bear good handling. It stains fingers. When the soil is pulverized, it feels floury.

**SANDY CLAY**

A sandy clay is a fine texture soil with 45%–65% sand, 35%–55% clay and 0%–20% silt. Dry, it is very hard—aggregates can only be broken with extreme pressure. Moist, it is sticky or very sticky and plastic and shows a good fingerprint; it ribbons well and stains fingers.

**SILTY CLAY**

A silty clay soil is a fine-textured soil with 40%–60% silt, up to 20% sand and 40%–60% clay. Dry, it is extremely hard and it feels quite floury when crushed. It is very sticky and very plastic when moist and it shows a good fingerprint. It forms a cast that can bear much handling and ribbons very well, and clouds water and stains fingers.

**CLAY**

Clay is also a fine-textured soil that usually forms very hard or extremely hard blocks or prisms. It is very sticky and very plastic when moist, it ribbons very well and forms a very good fingerprint. Some clays are very firm or extremely firm when moist.



# Demonstration 2: Soil Pit Examination

## *for the instructor*

### **INSTRUCTOR OVERVIEW**

*In this demonstration students examine the soil profile and various soil properties exposed in a shallow soil excavation. Discuss the soil profile and how the soil properties observed affect the use of the soil for farming, gardening, and other purposes.*

### **MATERIALS**

- Shovel and Pic mattock (to dig pit)
- Munsell soil color book
- Water bottle for moistening soil
- pH kit

### **SITE PREPARATION**

Several hours before the demonstration dig a pit approximately 2–4 feet deep (or until distinct soil horizons are observed). For ease, the pit may be triangular in shape and stepped. Plan to have the soil profile in full sun at the time of the demonstration.

### **PREPARATION TIME**

Approximately 1 hour

### **DEMONSTRATION TIME**

1 hour

### **DEMONSTRATION OUTLINE**

- A. Determine Approximate Textural Classification of Soil by Feel**
- B. Identify Distinct Soil Horizons**
  1. A Horizon and what defines it
  2. B Horizon and what defines it
  3. C Horizon and what defines it
  4. Identify indicators of soil disturbance (e.g., tillage)
- C. Describe/Define the Type(s) of Soil Structure Observed**
  1. Describe general soil structure and how it is created
  2. Identify and provide examples of soil aggregates and how they form



# Supplemental Demonstrations and Examples

## *for the instructor*

### **INSTRUCTOR OVERVIEW**

*These demonstrations and examples use analogy and models to illustrate various soil physical properties. Note the references to sections of the detailed lecture outline for specific topics.*

### **SOIL EXAMPLES**

Lecture Outline Reference: Throughout

#### **PURPOSE**

To show examples of certain soil physical properties

#### **MATERIALS: EXAMPLES OF SOIL TO SHOW**

- Color (dark = high organic matter, bright = well drained, redoximorphic features = wetness)
- Structure
- Texture (sand, silt, clay, loam, etc.)
- Hard pans

### **BAKLAVA DEMONSTRATION**

Detailed Lecture Outline Reference: C 1 a) iii

#### **PURPOSE**

To show layering akin to what is found in phyllosilicate (layer-lattice) clays

#### **MATERIALS**

- Baklava, preferably enough so that each student can have a piece

#### **METHODS**

Point out that many clay minerals are layered at the microscopic level much the way that baklava is and that cations are adsorbed to the sides of clay particles much the same as the nuts are stuck to the sides of the baklava.

### **MODELS DEMONSTRATION**

Detailed Lecture Outline Reference: C 1 a) iii

#### **PURPOSE**

To show the arrangement of molecules in silica tetrahedra and alumina dioctehedra

#### **MATERIALS**

- Molecular models or models made from cardboard and tape showing the shape of a tetrahedron and octrahedron

#### **METHODS**

If short on time, skip this. This is more than many can comprehend but I use it to illustrate the complexity of the clay minerals.



### TARGET DEMONSTRATION

Detailed Lecture Outline Reference: C 1 a) iii

#### PURPOSE

To show that clay is sticky (adhesion)

#### MATERIALS

- Moist clay, moistened enough so that it adheres to most surfaces
- A flipchart or blackboard with a target drawn on it
- Moist sandy loam (optional, for contrast)

#### METHODS

Form the clay into a ball, and throw it at the target (test the surface first to make sure that the clay will actually stick to it). Optionally, you can repeat the process with sandy loam or similar to show that it is not as sticky.

### RIBBON DEMONSTRATION

Detailed Lecture Outline Reference: C 1 a) iii

#### PURPOSE

To show that clay is plastic (cohesion)

#### MATERIALS

- Moist clay
- Moist sandy loam (optional, for contrast)

#### METHODS

Squeeze the clay through your thumb and forefinger to create a ribbon. Optionally, repeat the process with sandy loam to show that it does not ribbon as well.

### SLINKY DEMONSTRATION

Detailed Lecture Outline Reference: C 1 a) iii

#### PURPOSE

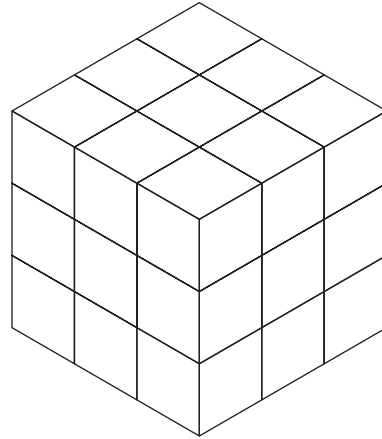
To show how clays shrink and swell by layers becoming separated

#### MATERIALS

- Slinky

#### METHODS

Stretch and compress a slinky in your hand while explaining that some clays can shrink and swell as layers get separated when water gets between them



### BLOCK DEMONSTRATION

Detailed Lecture Outline Reference: C 1 a) iii

#### PURPOSE

To show that smaller particles have a larger surface area than a single large particle occupying the same space.

#### MATERIALS

- 27 wooden blocks

#### METHODS

1. Form the blocks into a cube: 3 blocks by 3 blocks by 3 blocks. Assume the blocks each have a dimension of 1 on each side. Have the students calculate the surface area of the cube:

Each side is  $3 \times 3 = 9$

There are 6 sides,  $6 \times 9 = 54$

2. Have the students then calculate the total surface area of the individual blocks in the cube:

The side of each block has an area of  $1 \times 1 = 1$

Each block has 6 sides, and therefore a surface area of  $6 \times 1 = 6$

There are 27 blocks, so the total surface area is  $6 \times 27 = 162$

### COLOR BOOK EXAMPLE

Detailed Lecture Outline Reference: C 6 a)

#### PURPOSE

To show how soil color is described

#### MATERIALS

Munsell or Earth Colors soil color charts

#### METHODS

Show how the color charts and Munsell color notation are used.

### PERMEABILITY DEMONSTRATION

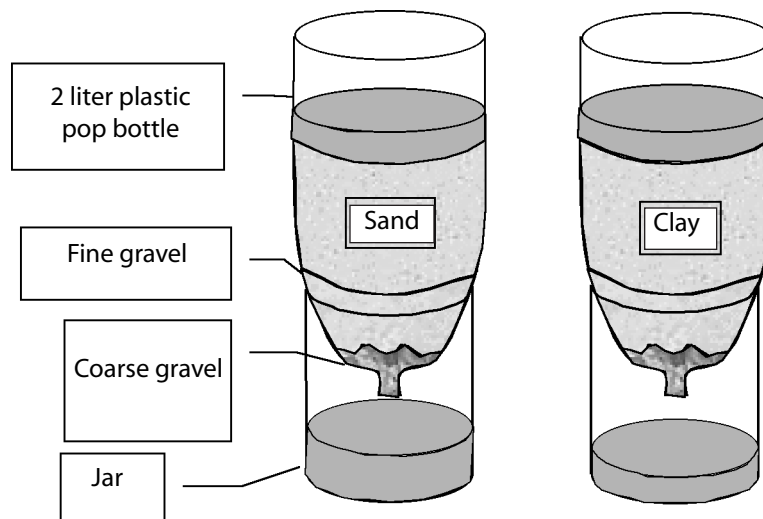
Detailed Lecture Outline Reference: C 11 c) i

#### MATERIALS

- 4 jars or beakers, about 2 cup size
- 2 2-liter plastic soda bottles
- Coarse gravel, rounded is better, 1/2–1inch, about 1 cup
- Fine gravel, < 1/4 inch, about 1 pint
- Sand, about 1 pint
- Clay, dry and ground, about 1 pint
- Water

#### METHODS

1. Cut the bottoms out of the soda bottles.
2. Invert the bottles into two of the jars to make funnels. Label one “Sand” and the other “Clay”.
3. Place the coarse gravel into the bottom of the funnels, enough to plug the holes so that the fine gravel won’t go through.
4. Cover the coarse gravel with about a 1 inch thick layer of fine gravel.
5. Place the sand and clay into the appropriate funnels. You want a layer about 2–3 inches thick.
6. Fill the other jars with about 3/4 to 1 cup of water each.
7. Using both hands, pour the water into the funnels at the same time and rate.
8. See which soil the water passes through faster.



### **PEAT MOSS DEMONSTRATION**

Detailed Lecture Outline Reference: C 11 d) i.

#### **PURPOSE**

To show how dry organic matter repels water

#### **MATERIALS**

- Dry peat moss (a handful)
- Water

#### **METHODS**

Hold up a handful of dry peat moss and pour the water over it, showing how the water runs off rather than soaking in.

### **SPONGE DEMONSTRATION**

Detailed Lecture Outline Reference: C 12

#### **PURPOSE**

To provide a conceptual model of available water capacity and field capacity

#### **MATERIALS**

- Sponge
- Water in a bowl or pan

#### **METHODS**

1. Soak the sponge in water until it is saturated.
2. Hold up the sponge until most of the water stops dripping. Explain that the sponge is analagous to soil. When the water has finished draining from the soil 24 hours after saturation, the soil is said to be at field capacity.
3. Squeeze the sponge to remove as much water as you can. Mention that this water would be analagous to what can be removed by plants and is called available water. There is still some moisture in the sponge and that is analagous to the water that is held so tightly in the soil that plants cannot remove it.

# Assessment Questions

## TRUE OR FALSE

1. Climate affects how a soil forms.  
True      False
2. Air is not an important part of soil.  
True      False
3. Clay holds more water than sand.  
True      False
4. Platy structure on the surface of the soil is desirable.  
True      False
5. Organic matter is not particularly beneficial to the physical condition of the soil.  
True      False

## MULTIPLE CHOICE

1. Which of the following is not a soil-forming factor?
  - a. Time
  - b. Parent material
  - c. Soil color
  - d. Topography
2. Of the soil separates listed below, which has the smallest particle size?
  - a. Sand
  - b. Silt
  - c. Clay
3. Which one of the following is not considered one of the major constituents of soil?
  - a. Chemical
  - b. Mineral
  - c. Organic matter
  - d. Pore space

4. Which of the following foods has a structure similar to silicate clays?
  - a. Ice cream
  - b. Cheese
  - c. Cake
  - d. Baklava
5. A soil that has a balanced amount of sand, silt and clay has which one of the following for a texture?
  - a. Platy
  - b. Loam
  - c. Silt
  - d. Granular
6. Of the following, which is the best to add to a clay soil to help offset the negative effects of the clay?
  - a. Sand
  - b. Silt
  - c. Organic matter
  - d. Sodium salts
7. Which one of the following does not contribute to the formation of soil structure?
  - a. Biological factors
  - b. Amount and type of clay
  - c. Iron
  - d. Climate
8. Gray or mottled colors in the soil indicate past or present:
  - a. Wormholes
  - b. Wetness
  - c. Drought
  - d. Texture
9. The rate at which water moves through the soil is called:
  - a. Porosity
  - b. Hydraulic speed
  - c. Permeability
  - d. Saturation potential

10. Which of the following influence the available water-holding capacity of the soil?

- a. Texture
- b. Structure
- c. Organic matter
- d. Salts
- e. a, b and c
- f. a, b, c, and d
- g. a, c and d

**ASSESSMENT**

1. Why are the “empty” places in the soil so important?

2. Clay contributes many good characteristics to soil, but if there is too much it can cause problems. What are some of the negative effects of too much clay in the soil and how can these effects be overcome?

3. What are some of the negative effects of too much sand in the soil and how can these effects be overcome?

4. Use a soil texture triangle to calculate the soil texture for the following combinations of sand, silt and clay:

- a. 25% sand, 30% silt, 45% clay
- b. 40% sand, 30% silt, 30% clay
- c. 60% sand, 10% silt, 30% clay
- d. 70% sand, 12% silt, 18% clay
- e. 90% sand, 5% silt, 5% clay
- f. 80% sand, 15% silt, 5% clay
- g. 10% sand, 85% silt, 5% clay
- h. 5% sand, 75% silt, 20% clay
- i. 40% sand, 40% silt, 20% clay
- j. 55% sand, 5% silt, 40% clay
- k. 10% sand, 60% silt, 40% clay
- l. 5% sand, 45% silt, 50% clay

5. What surface structure is most desirable? What can you do to help develop this structure and maintain it?

# Assessment Questions Key

## TRUE – FALSE

1. Climate affects how a soil forms.  
True      False
2. Air is not an important part of soil.  
True      False
3. Clay holds more water than sand.  
True      False
4. Platy structure on the surface of the soil is desirable.  
True      False
5. Organic matter is not particularly beneficial to the physical condition of the soil.  
True      False

## MULTIPLE CHOICE

1. Which of the following is not a soil-forming factor?  
a. Time  
b. Parent Material  
c. Soil Color  
d. Topography
2. Of the soil separates listed below, which has the smallest particle size?  
a. Sand  
b. Silt  
c. Clay
3. Which one of the following is not considered one of the major constituents of soil?  
a. Chemical  
b. Mineral  
c. Organic matter  
d. Pore space
4. Which of the following foods has a structure similar to silicate clays?  
a. Ice cream  
b. Cheese  
c. Cake  
d. Baklava

5. A soil that has a balanced amount of sand, silt and clay has which one of the following for a texture?  
a. Platy  
b. Loam  
c. Silt  
d. Granular
6. Of the following, which is the best to add to a clay soil to help offset the negative effects of the clay?  
a. Sand  
b. Silt  
c. Organic matter  
d. Sodium salts
7. Which one of the following does not contribute to the formation of soil structure?  
a. Biological factors  
b. Amount and type of clay  
c. Iron  
d. Climate
8. Grey or mottled colors in the soil indicate past or present:  
a. Wormholes  
b. Wetness  
c. Drought  
d. Texture
9. The rate at which water moves through the soil is called:  
a. Porosity  
b. Hydraulic speed  
c. Permeability  
d. Saturation potential
10. Which of the following influence the available water-holding capacity of the soil?  
a. Texture  
b. Structure  
c. Organic matter

- d. Salts
- e. a, b and c
- f. a, b, c, and d
- g. a, c, and d

#### ADDITIONAL QUESTIONS

1. Why are the “empty” places in the soil so important?
  - *Place for air and water to move and be stored*
  - *Place for roots to grow*
  - *Place for organisms to live*
  - *Place for nutrients to be stored*

2. Clay contributes many good characteristics to soil, but if there is too much it can cause problems. What are some of the negative effects of too much clay in the soil and how can these effects be overcome?

##### *Effects*

- *Hard to work when wet*
- *Hard to work when dry*
- *Tendency to seal up when wetted*
- *Hard for roots to grow*

##### *How to overcome*

- *Only work soil when the moisture is right*  
*Add lots of organic matter, even coarse material*
- *If irrigating, do so gently*

3. What are some of the negative effects of too much sand in the soil and how can these effects be overcome?

##### *Effects*

- *Droughty*
- *Low fertility*
- *Structure collapses easily*

##### *How to overcome*

- *Add lots of organic matter*
- *Don't till any more than necessary*

4. Use a soil texture triangle to calculate the soil texture for the following combinations of sand, silt and clay

- a. *25% sand, 30% silt, 45% clay*  
*clay*
- b. *40% sand, 30% silt, 30% clay*  
*clay loam*
- c. *60% sand, 10% silt, 30% clay*  
*sandy clay loam*
- d. *70% sand, 12% silt, 18% clay*  
*sandy loam*
- e. *90% sand, 5% silt, 5% clay*  
*sand*
- f. *80% sand, 15% silt, 5% clay*  
*loamy sand*
- g. *10% sand, 85% silt, 5% clay*  
*silt*
- h. *5% sand, 75% silt, 20% clay*  
*silt loam*
- i. *40% sand, 40% silt, 20% clay*  
*loam*
- j. *55% sand, 5% silt, 40% clay*  
*sandy clay*
- k. *10% sand, 60% silt, 40% clay*  
*silty clay loam*
- l. *5% sand, 45% silt, 50% clay*  
*silty clay*

5. What surface structure is most desirable for gardening? What can you do to help develop this structure and maintain it?

- *Granular or crumb structure is most desirable*
- *Add lots of organic materials and encourage biological activity*
- *Don't till the soil any more than necessary*
- *Only till under the proper moisture conditions*
- *Avoid compacting the soil with excessive traffic*
- *Rotate with a cover crop*
- *Use proper irrigation techniques*

# Resources

## PRINT RESOURCES

### BOOKS

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Brady, N. C., and Weil, R. R. 1999. *The Nature and Property of Soils*, 12th edition. Upper Saddle River, NJ: Prentice-Hall, Inc.

*A good general soils text, used for introductory soils classes at universities. Might be too technical for some.*

Buol, S. W., F. D. Hole, R. J. McCracken, and R. J. and Southard. 1997. *Soil Genesis and Classification, Fourth Edition*. Ames, IA: Iowa State University Press.

*College textbook used to teach soil classification.*

Dixon, J. B., and S. B. Weed, eds. 1989. *Minerals in Soil Environments*. Madison, WI: Soil Science Society of America.

*Very technical reference on soil minerals. Only the most hardy go here.*

Dubbin, William. 2001. *Soils*. The Natural History Museum, London. Available from Iowa State University Press, Ames, Iowa.

*Short overview of soil science. Easy to read and understand, lots of color photos.*

Gershuny, Grace. 1993. *Start with the Soil*. Emmaus, PA: Rodale Press.

*A general book on soils and soil management geared toward organic gardeners. Easy to read and understand.*

Gershuny, Grace. 2000. *The Soul of Soil: A Soil-Building Guide for Master Gardeners and Farmers, Fourth edition*. White River Junction, VT: Chelsea Green Publishing.

*Provides essential information on soil ecosystem management for organic growers. Topics include organic matter management, building and maintaining humus, on-site composting, green manures and crop rotations, cultivation and weed control, nutrient balances and soil testing, and using mineral fertilizers.*

Magdoff, Fred and Harold Van Es. 2000. *Building Soils for Better Crops, Second Edition*. Sustainable Agriculture Network, Handbook Series Book 4. Beltsville, MD: National Agricultural Library.

*An introductory overview of organic management of soil fertility covering the basics of soil organic matter, physical and chemical properties of soil, ecological soil and crop management. Practical and accessible information. Available from [www.sare.org](http://www.sare.org)*

Stell, Elizabeth P., 1998. *Secrets to Great Soil*. Pownal, VT: Storey Communications, Inc.

*An easy-to-read primer on soils, composting and basic gardening techniques. Lots of diagrams.*

### SOIL SURVEYS

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These can be obtained from Natural Resource Conservation Services offices. They are also available in many libraries.

Soil Survey Staff, Natural Resources Conservation Service. 1999. *National Soil Survey Handbook, title 430-VI*. United States Department of Agriculture, Washington, D.C., U.S. Government Printing Office.

*Contains all the technical details about making soil surveys and entering soil properties into the National Soils Information System (NASIS).*

*Available online at:*

[www.statlab.iastate.edu/soils/nssh/](http://www.statlab.iastate.edu/soils/nssh/)

Soil Survey Division Staff. 1993. *Soil Survey Manual*. United States Department of Agriculture, Washington DC., U.S. Government Printing Office.

*This is the manual that soil scientists use to carry out soil survey work. The most definitive guide on how to describe the physical properties of soil. Available online at:*

[www.statlab.iastate.edu/soils/ssm/gen\\_cont.html](http://www.statlab.iastate.edu/soils/ssm/gen_cont.html)

Soil Survey Staff, Natural Resources Conservation Service. 1999. *Soil Taxonomy*. United States Department of Agriculture. Washington, D.C.: U.S. Government Printing Office.

*The reference used to classify soils. Highly technical, used mainly by soil scientists.*

*Available online at:*

[www.statlab.iastate.edu/soils/nsdaf/](http://www.statlab.iastate.edu/soils/nsdaf/)



## WEB RESOURCES

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see “Course Curriculum”)

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

California NRCS home page

[www.ca.nrcs.usda.gov](http://www.ca.nrcs.usda.gov)

Canadian Soil Information System

[res.agr.ca/CANSIS](http://res.agr.ca/CANSIS)

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This sustainable agriculture education resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

Glossary of Soil Science Terms

[www.soils.org/sssagloss](http://www.soils.org/sssagloss)

National Sustainable Agriculture Information Service

[www.attraorg/soils.html](http://www.attraorg/soils.html)

*Science of Soils* online journal

[link.springer.de/link/service/journals/10112/index.htm](http://link.springer.de/link/service/journals/10112/index.htm)

Soils of Canada

[quarles.unbc.edu/nres/soc/soc.htm](http://quarles.unbc.edu/nres/soc/soc.htm)

USDA Soil Data

[soildatamart.nrcs.usda.gov](http://soildatamart.nrcs.usda.gov)

USDA Soil Information

[soils.usda.gov](http://soils.usda.gov)

## EDUCATION LINKS

[soilsassociation.org/links/educational.htm](http://soilsassociation.org/links/educational.htm)

## INSTITUTIONS

Cooperative Extension Service or Farm Advisors office

*Staff from these offices will be aware of crop nutrient needs and problems in your area. They can assist you with nutrient deficiency symptoms and known plant nutrition problems in your area.*

US Department of Agriculture–Natural Resources Conservation Service (USDA–NRCS) field offices

*Information about soils in your area can be obtained from NRCS field offices. They are usually listed in the U.S. Government pages of the phone book under US Department of Agriculture. They may also be listed as USDA Service Center. Some areas do not have NRCS offices but do have Resource Conservation District offices that can provide the same information.*

# Glossary

## REFERENCES USED FOR TERMS

<sup>1</sup> From the standard glossary used in soil survey reports

<sup>2</sup> National Soil Survey Handbook. 1998. Available online at [www.statlab.iastate.edu/soils/nssh/](http://www.statlab.iastate.edu/soils/nssh/)

<sup>3</sup> Glossary of Soil Science Terms. 1996, Soil Science Society of America. Available online at [www.soils.org/sssagloss/](http://www.soils.org/sssagloss/)

<sup>4</sup> Merriam-Webster Online. [www.m-w.com/](http://www.m-w.com/)

## Absorption

*Uptake of matter or energy by a substance<sup>3</sup>*

## Adsorption

*The process by which atoms, molecules, or ions are taken up from the soil solution or soil atmosphere and retained on the surfaces of solids by chemical or physical binding.<sup>3</sup>*

## Acidity

*Refers to the condition of the soil when the exchange complex is dominated by hydrogen and aluminum ions*

## Acidity, salt-replaceable

*The aluminum and hydrogen that can be replaced from an acid soil by an unbuffered salt solution such as KCl or NaCl<sup>3</sup>*

## Acidity, total

*The total acidity including residual and exchangeable acidity. Often it is calculated by subtraction of exchangeable bases from the cation exchange capacity determined by ammonium exchange at pH 7.0. It can be determined directly using pH buffer-salt mixtures (e.g., BaCl<sub>2</sub> plus triethanolamine, pH 8.0 or 8.2) and titrating the basicity neutralized after reaction with a soil.<sup>3</sup>*

## Aeration, soil

*The exchange of air in soil with air from the atmosphere. The air in a well-aerated soil is similar to that in the atmosphere; the air in a poorly aerated soil is considerably higher in carbon dioxide and lower in oxygen.<sup>1</sup>*

## Aggregate, soil

*Many fine particles held in a single mass or cluster. Natural soil aggregates, such as granules, blocks, or prisms, are called peds. Clods are aggregates produced by tillage or logging.<sup>1</sup>*

## Alkali soil

*(i) A soil with a pH of 8.5 or higher or with a exchangeable sodium ratio greater than 0.15. (ii) A soil that contains sufficient sodium to interfere with the growth of most crop plants.<sup>3</sup>*

## Anion

*A negatively charged ion (has surplus electrons)<sup>3</sup>*

## Anion exchange capacity

*The sum of exchangeable anions that a soil can adsorb. Usually expressed as centimoles, or millimoles, of charge per kilogram of soil (or of other adsorbing material such as clay).<sup>3</sup>*

## Aspect

*The direction in which a slope faces<sup>1</sup>*

## Atom

*The smallest particle of an element that can exist either alone or in combination<sup>4</sup>*

## Available water capacity (available moisture capacity) (AWC)

*The volume of water that should be available to plants if the soil, inclusive of fragments, were at field capacity. It is commonly estimated as the amount of water held between field capacity and wilting point, with corrections for salinity, fragments, and rooting depth. It is commonly expressed as inches of water per inch of soil.<sup>2</sup> The following classes are used in California, based on the AWC of 60 inch depth (or depth to a limiting layer):*

*AWC Class    AWC/60 inches or limiting layer*

*Very low    0 to 2.5*

*Low    2.5 to 5*

*Moderate    5 to 7.5*

*High    7.5 to 10*

*Very high    more than 10*

## AWC

*See available water capacity*

#### Base saturation

*The degree to which material having cation-exchange properties is saturated with exchangeable bases (sum of Ca, Mg, Na, and K), expressed as a percentage of the total cation-exchange capacity<sup>1</sup>*

#### Boulders.

*Rock fragments larger than 2 feet (60 centimeters) in diameter<sup>1</sup>*

#### Bulk density

*A measurement of the oven-dried weight of the less than 2 mm soil material per unit volume of soil. Common measurements are taken at a water tension of 1/10 bar; 1/3 bar; or 15 bar. Bulk density influences plant growth and engineering applications. It is used to convert measurements from a weight basis to a volume basis. Within a family particle size class, bulk density is an indicator of how well plant roots are able to extend into the soil. Bulk density is used to calculate porosity.<sup>2</sup>*

#### Calcareous soil

*A soil containing enough calcium carbonate (commonly combined with magnesium carbonate) to effervesce visibly when treated with cold, dilute hydrochloric acid<sup>1</sup>*

#### Calcium carbonate equivalent

*The quantity of carbonate (CO<sub>3</sub>) in the soil expressed as CaCO<sub>3</sub> and as a weight percentage of the less than 2 mm size fraction<sup>2</sup>*

#### Capillary water

*Water held as a film around soil particles and in tiny spaces between particles. Surface tension is the adhesive force that holds capillary water in the soil.<sup>1</sup>*

#### Cation

*An ion carries a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.<sup>1</sup>*

#### Cation-exchange capacity (CEC)

*The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value. The term, as applied to soils, is synonymous with base-exchange capacity but is more precise in meaning.<sup>1</sup>*

#### CEC

*See cation exchange capacity*

#### Clay

*As a soil separate, the minerals soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.<sup>1</sup>*

#### Claypan

*A dense, compact, slowly permeable layer in the subsoil, with a much higher clay content than overlying materials from which is separated by a sharply defined boundary. A claypan is usually hard when dry, and plastic or sticky when wet.<sup>2</sup>*

#### Coarse fragments

*See Rock fragments*

#### Coarse textured soil

*Sand or loamy sand<sup>1</sup>*

#### Cobble (or cobblestone)

*A rounded or partly rounded fragment of rock 3 to 10 inches (7.6 to 25 centimeters) in diameter<sup>1</sup>*

#### Colloid

*A particle, which may be a molecular aggregate, with a diameter of 0.1 to 0.001  $\mu\text{m}$ . Soil clays and soil organic matter are often called soil colloids because they have particle sizes that are within, or approach colloidal dimensions.<sup>3</sup>*

#### Compaction

*The process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the bulk density<sup>3</sup>*

#### Compound

*Something formed by a union of elements or parts; especially: a distinct substance formed by chemical union of two or more ingredients in definite proportion by weight<sup>4</sup>*

#### Consistence, soil

*Refers to the degree of cohesion and adhesion of soil material and its resistance to deformation when ruptured. Consistence includes resistance of soil material to rupture and to penetration; plasticity, toughness, and stickiness of puddled soil material; and the manner in which the soil material behaves when subject to compression. Terms describing consistence are defined in the Soil Survey Manual.<sup>1</sup>*

## Deep soil

*See Depth*

## Depth, soil

*Generally, the thickness of the soil over bedrock. Very deep soils are more than 60 inches deep over bedrock; deep soils, 40 to 60 inches; moderately deep, 20 to 40 inches; shallow, 10 to 20 inches; and very shallow, less than 10 inches.<sup>1</sup>*

## Drainage class (natural)

*Refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities, either through drainage or irrigation, are not a consideration unless they have significantly changed the morphology of the soil. Seven classes of natural soil drainage are recognized: excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained. These classes are defined in the Soil Survey Manual.<sup>1</sup>*

## Duripan

*A subsurface soil horizon that is cemented by illuvial silica, usually opal or microcrystalline forms of silica, to the degree that less than 50 percent of the volume of air-dry fragments will slake in water or HCl<sup>3</sup>*

## EC

*See electrical conductivity*

## Edaphology

*The science that deals with the influence of soils on living things; particularly plants, including human uses of land for plant growth<sup>3</sup>*

## Electrical conductivity (EC)

*The electrolytic conductivity of an extract from saturated soil paste<sup>2</sup>*

## Element

*Basic unit of matter that can't be broken down by chemical means. They are the building blocks of nature. Any of more than 100 fundamental substances that consist of atoms of only one kind and that singly or in combination constitute all matter.<sup>4</sup>*

## Eluviation

*The movement of material in true solution or colloidal suspension from one place to another within the soil. Soil horizons that have lost material through eluviation are eluvial; those that have received material are illuvial.<sup>1</sup>*

## Exchangeable anion

*A negatively charged ion held on or near the surface of a solid particle by a positive surface charge and which may be easily replaced by other negatively charged ions (e.g., with a Cl<sup>-</sup> salt)<sup>3</sup>*

## Fertility, soil

*The quality that enables a soil to provide plant nutrients, in adequate amounts and in proper balance, for the growth of specified plants when light, moisture, temperature, tilth, and other growth factors are favorable<sup>1</sup>*

## Field moisture capacity

*The moisture content of a soil, expressed as a percentage of the oven dry weight, after the gravitational, or free, water has drained away; the field moisture content 2 or 3 days after a soaking rain; also called normal field capacity, normal moisture capacity, or capillary capacity<sup>4</sup>*

## Fine textured soil

*Sandy clay, silty clay, or clay<sup>1</sup>*

## Fragments

*Unattached cemented pieces of bedrock, bedrock-like material, durinodes, concretions, and nodules 2 mm or larger in diameter; and woody material 20 mm or larger in organic soils<sup>2</sup>*

## Genesis, soil

*The mode of origin of the soil. Refers especially to the processes or soil-forming factors responsible for the formation of the solum, or true soil, from the unconsolidated parent material.<sup>1</sup>*

## Gravel

*Rounded or angular fragments of rock as much as 3 inches (2 millimeters to 7.6 centimeters) in diameter. An individual piece is a pebble.<sup>1</sup>*

## Gravelly soil material

*Material that is 15 to 35 percent, by volume, rounded or angular rock fragments, not prominently flattened, as much as 3 inches (7.6 centimeters) in diameter<sup>1</sup>*

## Great group

A group of soils that is characterized by common characteristics usually developed under the influence of environmental factors (as vegetation and climate) active over a considerable geographic range and that comprises one or more families of soil—called also great soil group.<sup>4</sup> See Soil Classification.

## Gypsum

The percent, by weight, of hydrated calcium sulfates in the <20 mm fraction of soil<sup>2</sup>

## Hardpan

A hardened or cemented soil horizon, or layer. The soil material is sandy, loamy, or clayey and is cemented by iron oxide, silica, calcium carbonate, or other substance.<sup>1</sup>

## Horizon, soil

A layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes. In the identification of soil horizons, an uppercase letter represents the major horizons. Numbers or lowercase letters that follow represent subdivisions of the major horizons. An explanation of the subdivisions is given in the Soil Survey Manual. The major horizons of mineral soil are as follows:<sup>1</sup>

O horizon = An organic layer of fresh and decaying plant residue.

A horizon = The mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material. Also, a plowed surface horizon, most of which was originally part of a B horizon.

E horizon = The mineral horizon in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these.

B horizon = The mineral horizon below an A horizon. The B horizon is in part a layer of transition from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics, such as (1) accumulation of clay, sesquioxides, humus, or a combination of these; (2) prismatic or blocky structure; (3) redder or browner colors than those in the A horizon; or (4) a combination of these.

C horizon = The mineral horizon or layer, excluding indurated bedrock, that is little

affected by soil-forming processes and does not have the properties typical of the overlying soil material. The material of a C horizon may be either like or unlike that in which the solum formed. If the material is known to differ from that in the solum, an Arabic numeral, commonly a 2, precedes the letter C.

Cr horizon = Soft, consolidated bedrock beneath the soil.

R layer = Consolidated bedrock beneath the soil. The bedrock commonly underlies a C horizon, but it can be directly below an A or a B horizon.

## Humus

The well decomposed, more or less stable part of the organic matter in mineral soils<sup>1</sup>

## Impervious soil

A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.<sup>1</sup>

## Infiltration

The downward entry of water into the immediate surface of soil or other material, as contrasted with percolation, which is movement of water through soil layers or material<sup>1</sup>

## Infiltration capacity

The maximum rate at which water can infiltrate into a soil under a given set of conditions

## Infiltration rate

The rate at which water penetrates the surface of the soil at any given instant, usually expressed in inches per hour. The rate can be limited by the infiltration capacity of the soil or the rate at which water is applied at the surface.<sup>1</sup>

## Iron depletions

Low-chroma zones having a low content of iron and manganese oxide because of chemical reduction and removal, but having a clay content similar to that of the adjacent matrix. A type of redoximorphic depletion.<sup>1</sup>

## Leaching

The removal of soluble material from soil or other material by percolating water.<sup>1</sup>



## Loam

*Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles<sup>1</sup>*

## Loamy

*Texture group consisting of coarse sandy loam, sandy loam, fine sandy loam, very fine sandy loam, loam, silt loam, silt, clay loam, sandy clay loam, and silty clay loam soil textures<sup>3</sup>*

## Medium textured soil

*Very fine sandy loam, loam, silt loam, or silt<sup>1</sup>*

## Microrelief

*(i) Generically refers to local, slight irregularities in form and height of a land surface that are superimposed upon a larger landform, including such features as low mounds, swales, and shallow pits. See also gilgai, shrub-coppice dune, tree-tip mound, tree-tip pit.*

*(ii) Slight variations in the height of a land surface that are too small to delineate on a topographic or soils map at commonly used map scales (e.g., 1:24 000 and 1:15 840)<sup>3</sup>*

## Mineral soil

*Soil that is mainly mineral material and low in organic material. Its bulk density is more than that of organic soil.<sup>1</sup>*

## Moderately coarse textured soil

*Coarse sandy loam, sandy loam, or fine sandy loam<sup>1</sup>*

## Moderately deep soil

*See Depth*

## Moderately fine textured soil

*Clay loam, sandy clay loam, or silty clay loam<sup>1</sup>*

## Molecule

*The smallest particle of a substance that retains all the properties of the substance and is composed of one or more atoms<sup>4</sup>*

## Morphology, soil

*The physical makeup of the soil, including the texture, structure, porosity, consistence, color, and other physical, mineral, and biological properties of the various horizons, and the thickness and arrangement of those horizons in the soil profile<sup>1</sup>*

## Mottling, soil

*Irregular spots of different colors that vary in number and size. Descriptive terms are as follows: abundance: few, common, and many; size: fine, medium, and coarse; and contrast: faint, distinct, and prominent. The size measurements are of the diameter along the greatest dimension. Fine indicates less than 5 millimeters (about 0.2 inch); medium, from 5 to 15 millimeters (about 0.2 to 0.6 inch); and coarse, more than 15 millimeters (about 0.6 inch).<sup>1</sup>*

## Muck

*Unconsolidated soil material consisting primarily of highly decomposed organic material in which the original plant parts are not recognizable (i.e., "sapric" in Soil Taxonomy). It generally contains more mineral matter and is usually darker in color, than peat.<sup>2</sup>*

## Munsell notation

*A designation of color by degrees of three simple variables: hue, value, and chroma. For example, a notation of 10YR 6/4 is a color with hue of 10YR, value of 6, and chroma of 4.*

## Neutral soil

*A soil having a pH value of 6.6 to 7.3 (see Reaction, soil)<sup>1</sup>*

## Nutrient, plant

*Any element taken in by a plant that is essential to its growth. Plant nutrients are mainly nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, boron, and zinc obtained from the soil and carbon, hydrogen, and oxygen obtained from the air and water.<sup>1</sup>*

## OM

*See Organic matter*

## Order

*The highest level (most general) of soil classification according to Soil Taxonomy. There are twelve orders: andisols, alfisols, aridisols, entisols, gelisols, histosols, inceptisols, mollisols, oxisols, spodosols, ultisols and vertisols.*

## Organic matter (OM)

*Plant and animal residue in the soil in various stages of decomposition<sup>1</sup>*

## Oxidation

*The loss of one or more electrons by an ion or molecule<sup>3</sup>*

**Pan**

*A compact, dense layer in a soil that impedes the movement of water and the growth of roots. For example, hardpan, fragipan, claypan, plowpan, and traffic pan.<sup>1</sup>*

**Parent material**

*The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum is developed by pedogenic processes<sup>2</sup>*

**Peat**

*Unconsolidated soil material consisting largely of undecomposed, or slightly decomposed, organic matter (i.e., “fibric” in Soil Taxonomy) accumulated under conditions of excessive moisture<sup>2</sup>*

**Ped**

*An individual natural soil aggregate, such as a granule, a prism, or a block*

**Pedogenesis**

*See Genesis, soil*

**Pedology**

*Soil science, especially the study of soils as a natural body*

**Pedon**

*The smallest volume that can be called “a soil.” A pedon is three dimensional and large enough to permit study of all horizons. Its area ranges from about 10 to 100 square feet (1 square meter to 10 square meters), depending on the variability of the soil.<sup>1</sup>*

**Percolation**

*The downward movement of water through the soil<sup>1</sup>*

**Permeability**

*The quality of the soil that enables water or air to move downward through the profile. The rate at which a saturated soil transmits water is accepted as a measure of this quality. In soil physics, the rate is referred to as “saturated hydraulic conductivity,” which is defined in the Soil Survey Manual. In line with conventional usage in the engineering profession and with traditional usage in published soil surveys, this rate of flow continues to be expressed as “permeability.” Terms describing permeability, measured in inches per hour, are as follows: <sup>1</sup>*

*Permeability class      rate per hour*

*Extremely slow      0.0 to 0.01 inch*

*Very slow      0.01 to 0.06 inch*

*Slow      0.06 to 0.2 inch*

*Moderately slow      0.2 to 0.6 inch*

*Moderate      0.6 inch to 2.0 inches*

*Moderately rapid      2.0 to 6.0 inches*

*Rapid      6.0 to 20 inches*

*Very rapid      more than 20 inches*

**pH value**

*A numerical designation of acidity and alkalinity in soil. (See Reaction, soil.)<sup>1</sup>*

**Plowpan**

*A compacted layer formed in the soil directly below the plowed layer<sup>1</sup>*

**Ponding**

*Standing water on soils in closed depressions. Unless the soils are artificially drained, the water can be removed only by percolation or evapotranspiration.<sup>1</sup>*

**Potential rooting depth (effective rooting depth)**

*Depth to which roots could penetrate if the content of moisture in the soil were adequate. The soil has no properties restricting the penetration of roots to this depth.<sup>1</sup>*

**Profile, soil**

*A vertical section of the soil extending through all its horizons and into the parent material<sup>1</sup>*

**Reaction, soil**

*A measure of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is described as precisely neutral in reaction because it is neither acid nor alkaline. The degrees of acidity or alkalinity, expressed as pH values, are: <sup>1</sup>*

*Reaction class      pH*

*Ultra acid      less than 3.5*

*Extremely acid      3.5 to 4.4*

*Very strongly acid      4.5 to 5.0*

*Strongly acid      5.1 to 5.5*

*Moderately acid      5.6 to 6.0*

*Slightly acid      6.1 to 6.5*

*Neutral      6.6 to 7.3*

<i>Slightly alkaline</i>	7.4 to 7.8
<i>Moderately alkaline</i>	7.9 to 8.4
<i>Strongly alkaline</i>	8.5 to 9.0
<i>Very strongly alkaline</i>	9.1 and higher

#### Redoximorphic concentrations

*Nodules, concretions, soft masses, pore linings, and other features resulting from the accumulation of iron or manganese oxide. An indication of chemical reduction and oxidation resulting from saturation.<sup>1</sup>*

#### Redoximorphic depletions

*Low-chroma zones from which iron and manganese oxide or a combination of iron and manganese oxide and clay has been removed. These zones are indications of the chemical reduction of iron resulting from saturation.<sup>1</sup>*

#### Redoximorphic features

*Redoximorphic concentrations, redoximorphic depletions, reduced matrices, a positive reaction to alpha, alpha-dipyridyl, and other features indicating the chemical reduction and oxidation of iron and manganese compounds resulting from saturation.*

#### Reduction

*The gain of one or more electrons by an ion or molecule<sup>3</sup>*

#### Relief

*The relative difference in elevation between the upland summits and the lowlands or valleys of a given region<sup>3</sup>*

#### Rock fragments

*Rock or mineral fragments having a diameter of 2 millimeters or more; for example, gravel, cobbles, stones, and boulders<sup>1</sup>*

#### Root zone

*The part of the soil that can be penetrated by plant roots<sup>1</sup>*

#### Runoff

*The precipitation discharged into stream channels from an area. The water that flows off the surface of the land without sinking into the soil is called surface runoff. Water that enters the soil before reaching surface streams is called groundwater runoff or seepage flow from groundwater.<sup>1</sup>*

#### Saline soil

*A nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set at 4 dS/m (mmhos/cm) at 25°C. Actually, sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.<sup>3</sup>*

#### Saline-sodic soil

*A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable sodium ratio is greater than 0.15, the conductivity of the soil solution, at saturated water content, of greater than 4 dS/m (at 25°C), and the pH is usually 8.5 or less in the saturated soil.<sup>3</sup>*

#### Salinity

*A measure of the “saltiness” of the soil expressed as the electrical conductivity of a saturation extract in decisiemens per meter (dS/m=mmhos/cm) at 25°C.*

*The following salinity classes are recognized:<sup>2</sup>*

<i>Salinity class</i>	<i>mbhos/cm</i>
<i>Non-saline</i>	0 - 2
<i>Very slightly saline</i>	2 - 4
<i>Slightly saline</i>	4 - 8
<i>Moderately saline</i>	8 - 16
<i>Strongly saline</i>	> 16

#### Sand

*As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter. Most sand grains consist of quartz. As a soil textural class, a soil that is 85 percent or more sand and not more than 10 percent clay.<sup>1</sup>*

#### Sandy

*Texture group consisting of sand and loamy sand textures.<sup>3</sup>*

#### SAR

*See sodium adsorption ratio*



## Saturation

Wetness characterized by zero or positive pressure of the soil water. Under conditions of saturation, the water will flow from the soil matrix into an unlined auger hole.<sup>1</sup>

## Series, soil

A group of soils that have profiles that are almost alike, except for differences in texture of the surface layer. All the soils of a series have horizons that are similar in composition, thickness, and arrangement (see soil classification).<sup>1</sup>

## Shallow soil

See *Depth*

## Silica

A combination of silicon and oxygen. The mineral form is called quartz.<sup>1</sup>

## Silt

As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). As a soil textural class, soil that is 80 percent or more silt and less than 12 percent clay.<sup>1</sup>

## Slick spot

A small area of soil having a puddled, crusted, or smooth surface and an excess of exchangeable sodium. The soil generally is silty or clayey, is slippery when wet, and is low in productivity.<sup>1</sup>

## Slope

The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance.<sup>2</sup>

## Slope aspect

The direction toward which the surface of the soil (or slope) faces<sup>2</sup>

## Sodic (alkali) soil

A soil having so high a degree of alkalinity (pH 8.5 or higher) or so high a percentage of exchangeable sodium (15 percent or more of the total exchangeable bases), or both, that plant growth is restricted<sup>1</sup>

## Sodicity

The degree to which a soil is affected by exchangeable sodium.<sup>1</sup> See sodium adsorption ratio. The following categories are commonly used in California:

Sodicity	SAR
Slight	less than 13:1
Moderate	13-30:1
Strong	more than 30:1

## Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the water extract from saturated soil paste. It is the ratio of the Na concentration divided by the square root of one-half of the Ca + Mg concentration.<sup>2</sup> SAR is calculated from the equation:

$$SAR = Na / [(Ca + Mg)/2]^{0.5}$$

## Soil

A natural, three-dimensional body at the earth's surface. It is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time.<sup>1</sup>

## Soil classification

The systematic grouping of soils based on their characteristics. The system used in the United States is called Soil Taxonomy. Soil Taxonomy uses the following levels grouping (from most general to most specific): order, suborder, great group, subgroup, family and series.

## Soil separates

Mineral particles less than 2 millimeters in equivalent diameter and ranging between specified size limits. The names and sizes, in millimeters, of separates recognized in the United States are as follows:<sup>1</sup>

Name	Size in mm
Very coarse sand	2.0 to 1.0
Coarse sand	1.0 to 0.5
Medium sand	0.5 to 0.25
Fine sand	0.25 to 0.10
Very fine sand	0.10 to 0.05
Silt	0.05 to 0.002
Clay	less than 0.002

### Stones

Rock fragments 10 to 24 inches (25 to 60 centimeters) in diameter if rounded or 15 to 24 inches (38 to 60 centimeters) in length if flat<sup>1</sup>

### Stony

Refers to a soil containing stones in numbers that interfere with or prevent tillage<sup>1</sup>

### Structure, soil

The arrangement of primary soil particles into compound particles or aggregates. The principal forms of soil structure are: platy (laminated), prismatic (vertical axis of aggregates longer than horizontal), columnar (prisms with rounded tops), blocky (angular or subangular), and granular. Structureless soils are either single grained (each grain by itself, as in dune sand) or massive (the particles adhering without any regular cleavage, as in many hardpans).<sup>1</sup>

### Subgroup

See Soil Classification

### Suborder

See Soil Classification

### Subsoil

Technically, the B horizon; roughly, the part of the solum below plow depth<sup>1</sup>

### Surface layer

The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, ranging in depth from 4 to 10 inches (10 to 25 centimeters). Frequently designated as the “plow layer,” or the “Ap horizon.”<sup>1</sup>

### Surface soil

The A, E, AB, and EB horizons, considered collectively. It includes all subdivisions of these horizons.<sup>1</sup>

### Texture, soil

The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. The sand, loamy sand, and sandy loam classes may be further divided by specifying “coarse,” “fine,” or “very fine.”<sup>1</sup>

### Tilth, soil

The physical condition of the soil as related to tillage, seedbed preparation, seedling emergence, and root penetration<sup>1</sup>

### Topsoil

The upper part of the soil, which is the most favorable material for plant growth. It is ordinarily rich in organic matter and is used to topdress roadbanks, lawns, and land affected by mining.

### Very deep soil

See Depth

### Very shallow soil

See Depth

### Water table

The upper surface of ground water or that level below which the soil is saturated by water. Also the top of an aquifer.<sup>1</sup>

### Weathering

All physical and chemical changes produced in rocks or other deposits at or near the earth's surface by atmospheric agents. These changes result in disintegration and decomposition of the material.<sup>1</sup>



# 2.2 Soil Chemistry and Fertility

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# Introduction: Soil Chemistry and Fertility

## UNIT OVERVIEW

*This unit introduces students to the basic concepts of soil chemistry, with an emphasis on how soil chemistry relates to the development and maintenance of soil fertility.*

*The unit begins with a review of basic chemistry concepts and terminology, including atoms, compounds, ions, and chemical reactions. Soil nutrients essential to plant growth and the processes involved in nutrient uptake are then introduced, with particular attention paid to cation exchange capacity and base saturation as it relates to soil fertility. Soil pH and its effects on nutrient availability is then introduced.*

*The unit concludes with an overview of the biogeochemical cycles involved in making essential nutrients available to plants; the physiological role of essential plant nutrients; the characteristic symptoms of plant nutrient deficiencies; and the soil amendments used to supply limiting nutrients for organic farming systems.*

## MODES OF INSTRUCTION

### > LECTURE (1 LECTURE, 3.0 HOURS)

The lecture covers basic chemistry concepts and definitions relating to soil chemistry, in particular, nutrient uptake processes and plant nutrients. Each plant nutrient is discussed individually.

### > DEMONSTRATIONS

Five suggested demonstrations are designed to be integrated into the lecture. They provide visual representations and analogies for the concepts presented in the outline.

### > ASSESSMENT QUESTIONS (1.0 HOUR)

Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- Basic chemistry concepts (atomic structure and atomic bonding) and terminology
- Principles and processes involved in cation exchange
- pH and its effects on nutrient availability
- Soil acidity
- Soil alkalinity
- Plant nutrients — what they are, movement in the soil, cycling, their use in plants, and nutrient deficiency problems

### SKILLS

This material is primarily conceptual, providing background for the skill-based sessions in Part 1

**REQUIRED READINGS (SEE RESOURCES SECTION)**

Gershuny, Grace. 1993. *Start With the Soil*, Chapter 5; Chapter 7, pages 163-173; Chapter 8, pages 187-195; Chapter 9, pages 200-205

Brady, Nyle C., and Ray R. Weil. 1999. *The Nature and Properties of Soils*, Chapter 1, 1.15-1.16 (pp. 23-27); Chapter 16: 16.1-16.4 (pp. 612-625); 16.12 (pp. 645-646)

**RECOMMENDED READINGS**

Stell, Elizabeth P. 1998. *Secrets to Great Soil*, Chapter 2; Chapter 6; Chapter 7, pp. 150-157

Parnes, Robert. 1990. *Fertile Soil: A Grower's Guide to Organic and Inorganic Fertilizers*, Chapter 2, pp. 9-19; Chapter 16 (micronutrients)

# Lecture Outline: Soil Chemistry and Fertility

## *for the instructor*

### **A. Pre-Assessment Questions**

1. What are some of the essential plant nutrients?
2. How do plants obtain them from the soil?
3. What may happen if levels of one essential plant nutrient are very low or very high?
4. What is soil pH and why is it important to know the pH of your soil?
5. How does the organic matter content of the soil influence soil fertility?

### **B. Introduction to Basic Chemistry Concepts**

1. Atoms and elements
2. Compounds, molecules, and atomic bonds
3. Ions
4. Elements needed by plants
5. Chemical reactions
6. Adsorption vs. absorption
7. Organic vs. organic

### **C. Soil Colloids**

1. Definition
2. Importance

### **D. Soil Solution**

1. Definition

### **E. Cation Exchange Capacity (CEC) and Base Saturation**

1. CEC
  - a) Measurement (meq/100g soil or cmol/kg [new units, numbers are the same])
  - b) Factors influencing CEC
2. Base saturation
  - a) Definitions
  - b) Significance

### **F. Anion Exchange**

1. Introduction
2. Definitions

### **G. pH**

1. What is pH?
2. Effect of pH on nutrient availability and uptake

### **H. Acidity**

1. Definitions
2. Distribution of acid soils



3. Problems associated with acidity
4. Acid soils and liming

### **I. Alkalinity, Alkali, Salinity, and Sodic Soils**

1. Definitions
2. Some elements contributing to alkalinity
3. Salinity (Electrical Conductivity–EC)
4. Sodicity
5. Distribution

### **J. Soil as a Medium for Plant Growth**

1. Nutrient uptake processes

### **K. Plant Nutrient Requirements**

1. Introduction
  - a) Nutrient balance
  - b) Feed the plant or feed the soil
  - c) Macronutrients and micronutrients
  - d) Nutrient cycling
  - e) Mobility of nutrients within the plant
2. Carbon, Hydrogen, and Oxygen
3. Nitrogen
  - a) Physiological role in plant development
  - b) Soil nutrient deficiencies, imbalances, toxicity
  - c) Forms of nitrogen in the soil
  - d) Nitrogen fixation
  - e) Nitrogen and mineralization
  - f) Denitrification
  - g) Immobilization
  - h) Losses of nitrogen through leaching and volatilization
  - i) Supplying nitrogen to the soil
  - j) The nitrogen cycle
4. Phosphorus
  - a) Physiological role in plant development
  - b) Soil nutrient deficiencies, imbalances, toxicity
  - c) The phosphorus cycle
  - d) Phosphorus in soils and factors affecting its availability
  - e) Phosphorus in amendments
5. Potassium
  - a) Physiological role in plant development
  - b) Soil nutrient deficiencies, imbalances, toxicity
  - c) The potassium cycle
  - d) Potassium in soils and factors affecting its availability
  - e) Potassium in amendments

6. Other macronutrients: Calcium, Magnesium, Sulfur

- a) Calcium
- b) Magnesium
- c) Sulfur

7. Micronutrients

- a) Introduction
- b) Boron ( $B_4O_7^{2-}$ )
- c) Copper ( $Cu^{2+}$ ),
- d) Iron ( $Fe^{2+}$ ,  $Fe^{3+}$ )
- e) Manganese ( $Mn^{2+}$ )
- f) Molybdenum ( $MoO_4^{2-}$ )
- g) Zinc ( $Zn^{2+}$ )
- h) Cobalt ( $Co^{2+}$ )
- i) Chlorine ( $Cl^-$ )
- j) Others



# Detailed Lecture Outline: Soil Chemistry

## *for students*

### **A. Pre-Assessment Questions**

1. What are some of the essential plant nutrients?
2. How do plants obtain them from the soil?
3. What may happen if levels of one essential plant nutrient are very low or very high?
4. What is soil pH and why is it important to know the pH of your soil?
5. How does the organic matter content of the soil influence soil fertility?

### **B. Introduction to Basic Chemistry Concepts**

1. Atoms and elements

Elements: basic unit of matter that can't be broken down by chemical means. They are the building blocks of nature. Each element is assigned a symbol of one or more letters derived from its Latin name. For example O is used for oxygen while Fe is used for iron.

Atoms: smallest part of an element that acts like that element.

The components of the atom are the proton, the neutron and the electron. The proton has a positive electrical charge and the neutron has no electrical charge. Protons and neutrons are in the center of the atom in what is called the nucleus. Usually there are an equal number of protons and neutrons +/- 1. Electrons are negatively charged and they orbit the nucleus.

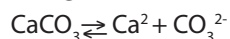
2. Compounds, molecules, and atomic bonds

Atoms combine to form molecules. A collection of like molecules that consist of two or more different kinds of elements is called a compound. Molecules are represented by using the symbols of the elements with subscripts to tell how many there are of each. For example, water is represented as H<sub>2</sub>O, which means it has two hydrogen atoms and one oxygen atom.

One way that different atoms can join together is by sharing electrons. This is a type of chemical bond or atomic bond.

3. Ions

A normal molecule has an equal number of protons (+) and electrons (-). Because of this they have a net charge of 0. Frequently, however, an imbalance occurs and the resulting atoms or molecules are called ions. This frequently happens when something dissolves in water. A cation is a positively charged ion (missing electrons), an anion is a negatively charged ion (has surplus electrons). An example is given below. In that example the superscripts indicate the number of ions missing (+) or surplus (-). If no number is given then it means only 1 electron is missing or surplus. A molecule in solution is usually in equilibrium with its constituent ions. In other words, some molecules are breaking into ions while other ions are recombining to form molecules.



Where:

CaCO<sub>3</sub> = Calcium Carbonate

Ca<sup>2+</sup> = Calcium (cation)

CO<sub>3</sub><sup>2-</sup> = Carbonate (anion)

#### 4. Elements needed by plants

##### a) From water and air

Carbon (C), Hydrogen (H), Oxygen (O)

##### b) From soil

Nitrogen (N), Phosphorus (P), Sulfur (S), Potassium (K), Calcium (Ca), Magnesium (Mg), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), Boron (B), Molybdenum (Mo), Cobalt (Co), Chlorine (Cl)

#### 5. Chemical reactions

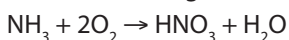
Chemical reactions occur when atoms are rearranged to form new molecules or compounds. For example, carbon dioxide and water can combine to form a sugar (as in photosynthesis). This reaction is written out like this:



(Note that since energy is required to make the reaction happen, this energy is released when the sugars are broken down. This opposite equation is called respiration and it is what happens in our bodies all the time.)

Oxidation/reduction reactions are special kinds of reactions that are very common and important in nature. Oxidation occurs when an element or molecule loses an electron and some other element or molecule gains the electron (reduction). The electron donor is said to be oxidized and the electron acceptor is referred to as reduced. The term "oxidized" is used because it is usually oxygen that accepts the electrons (and thus increases in quantity in the new molecule).

A common oxidation reaction occurs in the soil when ammonia is added. Ammonia is oxidized to form nitric acid (notice how oxygen becomes part of the new molecule in this equation). This equation also shows why long-term use of ammonia fertilizers can acidify a soil even though ammonia is a strong base.



(ammonia + oxygen → nitric acid + water)

#### 6. Adsorption vs. absorption

Adsorption and absorption are two terms used in soil science that can get confused.

Adsorption means to be held onto the outside of something. In soils this refers to how ions are held to the edges of mineral and organic particles.

Absorption means to be taken up into something, such as water being taken up by a sponge or nutrients taken into plant roots.

Picture a life raft at sea. Absorbed would be the people in the life raft, adsorbed would be the people hanging to the outside of the life raft.

#### 7. Organic vs. organic

Organic is another confusing term. To the chemist, organic refers to many kinds of compounds containing carbon, which may be natural or synthetic. Many of the synthetic pesticides used are organic by this definition.

Organic also refers to agricultural techniques based on maintaining soil fertility through organic matter. Such systems do not use synthetic organic chemicals, but they may use naturally occurring inorganic soil amendments.

## C. Soil Colloids

### 1. Definition

Colloid: A particle, which may be a molecular aggregate, with a diameter of 0.1 to 0.001  $\mu\text{m}$ . Soil clays and soil organic matter are often called soil colloids because they have particle sizes that are within or approach colloidal dimensions. Colloids go into suspension in a solution — they float around without settling out for great lengths of time.

### 2. Importance

Colloids have properties that are important in soil chemistry, such as the ability to adsorb cations

## D. Soil Solution

### 1. Definition

Usually the water in the soil is referred to as the soil solution because it contains dissolved materials (cations and ions) as well as suspended colloids of clay and organic matter.

While plants tend to get their nutrients from the soil solution, the solution does not contain sufficient nutrients at any one time to last the life of the plant. Usually these nutrients are replenished from the pool of exchangeable nutrients (those that are adsorbed onto colloids; see CEC, below). Still more nutrients are held in what is called the stable pool (bound up in solid form as minerals or organic matter).

## E. Cation Exchange Capacity (CEC) and Base Saturation

### 1. CEC

Definition: Ability of the soil to adsorb cations

It is primarily the ionic form of nutrients that plants are able to take up into their roots. Many of these nutrients are taken up in the cationic form, so it is important that the soil be able to supply these. Most soils have at least some ability to hold onto these ions at negatively charged sites within the soil. These sites are called exchange sites. The cations are held loosely to the edges (adsorbed) such that they can be easily replaced with similarly charged cations. (Use magnets to demonstrate attraction of positive to negative). The total amount of the cations that the soil can hold in such a fashion is the cation exchange capacity (CEC).

The cations in the soil are divided into acids and bases. The acids are predominantly hydrogen and aluminum. The bases are primarily calcium, magnesium, sodium, and potassium.

A more technical definition of CEC would be:

The sum of exchangeable bases plus total soil acidity at a specific pH value, usually 7.0 or 8.0. When acidity is expressed as salt-extractable acidity, the cation exchange capacity is called the effective cation exchange capacity (ECEC) because this is considered to be the CEC of the exchanger at the native pH value. It is usually expressed in centimoles of charge per kilogram of exchanger ( $\text{cmol kg}^{-1}$ ) or millimoles of charge per kilogram of exchanger.

a) Measurement ( $\text{meq}/100\text{g}$  soil or  $\text{cmol}/\text{kg}$  [new units, numbers are the same])

b) Factors influencing CEC

#### i. Amount and type of clay

Higher amounts of clay mean higher CEC. Certain kinds of clay (smectites, montmorillonite) have higher CEC than others (such as kaolinite).

#### ii. Amount of organic matter

Higher amounts of organic matter mean higher CEC

#### iii. pH dependent CEC

Amorphous clay minerals and organic matter have a CEC that varies with pH. As pH increases, so does the CEC. Under acid conditions, these have an anion exchange capacity. For organic matter the rule of thumb is that for every pH unit above 4.5 there is a 1  $\text{meq}/100\text{g}$  increase for each percent organic matter.

## 2. Base saturation

### a) Definitions

In simple terms, base saturation refers to the percentage of exchange sites (negatively charged sites on clay and organic particles) that are occupied with bases (usually  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$  and  $\text{Na}^+$ ) as opposed to ions that make the soil acid ( $\text{H}^+$  or  $\text{Al}^{3+}$ ). A more technical definition is the ratio of the quantity of exchangeable bases to the cation exchange capacity. The value of the base saturation varies according to whether the cation exchange capacity includes only the salt extractable acidity (see cation exchange capacity) or the total acidity determined at pH 7 or 8. Often expressed as a percent.

The term *exchangeable bases* usually refers to the  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$  and  $\text{Na}^+$  adsorbed to exchange sites.

### b) Significance

Soils with high base saturations are considered more fertile because many of the “bases” that contribute to it are plant nutrients. Usually the base saturation is 100 percent when the pH is above about 6.5. Since rainfall tends to leach bases out of the soil, areas with higher rainfall tend to have lower base saturations than areas with lower rainfall, unless the parent material is high in bases (such as limestone).

## F. Anion Exchange

### 1. Introduction

Anions are not adsorbed onto soil particles to anywhere near the extent that cations are. This is due to the fact that clay minerals only have negative charges and that most of the exchange sites in organic matter also have negative charges.

Many of the anionic nutrients are supplied through organic amendments from which they are released as the organic matter breaks down. Because there is little adsorption of the anions, many (particularly nitrates) are easily leached, which can lead to groundwater contamination. This can even happen in an organic farming situation if it is not well managed.

Nutrients that are usually supplied by anions are nitrogen ( $\text{NO}_3^-$ ), phosphorus ( $\text{H}_2\text{PO}_4^-$ ;  $\text{HPO}_4^{2-}$ ), sulfur ( $\text{SO}_4^{2-}$ ), chlorine ( $\text{Cl}^-$ ), boron ( $\text{B}_4\text{O}_7^{2-}$ ) and molybdenum ( $\text{MoO}_4^{2-}$ ).

### 2. Definitions

**Anion exchange capacity:** The sum of exchangeable anions that a soil can adsorb. Usually expressed as centimoles, or millimoles, of charge per kilogram of soil (or of other adsorbing material such as clay).

**Exchangeable anion:** A negatively charged ion held on or near the surface of a solid particle by a positive surface charge and which may be easily replaced by other negatively charged ions (e.g. with a  $\text{Cl}^-$  salt).

## G. pH

### 1. What is pH?

pH stands for “potential of hydrogen” and it is expressed as the negative of the log of the concentration of hydrogen ions (moles per liter); it is a number between 0 and 14. (Water,  $\text{H}_2\text{O}$  or  $\text{HOH}$  is usually in equilibrium with its constituent ions,  $\text{H}^+$  and  $\text{OH}^-$  and has a pH of 7.) In acid soils (pH < 7),  $\text{H}^+$  ions predominate. In alkaline soils (pH > 7),  $\text{OH}^-$  ions predominate. Soils with pH of 7 are neutral. (Demonstrate different methods of measuring pH; see pH demonstration in Demonstrations.)

**TABLE 1. SOIL REACTION AND pH**

REACTION	pH	REACTION	pH
Ultra acid	< 3.5	Neutral	6.6 – 7.3
Extremely acid	3.5 – 4.4	Slightly alkaline	7.4 – 7.8
Very strongly acid	4.5 – 5.0	Moderately alkaline	7.9 – 8.4
Strongly acid	5.1 – 5.5	Strongly alkaline	8.5 – 9.0
Moderately acid	5.6 – 6.0	Very strongly alkaline	> 9.0
Slightly acid	6.1 – 6.5		

## 2. Effect of pH on nutrient availability and uptake (see Figure 1)

pH does not directly affect plants. It does affect the availability of different nutrients and toxic elements to plants. This is mostly due to the fact that pH changes the form of many of the nutrients and many of the forms are relatively insoluble.

## H. Acidity

### 1. Definitions

Acidity refers to the condition of the soil when the exchange complex is dominated by hydrogen and aluminum ions. There are two forms of soil acidity; their technical definitions are:

Acidity, salt-replaceable: The aluminum and hydrogen that can be replaced from an acid soil by an unbuffered salt solution such as KCl or NaCl. (Also known as exchangeable acidity.)

Acidity, total: The total acidity including residual and exchangeable acidity. Often it is calculated by subtraction of exchangeable bases from the cation exchange capacity determined by ammonium exchange at pH 7.0. It can be determined directly using pH buffer-salt mixtures (e.g., BaCl<sub>2</sub> plus triethanolamine, pH 8.0 or 8.2) and titrating the basicity neutralized after reaction with a soil.

### 2. Distribution of acid soils

Acid soils usually occur where there is sufficient rainfall or other sources of precipitation to leach the bases out of the soil. When this happens, the exchange complex becomes dominated by hydrogen (lowers pH) and aluminum (toxic). In the U.S. there is a fairly strong correlation between precipitation and pH, with soils receiving more than about 30 inches of annual precipitation having a pH less than 6. (See map on page 163 of *Start with the Soil*.)

### 3. Problems associated with acidity

Aluminum toxicity: Aluminum is the third most common element in the earth's crust. It becomes more available at low pH's, and can be toxic to plants.

Manganese toxicity: This may occur in soil that are high in Mn and that have a pH less than 5

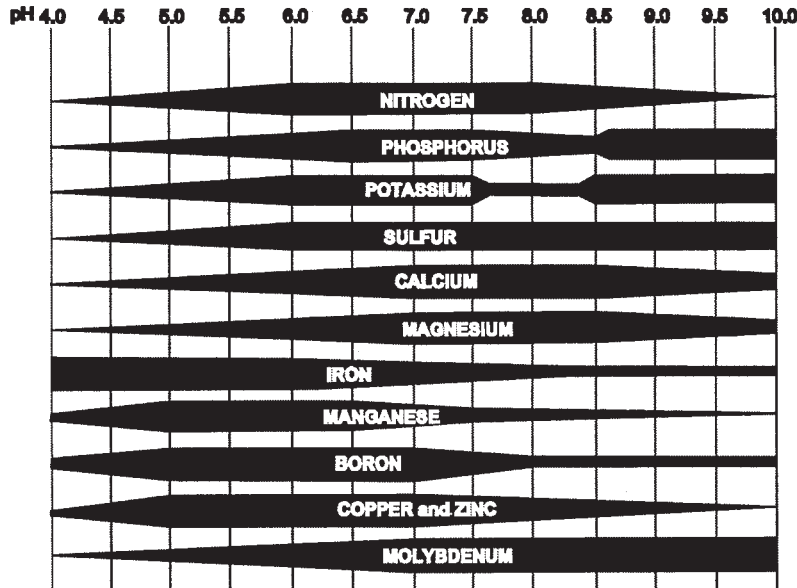
### 4. Acid soils and liming

Lime (calcium carbonate) is added to acid soils to raise the pH. Calcium replaces hydrogen and aluminum on exchange sites. For a good reference on liming, get the Soil Quality Technical note Number 8 from the website:

[soils.usda.gov/sqi/files/08d3.pdf](http://soils.usda.gov/sqi/files/08d3.pdf)



**FIGURE 1. NUTRIENT AVAILABILITY AT DIFFERENT pH VALUES. MAXIMUM AVAILABILITY IS INDICATED BY WIDEST PART OF BAR.**



## I. Alkalinity, Alkali, Salinity, and Sodic Soils

### 1. Definitions

**Alkalinity, soil:** The degree or intensity of alkalinity in a soil, expressed by a value  $>7.0$  for the soil pH

**Alkali soil:** (i) A soil with a pH of 8.5 or higher or with an exchangeable sodium percentage greater than 0.15 (ESP  $>15$ ). (ii) A soil that contains sufficient sodium to interfere with the growth of most crop plants. See also saline-sodic soil and sodic soil

**Saline soil:** A nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set at  $4 \text{ dS m}^{-1}$  (at  $25^\circ\text{C}$ ). Actually, sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.

**Sodic soil:** A nonsaline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most conditions of soil and plant type. The sodium adsorption ratio of the saturation extract is at least 13.

**Saline-sodic soil:** A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable sodium ratio is greater than 0.15, conductivity of the soil solution, at saturated water content, of  $>4 \text{ dS m}^{-1}$  (at  $25^\circ\text{C}$ ), and the pH is usually 8.5 or less in the saturated soil.

### 2. Some elements contributing to alkalinity

**Calcium:** Calcium is common in many soils in arid areas. It helps the soil to form aggregates. (Because it has a +2 charge (divalent), it can bind to two clay or organic particles). (Acid demonstration in Demonstrations)

**Magnesium:** Behaves similarly to calcium in helping to form aggregates.

**Potassium:** An important plant nutrient

**Sodium:** Toxic to plants at high levels

### 3. Salinity (Electrical Conductivity—EC) (see Salt Crust Example and Conductivity Demonstration in Demonstrations)

Salinity refers to the presence of salts. Since saline soils conduct electricity, it is usually measured as Electrical Conductivity—EC. The units for EC are mmhos/cm or dS/m (millimhos per centimeter or decisiemens per meter). A soil is considered saline if it has an  $EC > 4$  (though some plants cannot tolerate even this much). Saline soils mainly occur in dry areas. The reason plants cannot tolerate salinity is either due to the toxic effect of certain salts or to the fact that salts can hold on to the water so tightly that the plants cannot get it. Non-saline water may not infiltrate saline soils very easily. When irrigating saline soils with water that has a low salt content, it may be necessary to add gypsum to the water so that it will infiltrate the soil.

In order for there to be salts in the soil, there must be a source for them. For example, in many parts of California there are old marine beds, which contain salts that have been lifted into various mountain ranges. Also, feldspars usually contain some sodium that is released upon weathering. (The granite that makes up much of California is a source of such feldspars.) If there is sufficient rainfall to leach out these salts and if there is a watershed to carry the salts out to the ocean, then these salts won't be a problem. However, in many parts of California there is usually not enough precipitation to accomplish this and also, in many places, there are closed basins that do not drain to the ocean. Frequently, in these areas there are playas—salty basin floors that may hold intermittent, saline water.

The salts that usually contribute to soil salinity are magnesium ( $Mg^{2+}$ ), sodium ( $Na^+$ ), calcium ( $Ca^{2+}$ ), chloride ( $Cl^-$ ), sulfate ( $SO_4^{2-}$ ), bicarbonate ( $HCO_3^-$ ) and carbonate ( $CO_3^{2-}$ ).

### 4. Sodicity

Sodicity refers to the presence of sodium. Many saline soils are also sodic (though it is possible for a soil to be sodic and not saline). Sodium is toxic to plants. It also causes soil particles to disperse (separate), which causes cracking and sealing of the soil surface. Sodium in the soil is usually expressed in the term Sodium Adsorption Ratio (SAR), which reflects the degree to which the exchange sites in the soil are occupied by sodium (rather than other cations). A soil with a SAR greater than about 13 is considered to be sodic. Sometimes the term Exchangeable Sodium Percentage (ESP) is used instead. An ESP of 15 is roughly equivalent to a SAR of 13.

Sodic soils can be reclaimed with a two step process. First the sodium is flushed from exchange sites by adding amendments containing calcium (such as lime, gypsum or dolomite) or by adding sulfur followed by calcium. (The sulfur is converted to sulfuric acid by microbial activity. The acid reacts with lime to free calcium.) The next step is to leach out the sodium salts by providing water in excess of what the plant needs. This excess amount of water is called the leaching fraction.

### 5. Distribution

Alkaline soils usually occur where there is insufficient rainfall to leach the bases out of the soil, that is, where annual evapotranspiration is greater than the precipitation. (See map on page 167 of *Start with the Soil*.)

## J. Soil as a Medium for Plant Growth

### 1. Nutrient uptake processes

(This section is adapted from material produced by the University of Saskatchewan)

Imagine you are a tiny creature trying to move around in the soil. Can you imagine the millions of pores of all sizes and shapes, many of which are blocked by organic matter and mineral particles? The surfaces of these pores are very active and are capable of adsorbing ions and organic molecules. Once you have found your way around, the system changes with each wet-and-dry, or freeze-and-thaw cycle. Maybe a burrowing animal drops by and creates a real mess of your little world. In short, the soil is a constantly changing system that has numerous barriers to the movement of organisms and chemicals.

In terms of soil fertility we are greatly interested in the soil physical system. For a nutrient to be available for the plant to take up it must first be in the proper chemical form to pass the root membrane and most importantly it must be available at the root surface.

The movement of nutrients in soil is dependent on

- their concentration in soil solution;
- how strongly they are adsorbed by clays and organic matter,
- and how fast they can move.

For any given nutrient if we know how it moves in soil then we can use this information to formulate and place fertilizers.

As an example: phosphorus exists in soil solution as the orthophosphate ion ( $\text{H}_2\text{PO}_4^-$  or  $\text{HPO}_4^{2-}$ ) in very low concentrations and is strongly adsorbed by the soil surfaces. In contrast, nitrogen usually has a much greater concentration in soil solution (usually as  $\text{NO}_3^-$ ), and is very weakly adsorbed. Knowing these facts we then can determine that we must place phosphorus fertilizers very close to the seed to be effective, whereas nitrogen can be broadcast over the surface of the soil where it can be washed down to plant roots.

Nutrients move through the soil to plant roots in three ways

- Root Interception
- Mass Flow
- Diffusion

Each nutrient will have one or more of these methods of movement depending on its chemical form and soil physical and chemical conditions.

### **Root Interception**

When you are hungry, if no one brings you food, you need to go out and get it. The roots of plants are constantly expanding (opening up blocked pores as they do so) and they grow from areas of depleted nutrients (e.g., because of plant uptake) to other regions where nutrients are more concentrated. These nutrients may be adsorbed on soil surfaces or locked in fertilizer pellets.

Although many plants such as cereals and grasses have a very extensive root system, they only can contact less than 5% of the soil volume. The root interception mechanism is very valuable, however, because root growth can extend to areas where mass flow and diffusion take over. For example, a root could grow within a few millimeters of some soil phosphorus pellet. Although the root does not technically bump into the nutrient and intercept it, the root is close enough for diffusion to occur. In some cases, the presence of mycorrhizal fungi increases the nutrient-absorption capacity of root systems (see Unit 2.3, Soil Biology and Ecology).

### **Mass Flow**

Growing plants are continually absorbing water from the soil profile. Dissolved in this water are soluble nutrients. These nutrients are transported along with the water to the root surface. Nutrients that are strongly adsorbed to the soil surfaces, like phosphorus, would never get there. But nutrients, like nitrogen, that are held very weakly by soils readily move along with the water. Nutrients that move by mass flow are those that have a high concentration in soil solution relative to the plant requirements, e.g. nitrate and sulfate.

### **Diffusion**

The random movement of ions in response to thermal energy is called diffusion. Imagine you have a tank of water with a removable barrier in the middle. On one side of the barrier you have ink, the other side pure water. When you remove the barrier very slowly you will see the ink and water mixing due to random movement of molecules. This is the process of diffusion. Similarly if we place a particle of fertilizer into soil it will slowly dissolve and the solution will spread out slowly and mix with the soil solution. How slow is diffusion? Phosphorus will rarely move more than a few millimeters from a fertilizer granule in a whole growing season! It is very important that we place this fertilizer so that the root can intercept it. Diffusion is the dominant mechanism of movement for phosphorus and most of the micronutrients.

## K. Plant Nutrient Requirements

### 1. Introduction

#### a) Nutrient Balance

Before we begin our discussion of nutrient requirements, we need to consider the concept of balance. Even though it is easier to consider one nutrient at a time, it is important to think of plant needs holistically. Supplying one nutrient while ignoring other plant needs (nutrients and environmental factors) may not benefit the plant at all and, in fact, may be bad for the crop.

Justus von Liebig (1803–1873) analyzed plant samples and proposed a law of the minimum. This law states that plant growth is proportional to the amount available of the most limiting plant nutrient. For example, if I supply nitrogen sufficient to produce 70 bushels of wheat per acre but only supply enough phosphorus for 50 bushels per acre, then I will get only 50 bushels per acre (providing everything else is sufficient). This concept has since been expanded to include not only nutrients but also such things as water, temperature and other soil factors.

As important as Liebig's contributions are, they do not go far enough in addressing the situation holistically. In the above example, for instance, nitrogen that is applied in excess of what the crop will consume is in danger of being leached into the groundwater where it will become a pollutant. Also, application of too much of any one nutrient can be injurious. For example, if too much nitrogen is supplied to tomatoes relative to the amount of phosphorus supplied, the tomatoes may grow very pretty plants but not produce any fruit.

The advantage of organic farming and gardening is that natural and organic soil amendments, unlike many synthetic ones, frequently supply many more nutrients than the primary one for which it is used, especially in regard to micronutrients.

#### b) Feed the plant or feed the soil

One of the main distinctions of organic farming and gardening is its emphasis on feeding the soil rather than on feeding the plant (which most contemporary agricultural practices do). The idea is that if the soil is happy, the plant will be happy. However, we still need to keep in mind the nutrient needs of the plant, because the plant may need some nutrient of which the soil is perfectly content to do without.

The reason for this is that most soils are well suited to supply the needs of the native vegetation. And while a soil may have no problem supporting, let's say, southern hardwoods, it may be ill prepared to nurture a field of corn.

#### c) Macronutrients and micronutrients

Plant nutrients are divided into two categories. Macronutrients are those that build up the bulk of the plant and so are needed in large quantities. Micronutrients are needed in small quantities, but are no less important. However, deficiencies of these are less likely to occur. Macronutrients include nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. Micronutrients include boron, copper, iron, manganese, molybdenum, zinc, chlorine, and cobalt.

#### d) Nutrient cycling

The amount of each chemical element in the world (with some exceptions) is fixed. Consequently, if we remove all of one element from a location, it's not going to be available there anymore unless it gets put back. This is a very important consideration in soil chemistry and plant nutrition. Many nutrients never leave the farm and are recycled through the use of things like manures and compost. But many nutrients are exported from a farm (in the crop or down the sewer, for example), and there needs to be a way to replace those nutrients in the soil. Looking at things this way, farming and gardening are nothing more than moving ions and nutrients around.

Some of the details of different nutrient cycles will be considered further when individual nutrients are discussed.

e) Mobility of nutrients within the plant

Some nutrients are mobile within plants; others remain where they are. This affects how nutrient symptoms appear. Nutrients that are mobile can move from older leaves to newer, growing tissues when there is a deficiency of them. Consequently, when these are lacking, symptoms appear in the older (lower and inner) leaves first. Nutrients that are immobile cannot be translocated to young, new growth. As a result, deficiency symptoms will appear in younger (upper and outer) tissues first. Nutrients that are mobile include nitrogen, potassium, phosphorus, magnesium, molybdenum, and zinc. Nutrients that are immobile include sulfur, calcium, iron, manganese, boron, and copper.

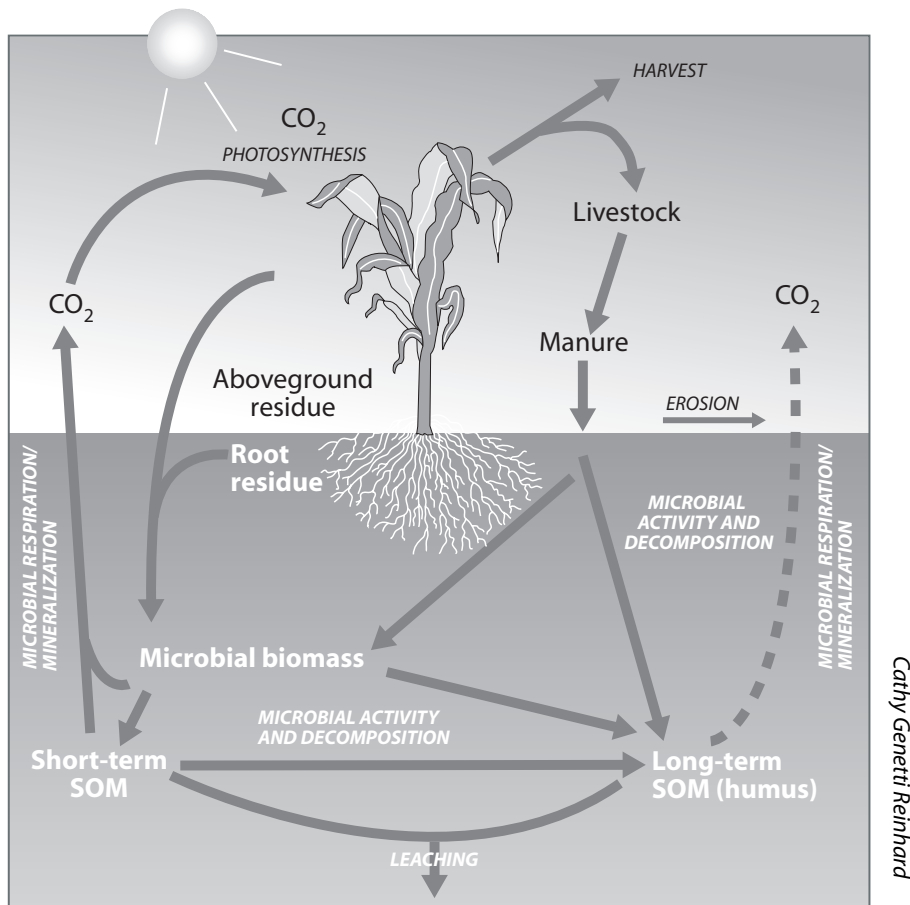
2. Carbon, hydrogen, and oxygen

Most of the bulk of plants and animals is made up of carbon, hydrogen and oxygen. A common term for these compounds is carbohydrates. Plants get these elements primarily from air (carbon dioxide—CO<sub>2</sub>) and water (H<sub>2</sub>O). This happens in the leaves of plants during photosynthesis:



Carbon is the core element of the large organic molecules that comprise all living things. It combines with elements such as hydrogen, oxygen, nitrogen, sulfur, phosphorus and other carbon atoms to form not only carbohydrates, but also fats, proteins and other compounds. In recent years there has been renewed interest in carbon due to its purported role in global warming. In some areas they are practicing carbon sequestration—an attempt to build up reserves of carbon in the soil to keep it from being released to the atmosphere as greenhouse gases.

FIGURE 2. THE CARBON CYCLE (ADAPTED FROM MICHIGAN STATE UNIVERSITY EXTENSION BULLETIN E-2646)



### 3. Nitrogen (N)

#### a) Physiological role in plant development

Plants take up nitrogen either as the ammonium ion ( $\text{NH}_4^+$ ) or nitrate ( $\text{NO}_3^-$ ). Most organic compounds in plants contain nitrogen, including amino acids, nucleic acids, many enzymes and energy transfer materials such as chlorophyll, ADP, and ATP. N is necessary for the production of sugars such as is found in sweet ripe fruit. Growing plants must have nitrogen to form new cells. Consequently, plants cannot function without nitrogen.

#### b) Soil nutrient deficiencies, imbalances, toxicity

Nitrogen deficiency symptoms include:

- Slow growth, stunted plants
- Yellow-green color (chlorosis)
- Firing (burnt look) of tips and margins of leaves beginning with more mature leaves
- Low protein content of crops

Symptoms of nitrogen excess include:

- Dark green, succulent, vegetative growth at the expense of seed production in grain crops, fruit production in tomatoes and some tree crops and sugar content in beets
- Watery potatoes
- Frost damage if there is too much succulent growth when frost hits
- Weakened stems (lodging)
- Flowering or fruiting delayed
- Boron or copper deficiency due to inhibited uptake of these nutrients

#### c) Forms of nitrogen in the soil

Nitrogen occurs in the soil in various forms

- Nitrogen gas in the soil air ( $\text{N}_2$ )
- Nitrate ( $\text{NO}_3^-$ )
- Nitrite ( $\text{NO}_2^-$ )
- Ammonium ( $\text{NH}_4^+$ )
- Ammonia ( $\text{NH}_3$ )—a gaseous (volatile), transitory form
- In various other forms as part of complex organic molecules frequently as an amine group ( $-\text{NH}_2$ )

#### d) Nitrogen fixation

Nitrogen gas makes up about 70% of the atmosphere. It is a very stable form of nitrogen, but it is unavailable to plants. Certain bacteria (Rhizobium) and actinomycetes (Frankia) are able to transform nitrogen gas into nitrate. This is called biological nitrogen fixation (as opposed to industrial nitrogen fixation carried out by chemical factories). The microbes form symbiotic relationships with plants in which the plants provide food to them and they provide nitrogen to the plants. Rhizobium is a genus of bacteria that work almost exclusively in plants of the bean (legume) family. Frankia are actinomycetes that are active with plants such as alder (*Alnus* spp.), bayberry (*Myrica* spp.), ornamental "olives" (*Elaeagnus* spp.), ceanothus (*Ceanothus* spp.) and Australian pine (*Casuarina* spp.). There are also some species of free-living cyanobacteria that are able to fix nitrogen. These frequently form cryptobiotic or microbiotic crusts that can be important parts of desert ecosystems. Some nitrogen fixing cyanobacteria live in conjunction with other organisms to form lichens.

In many cases, there may not be sufficient Rhizobium or Frankia in the soil to give a good boost to the crop. Or it may be that the type of Rhizobium is not the right species for the crop you are planting (not all Rhizobium species work with all species of legumes). In this case it may be necessary to inoculate the seed when the crop is planted. Inoculants are supplied by many of the companies that sell legume seed.

Inoculating legume seed does not mean that it will not be necessary to supply additional nitrogen to the crop. The Rhizobium themselves will need nitrogen to get started and the crop must have sufficient nitrogen to last until the Rhizobium are producing enough. Also, Rhizobium need sufficient phosphorus, iron, molybdenum, and cobalt in order to live.

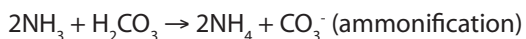
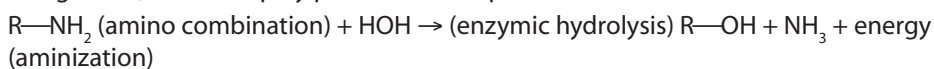
Nitrogen can also be fixed by lightning (with the nitrates then being carried to ground by rainfall), combustion (as in nitrous oxides in auto exhaust), or through synthetic processes (as in the manufacture of nitrogen fertilizers).

**TABLE 2.** COMPARISON OF NITROGEN FIXATION SOURCES.  
VALUES ARE IN MILLIONS OF METRIC TONS PER YEAR ON A GLOBAL BASIS (APPROXIMATE VALUES)

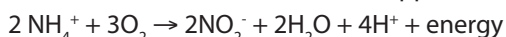
NON BIOLOGICAL		BIOLOGICAL	
Industrial	~50	Agricultural land	~90
Combustion	~20	Forest and other land	~50
Lightning	~10	Seas	~35
TOTAL	~80		~175

e) Nitrification and mineralization

Mineralization (aminization and ammonification) is the release of ammonium ions from decomposing organic matter. Many microbes are capable of doing this, so an environment that is favorable to microbial growth makes for fairly rapid ammonification. The ammonium that is produced is held in the soil solution, adsorbed onto cation exchange sites, or taken up by plants. An example of a mineralization reaction is:



Nitrification is a two stage process in which ammonium is transformed into nitrate (which is more readily taken up by plants). This, too, depends on microbial activity, but there are specific bacteria involved. *Nitrosomas* spp. (and a few others) oxidize ammonium to nitrite and *Nitrobacter* spp. oxidize nitrite to nitrate.



f) Denitrification

Nitrogen can be lost from wet soils where anaerobic (oxygen free) conditions occur. Under these conditions specialized bacteria can get their oxygen from nitrate (rather than oxygen), releasing nitrogen gas back into the atmosphere. This process is called denitrification. Though nitrogen can be lost from the ecosystem this way, denitrification can be a very useful function where excesses of nitrate occur in the soil. Note that even well drained soils may have parts that become anaerobic at some times.

To minimize denitrification one should maintain good aeration (structure) in the soil, keep the pH near neutral, avoid over-fertilization with nitrate, and incorporate residues in the upper few inches of the soil where there is more oxygen

g) Immobilization

Nitrogen is unavailable to plants (immobilized) when it is in the organic form. Usually, rates of mineralization in the soil are higher than rates of immobilization. However, if organic matter added to the soil has less than 1.5% N, the rate of immobilization will temporarily exceed the rate of mineralization, decreasing the amount of N available to plants.



- h) Losses of nitrogen through leaching and volatilization  
Nitrogen is one of the easiest nutrients lost from the system. Nitrogen, especially ammonia, is easily volatilized. Amendments left on the soil surface will rapidly lose the nitrogen value. Volatilization is higher with warmer temperatures.

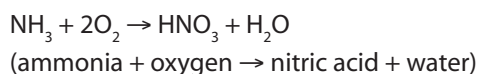
Nitrogen is also easily leached. This is not only a loss to the crop because the nitrates can contaminate the ground water, making it toxic. Leaching is most likely to occur in sandy soils, fallow areas, or in soils low in organic matter.

“The more one tries to force nitrogen into the soil, the greater are the chances of nitrogen losses” (Parnes, 1990, p. 75)

- i) Supplying nitrogen to the soil.

There are many ways that nitrogen can be supplied to the soil. These include green manures, crop rotation with leguminous crops, and amendments. Amendments that can be used to supply nitrogen include animal manures, guano, cottonseed meal, bone meal, hoof and horn meal, bloodmeal, peanut shells, and fish emulsion.

Care must be taken when using amendments high in ammonia (such as fresh poultry manure). Ammonia is a strong base that can “burn” plants. However, its use over an extended period of time will acidify the soil as bacteria oxidize the ammonia to form nitric acid. The chemical formula for this is:



- j) The nitrogen cycle (see Figure 3)

#### 4. Phosphorus (P)

- a) Physiological role in plant development

Phosphorus is present in all living cells. It is used by plants to form nucleic acids (DNA, RNA) and is used in the storage of energy trapped by photosynthesis and its transfer. Phosphorus also stimulates early growth and root formation and it hastens maturity (bloom time) and promotes seed production and size. It is used in protein synthesis and it is found in legume nodules.

- b) Soil nutrient deficiencies, imbalances, toxicity

Phosphorus must be balanced with nitrogen both in the plant and in the soil. In the soil, P and N compete to be taken up. Because N is highly mobile and P is one of the least mobile nutrients (both in the plant and in the soil), excessive N can cause a P deficiency even if there is enough P in the soil for the crop.

In the plant, N is required to trap energy, but P is required to facilitate its transfer. Also, N is a primary ingredient of protein but P is required for its synthesis.

#### CARBON-NITROGEN RATIOS

Microbial action can either mineralize or immobilize nitrogen. The main factor in determining which will happen is the carbon to nitrogen (C:N) ratio. Microbes use carbon (from organic matter) for bodybuilding as well as for energy. The nitrogen entering their bodies needs to be in a fixed ratio to the amount of carbon. The critical range of the C:N ratio is ~22:1 to 25:1. Ratios wider than this (caused by the addition of residues with a C:N ratio higher than this) will cause N to be immobilized. Narrower ratios will permit N to be freed as organic matter decomposes. Most plant residues have C:N ratios of 20:1-100:1; the bodies of microorganisms have a C:N ratio of 4:1 to 9:1. Usually the organic matter in the soil stabilizes with a C:N ratio somewhere between 8:1 to 15:1.

#### NITRATE TOXICITY

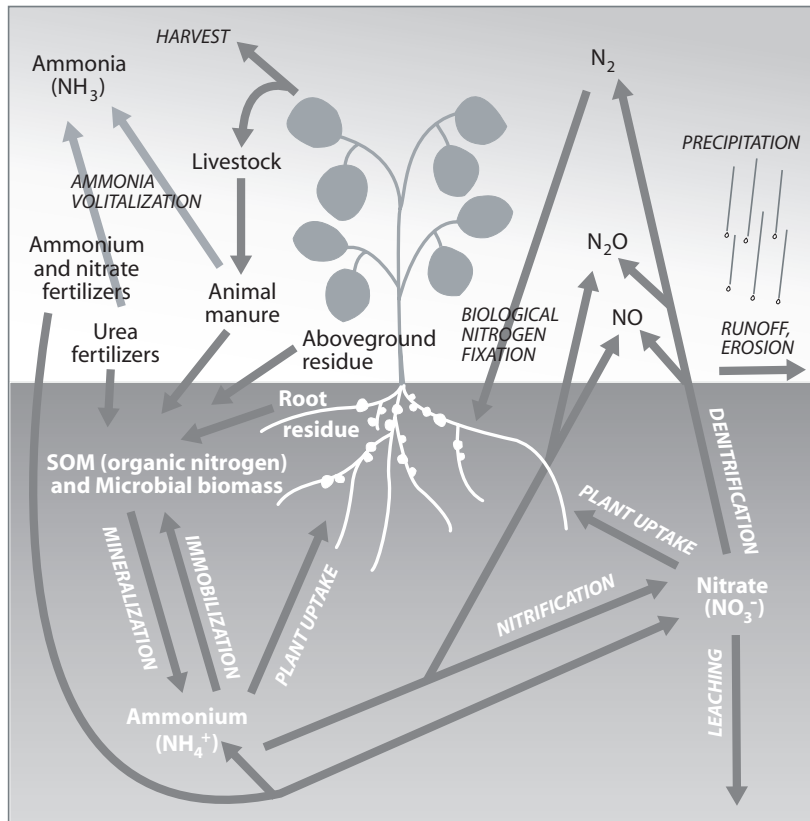
When nitrate is consumed, it is converted (reduced) to nitrite in the anaerobic (oxygen depleted) conditions in the gut. This nitrite gets absorbed into hemoglobin molecules, which reduces their oxygen carrying capacity (a cause of “blue-baby syndrome”). Nitrate can also react with amino acids to form nitrosamines, which are carcinogenic.

#### PHOSPHORUS AND WATER QUALITY

When soil is lost through erosion, it carries any phosphorus that has become attached to it. When this phosphorus enters freshwater lakes and streams it acts as a fertilizer, causing an excess growth of plants and algae. When they die, the plants and algae sink to the bottom where they decompose. The bacteria involved in decomposition use up dissolved oxygen in the water, which limits the amount available for fish and plant life. The amount of oxygen needed to decompose organic materials is called Biochemical Oxygen Demand (BOD).



**FIGURE 3. THE NITROGEN CYCLE** (ADAPTED FROM MICHIGAN STATE UNIVERSITY EXTENSION BULLETIN E-2646)



Phosphorus deficiency symptoms include:

- Slow growth, stunted plants
- Purplish coloration on foliage of some plants
- Dark green coloration with tips of leaves dying
- Delayed maturity
- Poor grain, fruit or seed development

c) The phosphorus cycle (see Figure 4)

Phosphorus is not easily leached from the soil as it remains bound to soil particles. Consequently, the main losses of P from the system are either by export of crops or by soil erosion. Most phosphate pollution of lakes and streams is from sediment that is high in P.

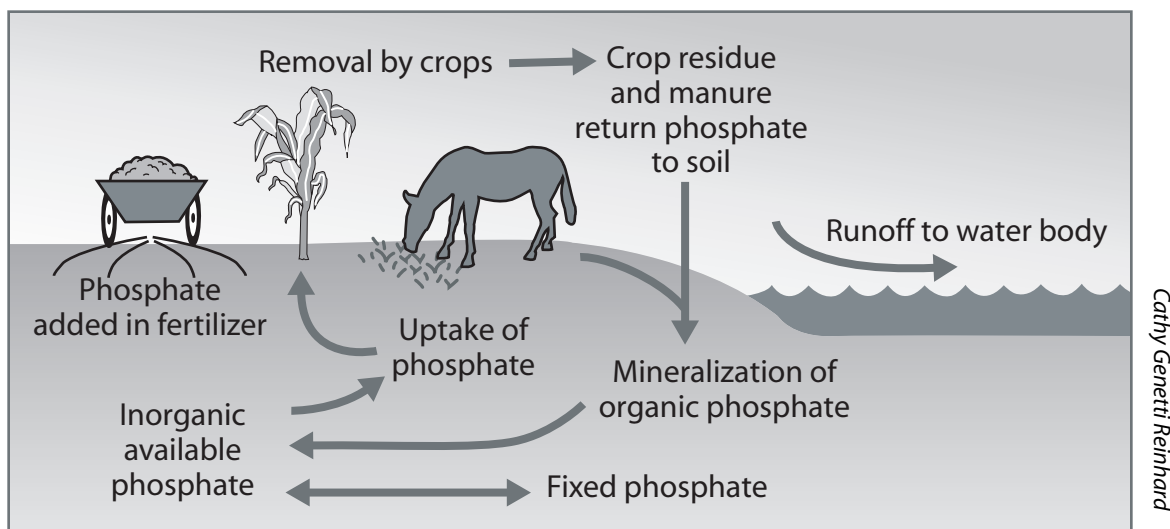
d) Phosphorus in soils and factors affecting its availability

Phosphorus is taken up as  $\text{H}_2\text{PO}_4^-$  or  $\text{HPO}_4^{2-}$  or  $\text{PO}_4^{3-}$  depending on pH.  $\text{H}_2\text{PO}_4^-$  is more available in very acid conditions while  $\text{PO}_4^{3-}$  is more available in very alkaline conditions. Most of the total P in the soil is tied up in compounds with limited solubility. In neutral to alkaline soils, it is usually bound as calcium phosphate, while in acid soils it forms iron and aluminum phosphates. Maximum availability occurs between pH 6.5 and 7.2.

Some soils are capable of fixing (binding nearly irreversibly) phosphorus when the P gets bound with reactive forms of iron, aluminum, and manganese. The fixing capacity of a soil is largely dependent on the amount and types of clay present in the soil. Clays made up of iron, aluminum, and manganese oxides or allophane have high P fixing ability. These clays are commonly found in warm humid climates (oxisols and ultisols) and areas affected by volcanic ash (Andisols). Usually these conditions are dealt with by adding enough P to the soil to satisfy its P fixing ability.

**FIGURE 4. THE PHOSPHORUS CYCLE**

(ADAPTED FROM WWW.EXTENSION.UMN.EDU/DISTRIBUTION/CROPSYSTEMS/)



Phosphorus is highly immobile and roots only take up what is only a fraction of an inch away, so if the P is not close to the root, it will not be available. Maintaining adequate moisture throughout the growing season will facilitate P movement. Phosphorus availability is also affected by temperature. In cool temperatures P may show as deficient in plants even though there is enough present for the plant needs. As temperatures warm, deficiency signs may go away. Organic P tends to be more available than inorganic, so use of organic amendments, along with promoting biological activity, will make P more available.

e) Phosphorus in amendments

The best source of phosphorus to use in the garden is “recycled” — compost and manures. Compost and manures are fairly low in P content but may have more available P than some other sources. Poultry manure has the highest amounts. Organic amendments should have a pH between 6.5 and 6.8 to maximize availability. If these are not sufficient to meet needs, bone meal (finely ground bones from slaughterhouses) or colloidal or rock phosphate are some sources that are high in phosphorus. The negative side to bonemeal is that it is usually dependent on large-scale confined animal operations. Colloidal and rock phosphates come from non-renewable sources. Another drawback to bone meal and rock phosphate is that, while they are P rich, the phosphorus is slowly available and most of what is applied serves more for crops to be planted in following years.

## 5. Potassium (K)

### a) Physiological role in plant development

Potassium is essential for the movement of sugars within the plant and for starch formation. It is necessary for the opening and closing of stomata by guard cells, controlling water use by the plant. It encourages root growth and helps build disease resistance. It is involved with photosynthesis and enzyme activity. It helps regulate metabolic activity and is involved in protein synthesis. Potassium promotes larger and better-quality fruits and grains. In some plants, more potassium is required than any other nutrient.

### b) Soil nutrient deficiencies, imbalances, toxicity

Potassium deficiency symptoms include:

- Slow growth
- Tip and marginal "burn" starting on more mature leaves. As severity of the deficiency increases, this condition progresses toward the top of the plant.
- Weak stalks, plants lodge easily
- Small fruit or shriveled fruit and seeds
- Reduced disease and pest resistance
- Increased sensitivity to drought, frost, and salts
- White or yellow spots develop along the edges of clover leaves, in severe cases these join to give a scorched appearance.

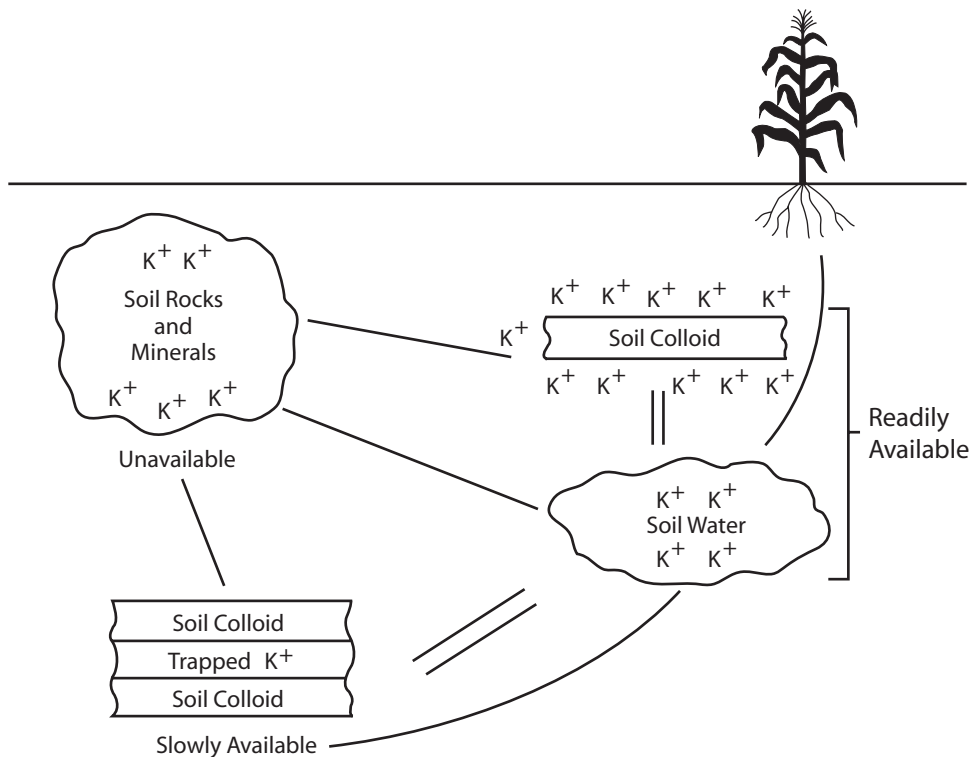
Excess potassium can cause:

- Magnesium deficiency
- Calcium deficiency in acid soils

### c) The potassium cycle (see Figure 5)

**FIGURE 5. THE POTASSIUM CYCLE**

(FROM [WWW.AGCENTRAL.COM/IMCDEMO/07POTASSIUM/07-06.HTM](http://WWW.AGCENTRAL.COM/IMCDEMO/07POTASSIUM/07-06.HTM))



d) Potassium in soils: Factors affecting its availability

Plants take up potassium in the form of potassium ions ( $K^+$ ). They may take up potassium that is adsorbed onto exchange sites (exchangeable K) or potassium that is dissolved in the soil solution. Consequently, in dry areas (where there is less soil solution) exchangeable K tends to be more important than dissolved K. Because K dissolves readily, it is highly mobile in the soil. However, it can get trapped between layers of expanding clays. Potassium tends to remain in ionic form within cells and tissues.

Potassium is present in feldspars and is released upon weathering of the minerals. Soils formed from feldspar-rich materials (such as granite or granitic alluvium) have a large supply of potassium to draw from. Even though a soil test may not show much potassium in such soils, it is usually released in sufficient quantities for plant growth. (Since much of the Sierras and southern California mountains are granitic, soils formed in these areas or in alluvium from these areas tend to have sufficient potassium.)

e) Potassium in amendments

Potential sources of potassium include wood ashes, granite dust, seaweed, greensand and langbeinite (Sulfate of Potash-Magnesia or Sul-Po-Mag). Greensand and langbeinite are non-renewable resources. Granite dust is also non-renewable, but granite occurs in such huge quantities over such extensive areas that using it should not be an issue. Wood ashes may increase the soil pH to undesirable levels and may not be available in large enough quantities.

Potassium in organic residues tends to be more highly available than that supplied by inorganic sources. So even though the total quantity of potassium supplied by these residues may be less, it may be more effective. With a steady program of recycling these residues, K is not likely to be deficient. Usually if the C:N ratio is high, the K:N ratio is also high.

6. Other macronutrients: Calcium, magnesium, sulfur

a) Calcium (Ca)

Plants take up calcium in its ionic form ( $Ca^{2+}$ ). Calcium is an essential part of cell wall structure and it must be present for the formation of new cells both in the tops and in the roots. Calcium also helps control movement into and out of cells. It also reacts with waste products precipitating them or chelating them to render them harmless to the plant.

Calcium is normally so abundant that it usually only needs to be added to very acid soils where lime is required. However, excessive irrigation can leach calcium from the soil in sufficient quantities to bring about deficiency symptoms in plants. Plant roots are relatively inefficient at taking up calcium from the soil so the amount extracted is usually small compared to what is in the soil. Excess calcium can lead to a deficiency of magnesium or potassium.

Sources of calcium include poultry manure, wood ashes, seashells, lobster shells, legume hay (which has no liming value), limestone, and gypsum.

Calcium is not mobile in plants. Young tissue is first affected when there is a deficiency.

Deficiency symptoms include:

- Death of growing points (terminal points) on plants. Root tips are also affected.
- Abnormal dark green appearance of foliage
- Premature shedding of blossoms and buds
- Weakened stems (causes cell membranes to lose permeability and disintegrate)
- "Blossom end rot" of tomatoes
- Short, thick, bulbous roots

## b) Magnesium (Mg)

Plants take up magnesium in its ionic form ( $Mg^{2+}$ ). Magnesium is required for photosynthesis since it is contained in chlorophyll molecules. It helps in the assimilation of carbon dioxide during photosynthesis. Magnesium is also an activator for many plant enzymes required in growth processes. Magnesium is necessary for every operation that involves phosphorus in the plant and it also influences nitrogen metabolism.

Magnesium is generally available throughout the western states (where it is drier) but it is often more deficient than calcium. Magnesium, like calcium, is easily leached in humid areas. Soils with low CEC's cannot hold much Mg. It is important to have a balance of magnesium, potassium, and calcium so that no one of these elements dominates the cation exchange sites in the soil. Soils derived from serpentine often have a high Mg to Ca ratio. This makes the soil unsuitable for many plants and the worst areas are barren of vegetation.

Sources of magnesium include plant residues, fresh poultry manure, dolomitic limestone, and langbeinite (Sul-Po-Mag—see section on phosphorus)

Magnesium is mobile within plants and can be translocated from older tissue to younger tissue during conditions of deficiency. Symptoms of magnesium deficiency include:

- Interveinal chlorosis (yellowing) in older leaves
- Curling of leaves upward along margins
- Marginal yellowing with green “Christmas tree” area along midrib of leaf
- Stunted growth
- Ripe fruit is not sweet

## c) Sulfur (S)

Plants take up sulfur in the form of the sulfate ion  $SO_4^{2-}$ . Sulfur is also sometimes absorbed from the air through leaves in industrial areas where sulfur is emitted into the atmosphere. Atmospheric sulfur can also come from volcanoes, sea spray and hydrogen sulfide ( $H_2S$ ) emissions from swamps and oilfields.

As a constituent of three amino acids (cystine, methionine, and cystine), sulfur is very important for protein synthesis. Sulfur is also essential for nodule formation by nitrogen fixing bacteria on the roots of legumes. Sulfur is also present in oil compounds that give plants such as garlic and onions their characteristic odor. (Vidalia onions, known for their sweetness, come from an area that has low sulfur soils.)

The use of organic residues in amounts to satisfy other nutrient requirements will usually provide sufficient sulfur. Other sources of sulfur include animal manures (sulfur is usually well balanced with respect to nitrogen), langbeinite (Sul-Po-Mag—see section on phosphorus), gypsum, and pure sulfur from natural sources (granular is preferred since sulfur dust is an explosion hazard).

Sulfur deficiency problems can occur if concentrated fertilizers for other nutrients are used that are free of sulfur. Symptoms of sulfur deficiency include:

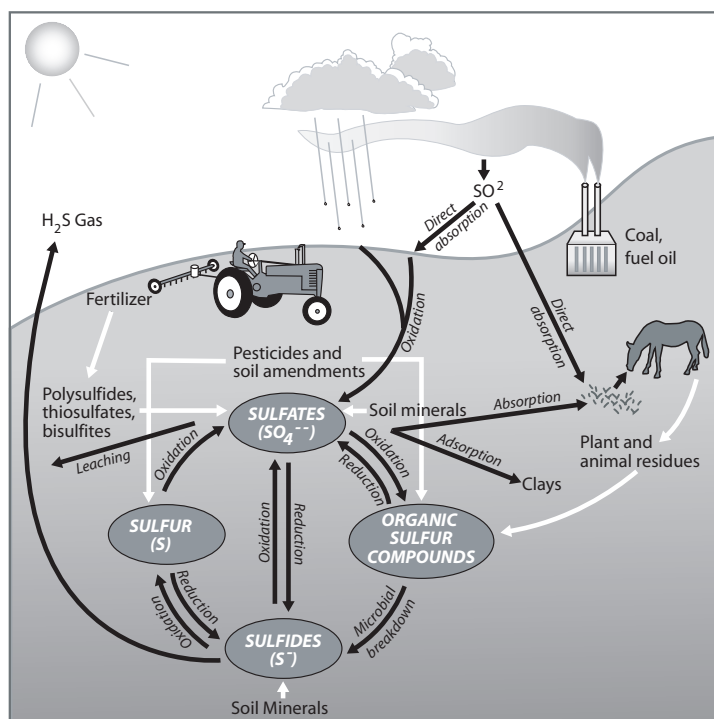
- Young leaves light green to yellowish in color. In some plants older tissue may be affected also.
- Small and spindly plants
- Retarded growth rate and delayed maturity
- Interveinal chlorosis on corn leaves

## 7. Micronutrients

### a) Introduction

Micronutrients are those plant nutrients that are needed only in small quantities compared to other (macro-) nutrients. This fact, however, does not diminish their importance. The effects of micronutrients on plants are difficult to understand, partly because of their interrelationships with each other and partly due to how the plants respond to micronutrients individually.

FIGURE 6. THE SULFUR CYCLE



Cathy Genetti Reinhard

The response of many plants to micronutrients is almost an all or nothing affair. As long as the concentration of the micronutrients falls within a certain range, the response of the plant is the same, regardless of the exact concentration of the nutrient. If the concentration of the nutrient falls above this range, toxicity problems occur and if the concentration is below the range, the plants become deficient in the nutrient.

Interrelationships of micronutrients are many. For example, nitrogen fertilization can cause a deficiency of iron or copper. Prolonged phosphorus fertilization can lead to an iron deficiency. Excess phosphorus can lead to manganese deficiency. Sulfur and copper can cause molybdenum deficiencies, while the availability of molybdenum is increased by phosphorus. Iron, copper, manganese, and zinc compete with each other.

Availability of micronutrients is highly dependent on soil pH and organic matter. At certain pHs, micronutrients can get bound to inorganic compounds and become unavailable. Organic matter can diminish the effect of pH. If micronutrient levels become too low, organic matter can often supply them. Copper, iron, manganese, and zinc can get bound to soluble organic compounds that are readily available to plants. These are called chelates. If micronutrient levels get too high, organic matter can bind them up so they don't become toxic.

b) Boron ( $B_4O_7^{2-}$ )

Boron is required in minute quantities by plants, but in spite of this, there may not be sufficient boron in some soils. Boron can also become toxic in amounts not much higher than that needed by the plants. Boron toxicity is most frequently a problem in soils formed at the bottoms of enclosed basins in arid areas where groundwater evaporates through the soil, leaving salt concentrations near the surface (playas). Boron is needed for protein synthesis; for starch and sugar transport; to regulate nitrogen and carbohydrate metabolism; for root development and fruit and seed formation; for differentiation of meristem cells; and for water uptake and transport. Boron contributes more than any other micronutrient to the quality of produce. Boron is non-mobile in plants and so a continuous supply is necessary at all growing points.

Symptoms of boron deficiency include:

- Death of terminal growth, causing lateral buds to develop and producing a “witches’-broom” effect
- Thickened, curled, wilted and chlorotic leaves
- Soft or necrotic spots in fruit or tubers
- Reduced flowering or improper pollination

c) Copper ( $\text{Cu}^{2+}$ )

Copper occurs as impurities in crystal structures of clays and other minerals. It may also occur in other compounds in the soil. As these materials weather the copper is released, after which it is adsorbed onto exchange sites from where it may be taken up by plants or leached from the soil. Consequently, soils formed from highly weathered materials may be deficient in copper. Copper is fairly abundant and deficiencies rarely occur. Also, since copper can be highly toxic at low levels, amendments should not be used except where the need for it has been established.

Copper is a catalyst for respiration and an activator of several enzymes. It is important for carbohydrate and protein synthesis. It may also play a role in carotene production.

Symptoms of copper deficiency include:

- Stunted growth
- Dieback of terminal shoots in trees
- Poor pigmentation
- Wilting and eventual death of leaf tips
- Formation of gum pockets around central pith in oranges

d) Iron ( $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ )

Plants require iron in larger amounts than any other micronutrient. It is used in chlorophyll synthesis; in oxidation-reduction during respiration; and as a constituent of various enzymes and proteins. It also serves as an activator for nitrogen fixation.

Iron is a very abundant in the soil, but some of its forms are so insoluble that plants may suffer a deficiency in spite of its abundance. (Like being stranded in the ocean and being thirsty for want of fresh water.) This is particularly true at pH levels above 7; where there is a high content of lime or manganese; or where there is poor aeration (though Fe requires some period where oxygen is lacking). Some plants, such as peppers, are more susceptible than others. Treatment may consist of adding iron in a form that won't be bound up in the soil or by lowering the pH.

Symptoms of iron deficiency include:

- interveinal chlorosis—a yellowing of the leaves between the veins
- twig dieback
- death of entire limbs or plants

e) Manganese ( $\text{Mn}^{2+}$ )

Manganese is used in the metabolism of nitrogen and inorganic acids; for the formation of vitamins (carotene, riboflavin and ascorbic acid); for the assimilation of carbon dioxide during photosynthesis; and in the breakdown of carbohydrates. Manganese may be oxidized in the soil to form  $\text{MnO}_4^-$ . High manganese levels may induce iron deficiency.

Symptoms of manganese deficiency include:

- Interveinal chlorosis of young leaves. Gradation of pale green coloration with darker color next to veins. No sharp distinction between veins and interveinal areas as with iron deficiency.
- Development of gray specks (oats), interveinal white streaks (wheat), or interveinal brown spots and streaks (barley)

f) Molybdenum ( $\text{MoO}_4^{2-}$ )

As with boron, molybdenum is needed only in minute quantities. Molybdenum is needed for nitrogen fixation and for reducing nitrate nitrogen to the amine form (plants take up nitrate- $\text{NO}_3$  but use it to create amines  $-\text{NH}_2$  for amino acids). Because of this a molybdenum deficiency can cause a nitrogen deficiency in plants. Molybdenum has been found in quantities sufficient to be toxic to livestock in forage grown in inland desert areas such as the San Joaquin Valley and Nevada. Molybdenum levels tend to be low in highly leached soils.

Symptoms of molybdenum deficiency include:

- Stunting and lack of vigor (induced nitrogen deficiency)
- Marginal scorching and cupping or rolling of leaves
- “Whiptail” of cauliflower
- Yellow spotting of citrus

g) Zinc ( $\text{Zn}^{2+}$ )

Zinc occurs as impurities in crystal structures and in other compounds in the soil. As it is released by weathering, it is adsorbed onto exchange sites from where it may be taken up by plants or leached from the soil. Consequently, soils formed from highly weathered materials (such as quartz and sandstone) may be deficient. Soils formed from igneous rocks tend to have higher levels of zinc. Zinc is used in the formation of growth hormones; for protein synthesis; and in seed and grain maturation and production.

A well-aerated soil is necessary for zinc availability.

Symptoms of zinc deficiency include:

- Decrease in stem length and a rosetting of terminal leaves
- Reduced fruit bud formation
- Mottled leaves (interveinal chlorosis)
- Dieback of twigs after first year
- Striping or banding on corn leaves

h) Cobalt ( $\text{Co}^{2+}$ )

Cobalt occurs as impurities in crystal structures and in other compounds in the soil. As it is released by weathering, it is adsorbed onto exchange sites from where it may be taken up by plants or leached from the soil. Consequently, soils formed from highly weathered materials may be deficient. Cobalt has not yet been shown to be essential to higher plants, but it is essential in the symbiotic relationship between legumes and Rhizobia.

i) Chlorine ( $\text{Cl}^-$ )

Minute amounts of chlorine are essential to some plants. Even touching plants with sweaty hands may be sufficient to provide sufficient chloride. Chlorine is required for photosynthetic reactions in plants. However, the quantities needed are so small and chlorine is so abundant that deficiencies never occur in nature.

Symptoms of chlorine deficiency include:

- Wilting, followed by chlorosis
- Excessive branching of lateral roots
- Bronzing of leaves
- Chlorosis and necrosis in tomatoes and barley



j) Others

Other micronutrients that may be of importance are:

i. Silicon

Silicon gives plants mechanical strength and may help minimize water loss and increase disease resistance

ii. Vanadium

Vanadium is not used directly by plants but seems to be required by soil organisms, which, in turn, benefit the plants

iii. Selenium, iodine and chromium

These elements are important to human and animal health. If they are present in the soil they can be taken up by plants and become available to plant consumers.

# Demonstrations: Soil Chemistry

## DEMONSTRATION OVERVIEW

*The following demonstrations provide visual representations and visual analogies for the concepts presented in the outline. When possible, they should be integrated into the lectures.*

## MAGNET DEMONSTRATION

Detailed Lecture Outline Reference: D 1

### PURPOSE

To show how unlike charges attract and like charges repel

### MATERIALS

- 2 bar magnets, preferably labeled

### METHODS

Hold the negative ends of the magnets together, show how they repel, then hold the negative to the positive and show how they attract.

## pH DEMONSTRATION

Detailed Lecture Outline Reference: G 1

### PURPOSE

To demonstrate different methods of measuring pH

### MATERIALS

- pH meter
- Colorimetric pH test kit (I use the Hellige-Truog)

### METHODS

Measure the pH of the soil sample using the different techniques. Compare the results. Explain why differences may occur.

## ACID DEMONSTRATION

Detailed Lecture Outline Reference: H 2

### PURPOSE

To show how to test for the presence of carbonates in the soil

### MATERIALS

- Soil sample with free carbonates
- Dilute hydrochloric acid or vinegar

### METHODS

Drop some acid onto the soil to show how it effervesces

### **SALT CRUST EXAMPLE**

Detailed Lecture Outline Reference: I 3

#### **PURPOSE**

To show how high salt concentrations might show up in the soil

#### **MATERIALS**

- Salt crust

#### **METHODS**

Pass some samples of salt-encrusted soil around

### **CONDUCTIVITY DEMONSTRATION**

Detailed Lecture Outline Reference: I 3

#### **PURPOSE**

To demonstrate that saline soils conduct electricity

#### **MATERIALS**

- Saline soil sample
- Nonsaline soil sample
- Distilled water
- 2 beakers or jars
- Table salt
- Conductivity tester: Any kind of device that shows that electricity will pass through a saline soil but not a nonsaline soil will do. I use one that combines a light bulb and a voltmeter, but a small horn could also work.

#### **METHODS**

1. Prepare the two samples (saline and nonsaline) by placing them into separate jars and mixing in distilled water until a smooth paste is created.
2. Place the electrodes of the tester into the nonsaline sample. Notice that the light bulb does not light.
3. Remove the electrodes and rinse them with distilled water. Then place them into the saline soil. Notice that the light bulb lights.
4. Remove electrodes from sample and rinse them with distilled water. Place them back into the nonsaline sample. Stir in table salt until enough has been added to make the light bulb light up.

Note: The operation can be simplified by having four electrodes. Use alligator clips on the tester wires to connect them to the electrodes.

# Assessment Questions

## TRUE OR FALSE

- 1) The bulk of a plant is made up of minerals extracted from the soil.  
True      False
- 2) Clay soils can hold more nutrients than sandy soils.  
True      False
- 3) The main source of nitrogen in the soil is rocks.  
True      False
- 4) Phosphorus becomes a pollutant when it is leached into the groundwater.  
True      False
- 5) Alkaline soils are predominant in the arid western states.  
True      False

## MULTIPLE CHOICE

- 1) Which one of the following refers to the nutrient-holding ability of the soil?
  - a. Alkalinity
  - b. Cation Exchange Capacity
  - c. Available Water Capacity
  - d. Nutrient Loading
- 2) Leaching of bases out of a soil causes the soil to become
  - a. Alkaline
  - b. Acid
- 3) Salinity problems are most likely to occur in
  - a. Dry environments
  - b. Upper New York state
  - c. Tropical rainforests
  - d. Humid areas
- 4) Which of the following is NOT a plant nutrient?
  - a. Nitrogen
  - b. Copper
  - c. Aluminum
  - d. Potassium
- 5) Nutrients needed in large quantities by plants are called
  - a. Meganutrients
  - b. Micronutrients
  - c. Macronutrients
  - d. High end nutrients
- 6) Certain plant nutrients are called micronutrients because
  - a. They are too small to see with the naked eye
  - b. They are not all that important to the plant
  - c. They are only needed in small quantities

7) Which one of the following plant nutrients comes from the air?

- a. Carbon
- b. Potassium
- c. Hydrogen
- d. Copper

8) Which of the following affects nutrient availability? (circle all correct responses)

- a. pH
- b. Soil organic matter content
- c. Texture
- d. Soil moisture

9) An ion with a positive charge is called a(n)

- a. Cation
- b. Anion
- c. Onion
- d. Positron

10) Clay particles tend to have a

- a. Positive charge
- b. No charge
- c. Negative charge

#### ASSESSMENT

1) How can knowledge of the climate of an area help you make an initial assessment of soil fertility?

2) Your plants are showing signs of iron deficiency. You check the soil pH and it is 8.0. What would most likely be the best way to eliminate the iron deficiency and why?

3) You know that the air around you is full of nitrogen, yet your garden regularly shows signs that it could use a little of it. How can you harness some of the nitrogen for your garden?

4) Is adding a large quantity of nitrogen-rich amendments to your garden before you plant necessarily a good thing to do? Why or why not?

5) What is the most important thing you can do to a mineral soil in order to ensure an adequate supply of and maximum availability of plant nutrients?

# Assessment Questions Key

## TRUE OR FALSE

- 1) The bulk of a plant is made up of minerals extracted from the soil.  
True      False
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  - b. Anion
  - c. Onion
  - d. Positron

10) Clay particles tend to have a

- a. Positive charge
- b. No charge
- c. Negative charge

#### ASSESSMENT

1) How can knowledge of the climate of an area help you make an initial assessment of soil fertility?

- *Humid areas tend to be more heavily leached, have lower pH and lower fertility*
- *Dry areas tend to have higher base saturation, higher pH, more fertile*
- *Warm areas tend to have more highly weathered soils as compared to cooler ones, lower relative fertility*

2) Your plants are showing signs of iron deficiency. You check the soil pH and it is 8.0. What would most likely be the best way to eliminate the iron deficiency and why?

- *Lower the pH so that the iron in the soil can become more available (usually done by adding sulfur or acid organic materials). If iron supplements are used they, too, will be unavailable due to the high pH unless chelated forms of iron are used.*

3) You know that the air around you is full of nitrogen, yet your garden regularly shows signs that it could use a little of it. How can you harness some of the nitrogen for your garden?

- *Nitrogen-fixing green manures*
- *Intercrop with nitrogen-fixing plants*

4) Is adding a large quantity of nitrogen-rich amendments to your garden before you plant necessarily a good thing to do? Why or why not?

No.

- *Large amounts of nitrogen without plants to take it up can lead to losses by leaching (polluting groundwater) or volatilization (polluting air)*
- *Too much nitrogen can burn seedlings*

- *An imbalance of nitrogen with respect to other nutrients is unhealthy for the plants*

5) What is the most important thing you can do to a mineral soil in order to ensure an adequate supply of and maximum availability of plant nutrients?

*Maintain high levels of organic matter and foster biological activity*

*Organic matter helps by*

- *Buffers micronutrients, keeping them from becoming toxic or imbalanced*
- *Chelates certain micronutrients to keep them available to plants*
- *Increases cation exchange capacity*
- *Supplies certain nutrients such as nitrogen, phosphorus, and sulfur*
- *Improves physical condition of soil (air and water relationships enhanced), which helps to ensure maximum availability of nutrients*
- *Buffers the effect of high or low pH*

*Biological activity helps by*

- *Breaking down certain compounds to release nutrients*
- *Breaking down organic matter*
- *Some micro-organisms are involved with nitrogen fixation*
- *Organisms can help move otherwise immobile nutrients through the soil*

# Resources

## PRINT RESOURCES

Brady, Nyle C. 1974. *The Nature and Property of Soils, Eighth Edition*. New York: Macmillan Publishing Co., Inc.

*A good general soils text, used for introductory soils classes at universities. Might be too technical for some.*

Brady, Nyle C., and Weil, R.R. 1999. *The Nature and Property of Soils, Thirteenth Edition*. Upper Saddle River, New Jersey: Prentice-Hall, Inc.

*This is the most recent edition; covers some new subject matter and has improved charts and graphs. A good general soils text, used for introductory soils classes at universities. Might be too technical for some.*

California Fertilizer Association. 1985. *Western Fertilizer Handbook*. Danville, IL: The Interstate Printers & Publishers, Inc..

*This book contains general information about soils and more detailed information about plant nutrients and fertilizers. Some parts may be difficult to understand. Emphasis is on inorganic fertilizers. Newer editions are available.*

Foth, Henry D. 1984. *Fundamentals of Soil Science*. New York: John Wiley & Sons.

Gershuny, G. 1993. *Start with the Soil*. Emmaus, Pennsylvania: Rodale Press.

*A general book on soils and soil management geared toward organic gardeners. Easy to read and understand.*

Hanson, B., S. R. Grattan, and A. Fulton. 1999. *Agricultural Salinity and Drainage*. Publication 3375. UC Irrigation Program. Oakland, CA: University of California Division of Agriculture and Natural Resources.

*An indispensable reference for anyone farming in an area where salinity might be a problem.*

Parnes, Robert. 1990. *Fertile Soil: A Grower's Guide to Organic and Inorganic Fertilizers*. Davis, CA: agAccess.

*Probably the best reference here on plant nutrients, with good coverage of organic amendments. Some useful reference charts in the appendices.*

Stell, Elizabeth P. 1998. *Secrets to Great Soil*. Pownal, VT: Storey Communications, Inc.

*An easy to read primer on soils, composting, and basic gardening techniques. Lots of diagrams.*

Troeh, F. R., and L. M. Thomposon. 1993. *Soils and Soil Fertility, Fifth Edition*. New York: Oxford University Press.

*A general soils text used in introductory soils classes. Might be too technical for some.*

## WEB RESOURCES

### NITROGEN

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[www.extension.umn.edu/distribution/cropsystems/DC3770.html](http://www.extension.umn.edu/distribution/cropsystems/DC3770.html)

[helios.bto.ed.ac.uk/bto/microbes/nitrogen.htm](http://helios.bto.ed.ac.uk/bto/microbes/nitrogen.htm)

### PHOSPHORUS

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[www.extension.umn.edu/distribution/cropsystems/DC6288.html](http://www.extension.umn.edu/distribution/cropsystems/DC6288.html)

[www.extension.umn.edu/distribution/cropsystems/DC6795.html](http://www.extension.umn.edu/distribution/cropsystems/DC6795.html)

[www.ess.uci.edu/~reeburgh/fig4.html](http://www.ess.uci.edu/~reeburgh/fig4.html)

[www.soil.ncsu.edu/sera17/publications/sera17-1/index.htm](http://www.soil.ncsu.edu/sera17/publications/sera17-1/index.htm)

### POTASSIUM

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[www.ipipotash.org](http://www.ipipotash.org)

[www.extension.umn.edu/distribution/cropsystems/DC6794.html](http://www.extension.umn.edu/distribution/cropsystems/DC6794.html)

[www.agcentral.com/imcdemo/07Potassium/07-06.htm](http://www.agcentral.com/imcdemo/07Potassium/07-06.htm)



## SULFUR

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[www.agcentral.com/imcdemo/08Secondary/08-04.htm](http://www.agcentral.com/imcdemo/08Secondary/08-04.htm)

## CALCIUM

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[soils.usda.gov/sqi/files/08d3.pdf](http://soils.usda.gov/sqi/files/08d3.pdf)

[www.psu.edu/ur/NEWS/news/liming.html](http://www.psu.edu/ur/NEWS/news/liming.html)

## MISCELLANEOUS NUTRIENTS

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[www.agcentral.com/imcdemo/09Micronutrients/09-02.htm](http://www.agcentral.com/imcdemo/09Micronutrients/09-02.htm)

[interactive.usask.ca/ski/agriculture/soils/index.html](http://interactive.usask.ca/ski/agriculture/soils/index.html)

[edis.ifas.ufl.edu/BODY\\_MG091](http://edis.ifas.ufl.edu/BODY_MG091)

[eap.mcgill.ca/MagRack/COG/COGHandbook/COGHandbook\\_1\\_3.htm](http://eap.mcgill.ca/MagRack/COG/COGHandbook/COGHandbook_1_3.htm) (Organic field crop handbook)

[www.agcentral.com/imcdemo/Contributors/Con-2.htm](http://www.agcentral.com/imcdemo/Contributors/Con-2.htm) (Page full of links to graphics and figures)

[www2.hawaii.edu/~nvhue/sustain\\_ag/sustag895.html](http://www2.hawaii.edu/~nvhue/sustain_ag/sustag895.html) (Organically Acceptable Inputs to Improve Soil Fertility)

## DEFICIENCY SYMPTOMS

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[www.penpages.psu.edu/penpages\\_reference/29401/29401166.html](http://www.penpages.psu.edu/penpages_reference/29401/29401166.html) (text only)

[www.hortnet.co.nz/publications/guides/fertmanual/dguide1.htm](http://www.hortnet.co.nz/publications/guides/fertmanual/dguide1.htm) (good photos)

[www.back-to-basics.net/nds/index.htm](http://www.back-to-basics.net/nds/index.htm)

## INSTITUTIONS

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Cooperative Extension Service or Farm Advisors Office

*Staff from these agencies will be aware of crop nutrient needs and problems in your area. They can assist you with nutrient deficiency symptoms and known plant nutrition problems in your area.*

## Soil and Plant Tissue Labs

*These labs can test your soil or crop for deficiencies. Some websites containing listings of laboratories –*

[www.attra.org/attra-pub/soil-lab.html](http://www.attra.org/attra-pub/soil-lab.html)

[www.organicgardening.com](http://www.organicgardening.com)

(click on OG BASICS, then Building Healthy Soils, then Soil Test Labs)

[www.clemson.edu/agrvlb/sera6/changes/accompl.html](http://www.clemson.edu/agrvlb/sera6/changes/accompl.html)

[www.inotherearthnews.com/directory/soil\\_test](http://www.inotherearthnews.com/directory/soil_test)

## EDUCATION

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California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This sustainable agriculture education resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

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# Introduction: Soil Biology and Ecology

## UNIT OVERVIEW

*This unit introduces students to the biological properties and ecosystem processes of agricultural soils. Students will review the constituents of soils and the physical characteristics and soil ecosystem processes that can be managed to improve soil quality. Demonstrations and exercises will introduce students to techniques used to assess the biological properties of soils. Such assessments help inform decisions about soil management with the goal of maintaining crop productivity and soil health in certified organic farming and gardening systems.*

## MODES OF INSTRUCTION

- > LECTURE (1 LECTURE, 1.5 HOURS)  
Class lecture outline covers the basic biology and ecosystem processes of soils, focusing on ways to improve soil quality for organic farming and gardening systems.
- > DEMONSTRATION 1: ORGANIC MATTER DECOMPOSITION (1.5 HOURS)  
This exercise demonstrates how to assess the capacity of different soils to decompose organic matter. Discussion questions ask students to reflect on what environmental and management factors might have influenced the test results and what the results suggest about nutrient cycling rates and the quality/health of the soils tested.
- > DEMONSTRATION 2: SOIL RESPIRATION (1 HOUR)  
The demonstration outline covers the use of Draeger gas detection tubes for measuring carbon dioxide levels liberated from soils as an indicator of soil biological activity and soil quality/health.
- > DEMONSTRATION 3: EARTHWORM POPULATION (1 HOUR)  
The demonstration covers the preparations, material used to sample soil for the presence and abundance of earthworm types. Discussion questions ask students to consider the presence and abundance of certain earthworm types as indicators of soil quality/health.
- > DEMONSTRATION 4: SOIL ARTHROPOD (1 HOUR)  
The demonstration covers the preparation and materials used to collect and identify soil arthropods. Discussion questions ask students to consider the presence and diversity of soil arthropods as indicators of soil quality/health.
- > HANDS-ON EXERCISE: CARBON AND NITROGEN MINERALIZATION (0.5 HOUR)  
The demonstration covers the preparations and materials used in estimating how much mineral N (nitrate and ammonium) is liberated from organic matter inputs. This exercise simplifies the complex processes of the soil food web that occur during decomposition, as organic matter is converted into nutrient forms that plants can use.
- > ASSESSMENT QUESTIONS (1 HOUR)  
Assessment questions reinforce key unit concepts and skills.

## LEARNING OBJECTIVES

### CONCEPTS

- Soil quality/soil health
- Mineralization/immobilization
- Autotrophic/heterotrophic food webs
- Functional groups of soil biota
- Rhizosphere ecology
- Management effects on soil ecosystems

### SKILLS

- How to assess soils for biological activity through measuring the rate of decomposition of cellulose
- How to assess soil biological activity through measuring soil respiration
- How to assess soil biological activity through earthworm census
- How to assess the soil ecosystem structure through a soil arthropod census
- How to estimate the amount of mineral N (nitrate and ammonium) that is coming from organic matter inputs

# Lecture Outline: Soil Biology and Ecology

## *for the instructor*

### A. Pre-Assessment Questions

1. What is soil?
2. What forms of life exist in soil ecosystems?
3. How would you define a “healthy” agricultural soil?
4. What is a food web?
5. Can you describe a decomposer food web that may exist in the soil?
6. What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizers and pest control agents on the soil ecosystem?

### B. Review: What Is Soil? (should be a review in part; see Unit 2.1, Soils and Soil Physical Properties)

1. Soil components
  - a) Mineral fraction
  - b) Organic matter fraction
  - c) Water and air
  - d) Biota
2. Soil structure vs. soil texture (definitions, examples)
  - a) Soil texture, a native characteristic
  - b) Soil structure, a manageable characteristic influenced by soil biology and soil health

### C. What Is a Healthy/Quality Soil?

1. Is soil merely a solid medium that holds nutrients for plant growth?
2. Soil health and soil quality generally synonymous
3. Definition: “Capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health.” (For a more detailed definition, see Unit 1.1, Managing Soil Fertility.)
4. Assessment of soil quality/soil health
5. Protection of soil quality as a national priority

### D. Nutrient Cycling and Decomposition

1. Mineralize/immobilize
2. Organic matter: Includes all organic substances in or on the soil
  - a) Living organisms: Includes plant roots and all soil biota (<5%)
  - b) Fresh and decomposing organic residues (40–60%)
  - c) Resistant (recalcitrant) organic matter fraction: Humus, stable organic matter resistant to further decomposition (33–50%)

- d) See appendix 1, Major Organic Components of Typical Decomposer Food Sources, for a comparison of the components of some typical decomposer food sources
  - e) Physical factors influence decomposition
  - f) Limiting factors
  - g) Plant secondary compounds may inhibit decomposition (polyphenols, tannins)
3. Nitrogen cycle
- a) Proteins → amino acids → ammonium → nitrate
  - b) Ammonification aerobic or anaerobic
  - c) Nitrification aerobic
  - d) If C:N < 20–30:1 = net mineralization. If C:N > 20–30:1 = net immobilization
4. Carbon and nitrogen mineralization exercise (handout)

## E. Soil Food Webs

1. Soil food web ecology
2. Heterotrophic vs. autotrophic food webs
  - a) Autotrophic food webs → begin with C fixation by plants
  - b) Heterotrophic food webs → release nutrients required by all plants
  - c) Energy loss = 80–90% at each step in the food chain
  - d) Food web structure
  - e) Ways that soil animals interact with soil microorganisms
  - f) Unique food web for each ecosystem, determined by:

## F. Soil Biota

1. Characteristics
2. Habitats
3. Functional classification
  - a) Microorganisms
  - b) Microfauna
  - c) Mesofauna
  - d) Macrofauna
  - e) Megafauna

## G. Rhizosphere Ecology

1. Definitions
  - a) Rhizosphere (**R**) = the narrow zone of soil subject to the influence of living roots, as manifested by the leakage or exudation of substances that promote or inhibit microbial activity
  - b) Rhizoplane (**r**) = the actual root surface, which provides a highly favorable nutrient base for many species of bacteria and fungi
  - c) Edaphosphere (**S**) = soil beyond root influence
  - d) Rhizosphere effect = soil microorganisms and fauna stimulated
    - i. → **R/S** ratio generally increases
  - e) Rhizosphere succession = the sequence of changes in the area surrounding a growing root

2. Roots
  - a) Root environment
  - b) Root form
  - c) Root structure
  - d) Nutrition
  - e) Exudates
  - f) Variations
  - g) Management effects

3. Soil organisms
  - a) Bacteria
  - b) Fungi
  - c) Protozoans
  - d) Nematodes
  - e) Microarthropods
  - f) Rhizosphere succession
  - g) Examples

## **H. Management Effects on Soil Ecosystems**

1. No-tillage or reduced-tillage cropping systems
  - a) Organic litter is retained on the soil surface
  - b) Physical disturbance is minimized
  - c) Surface soil stays cooler and moister
  - d) More surface organic matter is available as food substrate
  - e) Ratio of fungi to bacteria increases over time
  - f) Earthworms and arthropods become more plentiful
2. Rotations
  - a) Monocultures and clean cultivation
  - b) Complex rotations
  - c) Multiculture
3. Biocides
  - a) Effects vary
  - b) High levels of pesticide use generally reduce food web complexity
  - c) Predator-release phenomenon
  - d) Earthworms
4. Food web structures
  - a) Fungi/bacteria ratio
  - b) Dominant microbe influences other trophic levels
5. Assessment of fertility needs
  - a) Measures of available nitrogen





# Detailed Lecture Outline: Soil Biology and Ecology

## *for students*

### **A. Pre-Assessment Questions**

1. What is soil?
2. What forms of life exist in soil ecosystems?
3. How would you define a “healthy” agricultural soil?
4. What is a food web?
5. Can you describe a decomposer food web that may exist in the soil?
6. What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizers and pest control agents on the soil ecosystem?

### **B. What Is Soil?**

1. Soil components
  - a) Mineral
    - i. Derived from parent material
  - b) Soil organic matter
  - c) Water and air
    - i. 1/2 soil volume = pore space
    - ii. Importance of gas diffusion: When diffusion is slow, as with saturated soil, respiration byproducts accumulate and inhibit aerobic processes
    - iii. CO<sub>2</sub> about 1% in dry soil, up to 10% in saturated soil
  - d) Biota: Smallest life forms are inseparable from soil organic matter
2. Soil structure vs. soil texture
  - a) Soil texture, a native characteristic
    - i. Soil texture: The relative percentage of sand, silt and clay particles
    - ii. Surface area/volume effects (e.g., influences CEC, pore space, water holding capacity, aggregate formation)
    - iii. The bricks, boards, and mortar (the physical materials) that make up soil
  - b) Soil structure, a manageable characteristic
    - i. Soil structure: The arrangement of soil particles. The “architecture” of soil.
    - ii. Determines movement of gases and water in soil
    - iii. Creates small habitat spaces
    - iv. Water stability: Aggregates that retain shape when wetted maintain a more stable soil structure
    - v. Influences soil tilth

### **C. What Is a Healthy Soil?**

1. Question: Is soil merely a solid medium that holds nutrients for plant growth or does soil serve other functions?
2. Soil health and soil quality generally synonymous

3. Definition: "Capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health." (For a more detailed definition, see Unit 1.1, Managing Soil Fertility.)
  - a) Soil recognized as essential component of biosphere
  - b) Soil is required for significant production of food and fiber
  - c) Soil contributes to maintaining and enhancing air and water quality
  - d) Soil filters and chemically alters water
  - e) Definition must be broad enough to encompass the many functions of soil
4. Assessment of soil quality/soil health
  - a) Analogy to monitoring human health
  - b) Indicators needed to identify problems and to monitor the effects of management
  - c) Requires a holistic approach
  - d) Should include physical, chemical, and biological attributes of soil
  - e) Indicators must be measurable by as many people as possible
  - f) Definition and assessment of soil quality complicated by the fact that soil is not (typically) directly consumed by animals and humans, as are air and water
  - g) Basic data set of soil quality indicators
    - i. Soil texture
    - ii. Rooting depth
    - iii. Water infiltration
    - iv. Bulk density
    - v. Water holding capacity
    - vi. Soil organic matter
    - vii. pH
    - viii. Electrical conductivity
    - ix. Extractable N, P, and K
    - x. Microbial biomass C and N
    - xi. Potentially mineralizable N
    - xii. Soil respiration
    - xiii. Water content
    - xiv. Soil temperature
5. Protection of soil quality as a national priority
  - a) National Research Council recommendation (1993)
  - b) "Protecting soil quality, like protecting air and water quality, should be a fundamental goal of national environmental policy"

## **D. Nutrient Cycling and Decomposition**

1. Mineralization/immobilization
  - a) Soil nutrients occur as parts of:
    - i. Inorganic compounds: Some of these are available to plants
    - ii. Organic compounds: Are part of living organisms and decaying organic matter. These nutrients are stored and temporarily unavailable.
  - b) Soil organisms are constantly transforming nutrients between these 2 forms
  - c) Mineralization: Soil organisms excrete inorganic waste compounds that may adhere to CEC sites and/or dissolve in soil water (soil solution) for possible uptake by crop plants. Net mineralization must be greater than net immobilization for nutrients to be available to crop plants.

- d) Immobilization: Soil organisms consume *inorganic* compounds to construct living tissues. These nutrients are temporarily stored and unavailable for plant uptake.
- 2. Soil organic matter (SOM): Includes all organic substances in or on the soil
  - a) Living organisms—includes plant roots and all soil biota (< 5% of SOM)
    - i. Cellulose, the major carbohydrate structural building block for plants, is the most abundant compound on earth and the major component of soil organic matter
    - ii. Lignin second largest input into SOM
  - b) Fresh and decomposing organic residues (40–60% of SOM)
    - i. Easily decomposable (active, labile) fraction: Quantity changes quickly in response to management changes and is the organic matter fraction from which the majority of plant nutrients are liberated into the soil solution for uptake by plants
    - ii. Moderately decomposable fraction: Physically and/or chemically more complex than labile OM. Decomposition slower and therefore fewer nutrients liberated in a given season.
  - c) Resistant (recalcitrant) fraction: Humus, resistant to further decomposition (33–50% of SOM). Has greater influence on the *structure/physical properties* of soils than on nutrient availability.
  - d) See appendix 1, Major Organic Components of Typical Decomposer Food Sources
  - e) Physical factors influencing decomposition
    - i. Particle size: High surface area:volume = more rapid decomposition
    - ii. Surface properties (waxes, pubescence) often decrease rate of decomposition
  - f) Limiting factors in decomposition of SOM
    - i. Decomposers tend to concentrate the nutrients that are in short supply
    - ii. Micronutrients are not usually a limiting factor
    - iii. Soil moisture
    - iv. Oxygen levels
    - v. C:N ratio of organic matter
  - g) Plant secondary compounds may inhibit decomposition (such as polyphenols, tannins found in many woody perennials)
- 3. Nitrogen cycle (see figure 3 in Unit 2.2, Soil Chemistry and Fertility)
  - a) Proteins → amino acids → ammonium (form of N useable by some plants) → nitrate (form of N useable by most plants)
  - b) *Ammonification* (aerobic or anaerobic): The biochemical process whereby ammoniacal nitrogen is released from nitrogen-containing organic compounds
  - c) *Nitrification* (aerobic): The biochemical oxidation/ change of ammonium to nitrate
    - i. Inhibited by low oxygen or low temperatures
    - ii. Ammonium build-up in cold, wet soils
  - d) If C:N < 20–30:1 = net mineralization. If C:N > 20–30:1 = net immobilization
- 4. See Hands-On Exercise, Carbon and Nitrogen Mineralization

## E. Soil Food Webs

- 1. Soil food web ecology
  - a) Trace the path of energy or nutrients passing from one organism to the next
- 2. Heterotrophic vs. autotrophic food webs
  - a) Autotrophic food webs → begin with C fixation by plants. Energy for most life is derived from sunlight that has been transformed by photosynthetic plants into organic compounds.
  - b) Heterotrophic food webs → *release* nutrients required by all plants
    - i. The decomposition food web begins with waste-products from autotrophic food webs

- c) Energy loss = 80–90% at each step in the food chain
- d) Food web structure and properties
  - i. Resilience = speed of recovery after disturbance
  - ii. Resilience *decreases* with increasing number of trophic levels due to increasing complexity—takes longer to reestablish complex food web relationships
  - iii. Disturbance selects for shorter food chains: In farmed soils, disturbance can be chemical (pesticides, fertilizers) or physical (cultivation, organic matter incorporation, removal of surface organic layer)
  - iv. Relate to timing of agricultural inputs and other disturbances
  - v. Fungi:bacteria biomass ratio characteristics of soil ecosystems
    - Productive agricultural soils ratio 1:1 or less (higher in no-till) = bacterial-dominated food webs with rapid cycling of nutrients
    - Deciduous forest, 5:1 to 10:1 (fungal dominated)
    - Coniferous forest, 100:1 to 1000:1 (fungal dominated)
- e) Ways that soil animals interact with soil microorganisms and influence soil properties
  - i. Shredding of organic matter (comminution)—“can openers”
  - ii. Spreading to new habitats and new food resources (dissemination)
  - iii. Grazing: Stimulate growth, control populations
  - iv. Predation: Similar effects as grazing
  - v. Soil structure changes (burrowing, mixing, defecating, crumb formation)
- f) Unique food web for each ecosystem, determined by:
  - i. Climate
  - ii. Soil/parent material
  - iii. Vegetation
  - iv. Land management practices

## F. Soil Biota

1. Characteristics
  - a) Diversity of organisms in soil can rival that of coral reef ecosystems
  - b) Characterized by small size and indistinct morphologies
  - c) Due to cryptic environment, visual cues are less important—bright colors and patterns are lacking in soil organisms
  - d) Biomass comparisons
  - e) Abundance
2. Habitats
  - a) Habitats within soil ecosystems are unevenly distributed
  - b) Habitats are concentrated at organic matter sites
    - i. Root zone (rhizosphere)
      - Succession of organisms as root grows
      - Some root exudates and root hairs may stimulate microorganisms by producing labile SOM
    - ii. Litter
    - iii. Surface of soil aggregates
    - iv. Incorporated organic matter

### 3. Functional classification

#### a) Microorganisms

- i. Colonial growth forms (cells about 1/25,000 inch wide)
  - Bacteria and yeast
  - Adapted to high surface area (SA)/volume
  - Colonize surfaces, crevices, pores
  - Teaspoon of soil contains 100 million to 1 billion bacteria
  - Biomass equivalent to 2 cows per acre
  - Many functions (N fixers, nitrifiers, denitrifiers, decomposers, pathogens, promote aggregation)
- ii. Mycelial growth forms (hypha length ranges from a few cells to many yards)
  - Fungi and actinomycetes
  - Penetrate organic matter
  - Translocation of nutrients
  - Functions: decomposers, mutualists, pathogens, nematode-trapping fungi

#### iii. Algae

#### b) Microfauna

- i. Protozoans (1/5000 inch to 1/50 inch wide)
  - Small animals (acellular) living in water films
  - Feed on bacteria, other microorganisms, detritus
  - Encystment: Distinctive response to drying out
  - Inhabit transitory environments
    - *Colpoda* divide once or twice per day at 12°C
  - Several distinct types
    - Ciliates have fringe of small hairs used for locomotion
    - Amoebae have an amorphous body shape
    - Flagellates have a whip-like tail for locomotion
- ii. Nematodes (1/500 inch in diameter, 1/20 inch in length)
  - Global distribution
  - Soil abundance = million/m<sup>2</sup>
  - Outer cuticle protects; resistant to toxins
  - Include microbivores, omnivores, predators, some parasites (10%)
  - Abundant at sites with high organic matter concentration
- iii. Rotifers, Tardigrades
- iv. No comminution, i.e., they don't shred organic matter into smaller pieces

#### c) Mesofauna

- i. Potworms (Enchytraeida)
  - Small annelids (related to earthworms), 1mm to 5 cm long
  - Tolerate pH < 4
  - Thousands/m<sup>2</sup> in high organic matter soil
  - No burrows
  - Feed on hyphae, microorganisms, feces
- ii. Collembolans (springtails)
- iii. Mites (acari)
- iv. Insect larvae
- v. Regulate microorganisms by grazing (feeding)

- vi. Minor comminution
- vii. 500 to 200,000 per square meter, far less biomass than microfauna
- d) Macrofauna
  - i. Earthworms
    - 3 ecological types (anecic, endogeic, epigeic)
    - Vermisphere concept
    - Obtain a portion of their nutrition from microbes living on organic residues they ingest
    - 7,000+ species
    - Stimulate microbial activity through effects on SOM, microbial inoculation onto substrates, soil structure, etc.
    - Mix and aggregate soil
    - Increase water infiltration
    - Provide channels for root penetration deep into soil
    - Bury and shred organic matter
    - Abundance decreases after disturbance (tillage, chemicals)
  - ii. Millipedes, isopods, mollusks, insects
  - iii. Shred and incorporate plant remains (may become pests by feeding on living plants if insufficient organic residues present)
  - iv. Alter soil structure
- e) Megafauna
  - i. Large invertebrates, vertebrates

## G. Rhizosphere Ecology

1. Definitions
  - a) Rhizosphere (**R**): The narrow zone of soil subject to the influence of living roots, as manifested by the leakage or exudation of substances that promote or inhibit microbial activity
  - b) Rhizoplane (**r**): The actual root surface, which provides a highly favorable nutrient base for many species of bacteria and fungi
  - c) Edaphosphere (**S**): Soil beyond root influence
  - d) Rhizosphere Effect: Soil microorganisms and fauna stimulated
    - i. **R:S** ratio generally greater than 1 (i.e., more biota in R than in S)
  - e) Rhizosphere succession: The sequence of changes in the composition and densities of soil microbes and fauna in the area surrounding a growing root (see below)
2. Roots
  - a) Root environment
    - i. Determined by above-ground processes (products of photosynthesis are translocated to roots)
    - ii. Exudates, sloughed hairs, and cells feed soil organisms in R and r
    - iii. Bicarbonate formation as a result of influences on pH
    - iv. Type and amount of exudates vary with species, age, soil
    - v. Oxygen decreases, CO<sub>2</sub> increases in root zone over time due to plant and R organism respiration

- b) Root form
  - i. Fibrous roots
    - Most monocots (e.g., grasses)
    - Primary root replaced by series of adventitious roots
  - ii. Tap roots
    - Most monocots and gymnosperms
    - Tap root persists and forms many lateral branches
    - Generally deeper than fibrous roots
  - iii. Root depth
    - Species specific, influenced by environmental conditions
- c) Root structure
  - i. Root cap
    - Live cells produced by meristem
    - Protects root, like a bud scale
    - Constantly replaced (5–6 day turn over)
    - Responds to gravity
  - ii. Meristematic zone: 2 mm zone where most cell division happens
  - iii. Zone of elongation: Rapid growth, cells from meristem
  - iv. Mucilage
    - Covers root from tip to beginning of root hair zone
    - Source is part microbial, part root cap
    - Possible functions: Nutrient uptake, protection, prevent drying, fill spaces between root and soil, food for microbes
  - v. Root hair (differentiation) zone
    - Root hairs have life span of days to weeks
    - Do not become large structural roots; play a nutrient absorption role
    - Are an outgrowth of epidermal cell
    - Rye plants can produce over 100 million per day
    - None in redwood trees, firs, some pines
    - Food sources that support rhizosphere microbes, contribute significant amounts of soil organic matter
  - vi. Lateral roots
    - Originate from the vascular bundle inside cortex
    - Cortex and epidermis are ruptured by new lateral root
    - Bacteria colonize these emergence sites
- d) Root nutrition
  - i. Maximum nutrient uptake occurs behind meristem (elongation and root hair zones)
  - ii. Water and nutrients are withdrawn from narrow band around roots
  - iii. Replenished from surrounding soil by *mass flow* (the movement of nutrients with the overall flow of water to plant roots)
  - iv. If mass flow is slow, depletion zone created, resulting in lack of some nutrients
- e) If uptake is slow certain ions may accumulate—all ions in solution move towards root during mass flow; those not used by plant will accumulate around root



- f) Root exudates
- i. Amounts
    - 20–50% more C enters the soil from exudates, sloughed cells, and root hairs than is present as fibrous roots at end of growing season = substantial contribution to SOM
    - Amount of exudates increased by:
      - wetting, after a drying spell
      - physical or chemical injury (i.e., mowing, grazing of perennial grass cover crop)
      - abrasion, phytotoxic residues, osmotic stress
  - ii. Types
    - Carbohydrates and amino acids: Most-researched compounds
      - 10 sugars, glucose and fructose most common
      - 25 amino acids
    - Also organic acids, fatty acids, sterols, enzymes, volatile compounds, and growth factors
    - Difficult to separate plant and microbe sources
  - iii. Exudates released from meristem zone
    - Nematodes and zoospores congregate there
  - iv. Foliar sprays may move into roots (depends on molecular weight)
    - Herbicides, antibiotics may also move into roots
    - Streptomycin moved from *Coleus* leaves to roots in 24 hrs
    - Bacteria suppressed by the streptomycin
- g) Variations in root exudates
- i. **R** effect increases with age
  - ii. **R** effect decreases with senescence of plants
  - iii. Annual crop plants have greater **R** effect than trees
  - iv. Legume **R** effect stronger than non-legume
  - v. **R** effect may be strongest at flowering
  - vi. Stronger in sandy soils than in heavier soils
  - vii. Highest **R** effect in dune and desert soils
- h) Management effects
- i. Synthetic fertilizers
    - Sometimes no effect
    - Sometimes increase **R:S** indirectly through stimulation of plant growth
  - ii. Organic manures
    - Same indirect positive effect on **R:S**
    - Also may decrease ratio since edaphic (**S**) microbes are also stimulated by organic matter input
    - After 4 weeks of decomposition, **R:S** generally increases
3. Soil organisms
- a) Bacteria
    - i. Most responsive to plant exudates
    - ii. 2 to 20 fold increase in bacterial populations in **R** vs. **S**
    - iii. *Pseudomonas* most consistently abundant in rhizosphere
    - iv. Also *Agrobacterium* (biocontrol agent) and *Achromobacter*

- v. *Azotobacter*, non-symbiotic nitrogen fixer
  - If inoculated on seed can persist in rhizosphere
- vi. *Rhizobium*, *Nitrosomonas*, and *Nitrobacter* common in **R**
- b) Fungi
  - i. Average increase 10 to 20 fold in **R** of crop plants from **S**
  - ii. *Fusarium* is a dominant genera of **R** fungi
  - iii. Mycorrhizae can provide physical and chemical suppression of pathogens
- c) Protozoans
  - i. Mainly bacteria grazers, so some increase is expected in **R**
  - ii. Example: In a wheat field, bacteria **R:S** was 23:1, protozoan **R:S** was 2:1
  - iii. Some large amoebae may provide biocontrol of some fungi
- d) Nematodes
  - i. Root substances stimulate egg hatching of some parasitic nematodes
  - ii. Host and non-host plants may stimulate hatching of nematodes, e.g., some crucifers and chenopods evoke *Heterodera* hatching, but don't support root invasion by larvae. Some plants will cause eggs of parasitic nematodes to hatch, but they are not susceptible to attack by the parasite. Therefore the plant stays healthy, and the nematodes fail to thrive.
  - iii. Nematodes tend to congregate around elongation zone of roots
  - iv. Degree of nematode attraction proportional to root growth rate
  - v. Some root exudates repel nematodes (e.g., isothiocyanates in mustard)
- e) Microarthropods
  - i. Some grazers consistently more abundant around roots
- f) Rhizosphere succession
  - i. Root tip releases labile carbon
  - ii. Labile carbon stimulates rapid increase of microbes and nutrient immobilization in **R**
  - iii. Grazers increase, tracking microbe increases
  - iv. Root hair zone, water, and carbon decrease
  - v. Microbes eventually decrease, grazers cause net mineralization and release of nutrients from SOM
  - vi. Further along, grazers encyst or migrate
- g) Examples

## H. Management Effects on Soil Ecosystems

1. No-tillage or reduced-tillage cropping systems
  - a) Organic litter is retained on the soil surface
  - b) Physical disturbance is minimized
  - c) Surface soil stays cooler and moister
  - d) More surface organic matter available as food substrate
  - e) Ratio of fungi to bacteria increases over time
  - f) Earthworms and arthropods become more plentiful
  - g) Effects on nutrient cycling
  - h) Effects on soil physical properties

2. Rotations
  - a) Monocultures and clean cultivation
    - i. Create little habitat for soil organisms, leading to less abundant and diverse soil ecosystems
    - ii. Consistent plant hosts may serve to develop populations of pathogenic organisms, causing pest problems, crop losses, or need for pesticide use.
  - b) Complex rotations
    - i. Results in greater variety of food sources (roots, root exudates, and residues)
    - ii. Increases diversity of soil organisms, leading to increased competition for resources, as well as predation of pathogens and pests.
    - iii. Interrupts plant-host cycle
  - c) Multiculture
    - i. Growing more than one crop in one field
    - ii. More closely mimics natural ecosystem
    - iii. Likely to support even greater diversity of soil organisms, especially invertebrates
    - iv. Interrupts plant-host cycle
3. Biocides (insecticides, herbicides, fungicides)
  - a) Effects vary depending on
    - i. Type of chemical
    - ii. Species of soil organism in question
    - iii. Concentration and other exposure factors
  - b) High levels of pesticide use generally reduce food web complexity
    - i. Methyl bromide and other fumigants are extreme examples, resulting in temporary soil sterilization
    - ii. Eliminate most organisms
    - iii. Some bacteria quickly return
    - iv. Other organisms only slowly return
  - c) Biocides and predator-release phenomenon
    - i. In cases where biocides selectively eliminate predators, lower trophic levels may become more abundant
    - ii. Destabilizing effect on food webs
      - Overgrazing on food sources resulting in depletion of food sources
      - Population explosion, followed by crash, resulting in...
      - Immobilization of nutrients, followed by rapid mineralization at a rate that is not necessarily compatible with crop needs. May result in leaching of water-soluble nutrients.
  - d) Earthworms
    - i. Most strongly effected (negatively) by fungicides and fumigants
    - ii. Herbicides
      - Don't seem to be directly toxic
      - Indirect negative effect through elimination of vegetation
4. Food web structures
  - a) Fungi/bacteria ratio
  - b) Dominant microbe influences other trophic levels

5. Assessment of fertility needs (also see Unit 1.1, Managing Soil Fertility)
- a) Measures of available nitrogen
    - i. Conventional cropping systems
      - Most N provided by additions of fertilizer
      - Measurements of nitrate reflect accurately what is available to plants
      - Key management decisions are when to apply fertilizer
    - ii. Cropping systems based on organic matter management
      - Soil food web becomes primary source of N derived from organic matter inputs
      - Soil analysis in efficiently-managed farming systems may indicate “inadequate” levels of N at any given time because much of soil N is immobilized
      - Cumulative release of mineral N over growing season may match amounts seen in conventional system
      - Managing the timing of mineralization (through tillage, OM quality [e.g., C:N ratio], incorporation of OM/fertilizers, irrigation) by soil food web becomes more critical
      - If managed well, less risk of nutrient loss through leaching or volatilization



# Demonstration 1: Organic Matter Decomposition in Litter Bags

## *for the instructor*

### OVERVIEW

*To demonstrate the capacity of different soils to decompose organic matter, this exercise requires you to bury cellulose disks (Whatman filter paper) in a variety of locations. This should be done at least two weeks prior to the class to allow decomposition to proceed before the disks are retrieved on the day of the class. To accelerate decomposition, filter paper disks can be dipped in a bucket of water with some fish emulsion added just before burial.*

### MATERIALS NEEDED

- Whatman filter paper discs
- Plastic mesh bags\*
- Flags to mark burial sites
- Flat shovel
- Litter Bag Data worksheets (see appendix 2)
- Pencils

\*for plastic mesh bags, you may use pond and pool netting obtained from a local feed and seed supply. It is a 3/8-inch polypropylene mesh. Cut mesh into 6-inch x 12-inch pieces, fold in half, then fold the edges over and staple the edges shut. Other sources are the mesh bags that bulbs are sold in, garlic or onion bags, or the mesh bags that imported rice noodles are packed in. The smaller the mesh size, the smaller the organisms that will be excluded from the bag. This phenomenon can be exploited by comparing decomposition rates of organic matter buried in bags with different mesh sizes. Organic matter in bags with very fine mesh will be decomposed primarily by microflora and microfauna. Organic matter in larger mesh bags will also be decomposed by larger fauna.

### PREPARATION

1. Place litter bags in soil at least two weeks prior to class. Place them vertically in soil, and place them all at the same depth. For a 10 cm disc, 0 to 10 cm is a convenient depth.
2. Flag the site, and make a note of location, or a map. A minimum of 3 bags should be placed in each habitat. Possible habitats include raised garden beds, cultivated fields, fallow fields, orchards, compost piles, vermicompost bins, soil surface (not buried), weedy borders.
3. Bags should be retrieved very gently, as the paper is likely to be very fragile. (If too rapid decomposition makes this demonstration difficult, an alternative material to use is a 50/50 cotton/polyester material. Even if the cotton is entirely degraded, the polyester matrix will remain intact. Strips would have to be weighed before and after burial to determine mass loss.)

4. Have students collect the bags and return them to a central location.
5. Ask students to observe the soil habitat that each bag is in. Suggest they note things like soil moisture, presence of any soil animals, vegetative cover and shading, knowledge of prior cultivation, and anything else they think may be important in explaining their results.
6. Gently brush soil from discs. Ask students to visually estimate percentage of the disc remaining.
7. Record results and calculate averages for each habitat selected. A sample form is provided (see appendix 2, Litter Bag Data Sheet) for recording data. Appendix 3 provides an example of what a filled-out data sheet might look like.

#### **PREPARATION TIME**

1 hour to make 24 bags, 1 hour to bury 24 bags  
(allow additional time for gathering materials)

#### **DEMONSTRATION TIME**

1.5 hours

#### **DISCUSSION QUESTIONS**

1. After retrieving the litter bags, ask students to offer hypotheses about why the disks decompose more rapidly in some habitats than others.
2. What environmental factors might have influenced the results?
3. What management factors might have influenced the results?
4. Can you see any signs of biological activity on the disks (e.g., fungal mycelia, soil animals, invertebrate feces, comminution)?
5. What do the results suggest about nutrient cycling rates in the soils tested?
6. Can these observations for cellulose decomposition rates be extrapolated to other types of organic matter?
7. What are the limitations of this method?

#### **VARIATIONS**

If possible, pair the litter bag demonstration with other methods of assessing biological activity, such as:

- Carbon dioxide evolution (see Demonstration 2, Soil Respiration)
- Earthworm density (see Demonstration 3, Earthworm Populations)
- Tullgren funnel extractions of microarthropods (see Demonstration 4, Soil Arthropods)
- Microbial biomass measurements

# Demonstration 1: Organic Matter Decomposition in Litter Bags

## *step-by-step instructions for students*

### **INTRODUCTION**

*The decomposition of organic matter is an important soil process for organically managed farms and gardens. Organic matter includes a vast array of compounds that can be biologically decomposed at various rates, depending on their physical and chemical complexity. Environmental factors such as temperature, moisture, and soil biological activity, which are affected by management practices, also determine decomposition rate.*

*We can use discs of filter paper to represent a uniform piece of cellulose-rich organic matter. If discs are placed in the soil for a set period and then retrieved, we can learn something about the capacity of various soils to decompose cellulose. By placing the discs in plastic mesh bags prior to putting them in soil, we can make it easier to retrieve the discs intact. Decomposition can be estimated by a visual estimate of percentage surface area remaining. A more quantitative method is to rinse and dry the discs, then weigh them to estimate mass loss (original mass must also be known).*

### **MATERIALS NEEDED**

Assemble materials as per instructor's outline

### **PREPARATION**

Litter bags are placed in soil at least two weeks prior to class. They are placed vertically in soil, all at the same depth. For a 10 cm disc, 0 to 10 cm is a convenient depth.

Bags should be retrieved very gently, as the paper is likely to be very fragile. When you retrieve the bags, make sure to observe the soil habitat that each bag is in. Note things like soil moisture, presence of any soil animals, vegetative cover and shading, and anything else you think may be important in explaining the results.

Gently brush soil from discs. Visually estimate percentage of the disc remaining. Record results and calculate averages for each habitat selected, using the data sheet supplied.

### **DISCUSSION QUESTIONS**

1. After retrieving the litter bags, discuss your hypotheses about why the disks decompose more rapidly in some habitats than others.
2. What environmental factors might have influenced the results?
3. What management factors might have influenced the results?
4. Can you see any signs of biological activity on the disks (e.g., fungal mycelia, soil animals, invertebrate feces, comminution)?
5. What do the results suggest about nutrient cycling rates in the soils tested?
6. Can these observations for cellulose decomposition rates be extrapolated to other types of organic matter?
7. What are the limitations of this method?





# Demonstration 2: Soil Respiration

## *for the instructor*

### OVERVIEW

*This demonstration uses Draeger gas detection tubes to measure carbon dioxide. See sources of supply at the end of this outline.*

### MATERIALS

- 6-inch diameter ring\*
- Lid with rubber stoppers
- Hand sledge and wood block
- Soil thermometer
- 2 sections of plastic tubing
- 2 needles
- Draeger tubes
- 140 cc syringe
- Stopwatch or timer
- Soil Respiration Data Sheets (appendix 4)
- Pencils

\*possible sources are sections of 6-inch irrigation pipe, PVC pipe with one end tapered, or coffee cans with bottom removed

### PREPARATION

Microbial activity is greatest when the soil is moist (at or near field capacity). If the soil is dry, a second respiration measurement should be made at a minimum of six hours (preferably 16 to 24 hours later) after the infiltration test or wetting of the soil. If the soil is saturated, soil respiration is inhibited, and this test should not be run. If necessary to save time, rings can be placed and soils wetted the day before the demonstration. It may be useful to combine the litter bag and soil respiration measurements, in order to compare results from two different methods that measure soil biological activity.

Divide class in teams of two or more, and assign each team to one sample site. Demonstrate the technique first, à la Julia Childs. Have one ring for showing how to place it and take headspace measurements. Have a second ring already placed and capped from which to collect a CO<sub>2</sub> sample. Then send teams out to do their own sampling.

Note: This description of the soil respiration measurement was taken from the USDA Soil Quality Test Guide, which you may want to consult for more details. See Resources section.

1. Clear the sampling area of surface residue, etc. If the site is covered with vegetation, trim it as close to the soil surface as possible.
2. Using the hand sledge and block of wood, drive the 6-inch diameter ring, beveled edge down, to a depth of three inches (line marked on outside of ring). If the soil contains rock fragments, and the ring cannot be inserted to depth, gently push the ring into the soil until it hits a rock fragment.
3. Measure the height from the soil surface to the top of the ring in centimeters. For a more accurate measurement of soil respiration, the chamber headspace should be measured. Inside the ring, take four measurements (evenly spaced) of the height from the soil surface to the top of the ring, calculate the average, and record on the Soil Respiration Data Sheet (appendix 4).

4. Cover the ring with the lid and note the time. Wait exactly 30 minutes (to allow CO<sub>2</sub> to accumulate in the chamber). If this is the SECOND respiration measurement, briefly remove the lid and replace it before timing to allow the release of gases that have built up over the 6–24-hour waiting period.
6. Insert the soil thermometer into the soil adjacent to the ring with lid (about one inch away from ring and one inch deep). If the thermometer can easily be inserted into the rubber stoppers, insert it into one of them to a 1-inch depth into the soil.
7. Assemble the Draeger tube apparatus just before the end of the 30-minute wait. Connect a needle to one of the sections of tubing. Break open both ends of a CO<sub>2</sub> Draeger tube, either by using the hole at the end of the syringe handle, or by clipping the tube ends with a finger nail clipper. Connect the Draeger tube to the other end of the needle's tubing. The arrow on the side of the Draeger tube should point away from the needle. With the second piece of tubing, connect the Draeger tube to the syringe.
8. After 30 minutes, insert the Draeger tube apparatus needle into a stopper. Insert a second needle into one of the other stoppers on the lid to allow air flow into the head space during the gas sampling. The second needle should be inserted just before the head space is sampled.
9. Over a 15-second span, draw the syringe handle back to the 100 cc reading (1 cc = 1 ml). [If the reading is less than 0.5%, take four additional 100 cc samples of the head space through the same Draeger tube. To do this, disconnect the tube from the syringe to remove the air, and reconnect the tube to the syringe. Take another 100 cc sample. Repeat.]
10. On the Soil Respiration Data worksheet, record the temperature in Celsius at the time of sampling. On the Draeger tube, read the "n=1" column if 100 cc was sampled or the "n=5" column if 500 cc was sampled. The % CO<sub>2</sub> reading should be an estimate of the highest point that the purple color can be easily detected. Enter this reading on the Soil Respiration Data worksheet.
11. Remove the thermometer, Draeger apparatus needle, air flow needle, and the lid from the ring. If this is the first respiration measurement, leave the ring in the soil for the infiltration measurement.

#### CALCULATIONS

$$\text{Soil Respiration (lb CO}_2\text{ - C/acre/day)} = \text{PF} \times \text{TF} \times (\% \text{CO}_2 - 0.035) \times 22.91 \times \text{H}$$

PF = pressure factor = 1

TF = temperature factor = (soil temperature in Celsius + 273) ÷ 273

H = inside height of ring = 5.08 cm (2 inches)

Calculations can be done quickly by entering data into a spreadsheet if a computer is available, or students can use hand-held calculators.

#### PREPARATION TIME

1–2 hours (varies depending on what materials are available)

#### DEMONSTRATION TIME

1–1.5 hours

#### DISCUSSION QUESTIONS

1. Compare soil respiration results for different sites. How may management practices on the different sites have influenced results?
2. If measurements were made before and after wetting soil, compare before and after results. How does soil moisture influence biological activity?
3. Would it be possible to estimate all carbon imports and exports to a soil system? What information would you need to start to make such an estimate?

#### SOURCES OF SUPPLIES

Fisher Scientific, Pittsburgh, PA  
 (800) 766-7000  
 Draeger tubes, latex tubing, hypodermic needles  
 Scientific Industries  
 227 Blue Bell Ave. Boulder, CO 80302  
 (303) 443-7087  
 Draeger tubes

# Demonstration 2: Soil Respiration

## *step-by-step instructions for students*

### **INTRODUCTION**

*Soil breathes! Soil respiration is an indicator of biological activity (i.e., microbial and root), or soil life. This activity is as important to the soil ecosystem as healthy lungs are to us. However, more activity is not always better because in some circumstances it may indicate an unstable system undergoing net carbon loss (i.e., after tillage).*

*Soil respiration is the production of carbon dioxide (CO<sub>2</sub>) as a result of biological activity in the soil by microorganisms, live roots, and macroorganisms such as earthworms, nematodes, and insects. Carbon dioxide emitted from soil is a colorless and odorless gas that enters the atmosphere and annually exceeds the amount emitted by all human activities. The activity of organisms in the soil is considered to be a positive attribute for soil quality.*

Soil respiration is highly variable both spatially and seasonally, and is strongly affected by moisture and temperature conditions. Because this variability can complicate interpretations, certain sampling precautions must be taken.

Knowing the history of the sampling site and characteristics of nearby soils becomes very important when evaluating respiration. Soil color may provide some assistance when interpreting respiration rates. A light colored soil with a high respiration rate may be indicative of a soil being depleted of organic matter. A relatively darker soil with the same rate could be considered healthy. The dark color indicates the presence of organic matter. Tillage or cultivation can result in loss of soil carbon (C) and increases in the amount of CO<sub>2</sub> released. The soil is loosened, which creates better accessibility of oxygen necessary for organic matter decomposition and respiration, resulting in the production of CO<sub>2</sub>.

Soil respiration can be limited by moisture, temperature, oxygen, soil reaction (i.e., pH), and the availability of decomposable organic substrates. Optimum respiration usually occurs at around 60% of water-filled pore space. Soil respiration will decrease under saturated or dry conditions. Biological activity doubles for every 18°F rise in temperature until the optimum temperature is reached (varies for different organisms). Activity declines as temperature rises above optimum. The most efficient soil organic matter decomposers are aerobic; thus, soil respiration rates decline as soil oxygen concentration decreases. Oxygen is most limiting in soils that are saturated with water. Greater oxygen flow occurs in well-aggregated soils that have many macropores.

Addition of organic materials will generally increase soil respiration. Organic matter provides the food or substrate on which heterotrophic soil microbes feed. Organic materials with low carbon to nitrogen (C:N) ratios (e.g. manure, leguminous cover crops) are easily decomposed; thus, the addition of these materials to soil will increase soil respiration. Materials with high C:N ratios (e.g., compost, sawdust) decompose more slowly but provide a more stable, long-term supply of organic material than legumes, biosolids, and manures. Soil microbes will compete with crop plants for nitrogen when soil is amended with products having C:N ratios higher than 25:1.

Agricultural chemicals that directly kill or otherwise impair soil microorganisms, such as fungicides and nematocides, reduce soil respiration. Although these chemicals target pathogenic

organisms, they may also impair the viability of beneficial organisms.

Organic matter decomposition provides benefits and drawbacks. Decomposition of organic matter is the primary route through which some essential nutrients (e.g., nitrogen) are released, but organic matter losses reduce the benefits that organic matter confers to soil physical and chemical properties. The addition of organic materials to the soil must equal the loss due to decomposition for the sustainability of the system to be maintained.

## MANAGEMENT FACTORS INFLUENCING SOIL RESPIRATION

### INCREASES SOIL RESPIRATION

- Adding organic amendments, such as manure, biosolids, and crop residues
- Irrigating to proper moisture content
- Tillage

### DECREASES SOIL RESPIRATION

- Removing or burning crop residues
- Continuous tillage without organic matter replacement
- Agricultural chemicals (e.g., fungicides and nematocides)

## MATERIALS

Assemble materials as per instructor's outline

## PREPARATION

Microbial activity is greatest when the soil is moist (at or near field capacity). If the soil is dry, a second respiration measurement should be made at a minimum of six hours (preferably 16 to 24 hours later) after the infiltration test or wetting of the soil. If the soil is saturated, soil respiration is inhibited, and this test should not be run.

1. Clear the sampling area of surface residue, etc. If the site is covered with vegetation, trim it as close to the soil surface as possible.

2. Using the hand sledge and block of wood, drive the 6-inch diameter ring, beveled edge down, to a depth of three inches (line marked on outside of ring). If the soil contains rock fragments, and the ring can not be inserted to depth, gently push the ring into the soil until it hits a rock fragment.
3. Measure the height from the soil surface to the top of the ring in centimeters (cm). For a more accurate measurement of soil respiration, the chamber head-space should be measured. Inside the ring, take four measurements (evenly spaced) of the height from the soil surface to the top of the ring, calculate the average, and record on the Soil Data worksheet.
4. Cover the ring with the lid and note the time. Wait exactly 30 minutes (to allow CO<sub>2</sub> to accumulate in the chamber). If this is the SECOND respiration measurement, briefly remove the lid and replace it before timing to allow the release of gases that have built up over the 6–24-hour waiting period.
5. Insert the soil thermometer into the soil adjacent to the ring with lid (about one inch away from ring and one inch deep). If the thermometer can easily be inserted into the rubber stoppers, insert it into one of them to a 1-inch depth into the soil.
6. Assemble the Draeger tube apparatus just before the end of the 30-minute wait. Connect a needle to one of the sections of tubing. Break open both ends of a CO<sub>2</sub> Draeger tube, either by using the hole at the end of the syringe handle, or by clipping the tube ends with a finger nail clipper. Connect the Draeger tube to the other end of the needle's tubing. The arrow on the side of the Draeger tube should point away from the needle. With the second piece of tubing, connect the Draeger tube to the syringe.
7. After 30 minutes, insert the Draeger tube apparatus needle into a stopper. Insert a second needle into one of the other stoppers on the lid to allow air flow into the head space during the gas sampling. The second needle should be inserted just before the head space is sampled.

8. Over a 15-second span, draw the syringe handle back to the 100 cc reading (1 cc = 1 ml). [If the reading is less than 0.5%, take four additional 100 cc samples of the head space through the same Draeger tube. To do this, disconnect the tube from the syringe to remove the air, and reconnect the tube to the syringe. Take another 100 cc sample. Repeat.]
9. On the Soil Respiration Data worksheet, record the temperature in Celsius at the time of sampling. On the Draeger tube, read the "n=1" column if 100 cc was sampled or the "n=5" column if 500 cc was sampled. The % CO<sub>2</sub> reading should be an estimate of the highest point that the purple color can be easily detected. Enter this reading on the Soil Respiration Data worksheet.
10. Remove the thermometer, Draeger apparatus needle, air flow needle, and the lid from the ring. If this is the first respiration measurement, leave the ring in the soil for the infiltration measurement.

*(This description of the soil respiration measurement was taken from the USDA Soil Quality Test Guide, which you may want to consult for more details).*

#### CALCULATIONS

$$\text{Soil Respiration (lb CO}_2\text{-C/acre/day)} = \text{PF} \times \text{TF} \times (\% \text{CO}_2 - 0.035) \times 22.91 \times \text{H}$$

$$\text{PF pressure factor} = 1$$

$$\text{TF temperature factor} = (\text{soil temperature in Celsius} + 273) \div 273$$

$$\text{H inside height of ring} = 5.08 \text{ cm (2 inches) if not measured}$$

#### INTERPRETATION OF SOIL RESPIRATION VALUES

In general, a higher respiration rate indicates better soil quality. Low respiration rate, when soil temperature and moisture are favorable for biological activity, would indicate less than desirable organic matter levels. This value must be interpreted within the context of other indicators. For example, a very low nitrate concentration plus a high respiration rate may indicate a high nitrogen immobilization rate, possibly due to the addition of crop residues or other soil amendments that possess wide C:N ratios. Some general guidelines to interpreting respiration values are presented in Table 1. These are only guidelines and should not be applied to every soil type and management situation.

**TABLE 1.** GENERAL SOIL RESPIRATION CLASS RATINGS AND SOIL CONDITION AT OPTIMUM SOIL TEMPERATURE AND MOISTURE CONDITIONS, PRIMARILY FOR AGRICULTURAL LAND USES (Woods End Research, 1997)

SOIL RESPIRATION (lbs. CO <sub>2</sub> -C/ac/day)	CLASS	SOIL CONDITION
0	No soil activity	Soil has no biological activity and is virtually sterile.
< 9.5	Very low soil activity	Soil is very depleted of available organic matter and has little biological activity.
9.5 - 16	Moderately low soil activity	Soil is somewhat depleted of available organic matter, and biological activity is low.
16 - 32	Medium soil activity	Soil is approaching or declining from an ideal state of biological activity.
32 - 64	Ideal soil activity	Soil is in an ideal state of biological activity and has adequate organic matter and active populations of microorganisms.
> 64	Unusually high soil activity	Soil has a very high level of microbial activity and has high levels of available organic matter, possibly from the addition of large quantities of fresh organic matter or manure.

A high soil respiration rate, indicative of high biological activity, can be a good sign of rapid decomposition of organic residues into nutrients available for plant growth. However, decomposition of the stable organic matter is detrimental to many physical and chemical processes such as aggregation, cation exchange, and water holding capacity. Also, immediately following a tillage operation, CO<sub>2</sub> evolution can rise dramatically due to exposure of organic matter to organisms and oxygen. Also, soil respiration can rise dramatically after rainfall. The rise in soil respiration is affected by the length of time the soil is dry before the rainfall event.

Under dry conditions, soil respiration tends to be higher in the crop row than in the interrow. The higher respiration rates are attributed to the contribution from plant roots. Under wet conditions, there tends to be no difference in respiration between the row and interrow. When the soil interrow is compacted (wheel track) and the soil is wet, soil respiration tends to be lower than in the row. The lower soil porosity accounts for the lower respiration rate under compacted conditions.

Biological activity is a direct reflection of the degradation of organic matter in the soil. This degradation indicates that two processes are occurring: (1) loss of soil carbon and (2) turnover of nutrients. Some optimum soil respiration rate, that balances the long-term detrimental aspects of soil carbon loss and soil nutrient turnover, must be defined.

#### **DISCUSSION QUESTIONS**

1. Compare soil respiration results for different sites. How may management practices on the different sites have influenced results?
2. If measurements were made before and after wetting soil, compare before and after results. How does soil moisture influence biological activity?
3. Would it be possible to estimate all carbon imports and exports to a soil system? What information would you need to start to make such an estimate?



# Demonstration 3: Assessing Earthworm Populations as Indicators of Soil Quality

## *for the instructor*

### OVERVIEW

*This demonstration introduces students to techniques for assessing earthworm populations as indicators of soil quality.*

*You have a choice of two methods for this demonstration. The shovel-count method will be more tedious for the students because they will have to sort through the soil and remove all earthworms. The vermifuge method may take a little more effort at first to gather the materials needed, but it will make the students' work easier.*

### MATERIALS

#### SHOVEL-COUNT METHOD

- Shovels
- Earthworm Data Sheets (appendix 5)
- Pencils

#### VERMIFUGE METHOD

- Sample rings\*
- Clippers
- Watering can
- Scoop
- Stirring rod
- Fresh water
- Jars
- Earthworm Data Sheets (appendix 5)
- Pencils
- Ground yellow mustard seed (available in bulk from health food stores or from herb companies)\*\*

\*Sample rings define the sample area and prevent vermifuge from escaping sample area. A simple design is to cut the top 8–12 inches from a 5-gallon drum and weld on a piece of metal pipe that overhangs each side by 6 inches to use as a handle. The ring is pressed into the soil to 2–3 inches depth, and vermifuge is added within the sample ring. Sample rings can also be fashioned from sheet metal, housing duct pipes, or large clean paint cans with the bottom cut off.

\*\*60 ml (volume) or 32 grams of yellow mustard powder to 4.5 liters of tap water = 13 ml/1 liter or 7g/liter. 4.5 liters of vermifuge is the amount required per sample area in this demonstration.



## PREPARATION

### SHOVEL-COUNT METHOD

For the shovel-count method, very little preparation is required. Identify sample areas, try to collect a similar soil volume at each location, and record results.

### VERMIFUGE METHOD

The vermifuge method requires more preparation. Sample rings must be obtained or made. Other materials must be gathered. To minimize the amount of time needed for the demonstration, sample rings can be set out the day before. Ideally a minimum of 4 can be set out per habitat. Select areas with contrasting management regimes. Possible habitats include orchard, row crop, fallow, and uncultivated field soils.

To begin the demonstration, gather group at one sample ring to explain technique. Divide class evenly among the number of sample rings and have each “ring-team” collect their sample. Have one person in each team do a shovel-count at each site for comparison. Collect results and derive an average abundance per habitat. Observe species differences and discuss results.

## PROCEDURE

1. Select sample area
2. Place sample rings on the surface of the site and push them several inches into the soil.
3. Carefully clip vegetation and removed all litter from inside sample area.
4. Slowly sprinkle 4.5 liters of vermifuge into each sample area, distributing it evenly over the entire surface.
5. After all of the vermifuge solution infiltrates the soil, wait 10 minutes, and make a second vermifuge application (4.5 liters).
6. Collect all earthworms that surface inside the sample area.
7. After 10 minutes elapse since infiltration of the second vermifuge application, use a hand spade to dig through the surface layer of soil (~5 cm deep) and collected any more earthworms found there.

8. Rinse earthworms in water, drain, and store in containers inside an insulated cooler with ice packs (unless samples are to be counted in the field and returned to the sample area).
9. An alternate method that does not require a sample ring can be found in the USDA Soil Quality Test Kit Guide, which is available on the internet (see Resources section).

## PREPARATION TIME

For the shovel-count method, 0.5 hour is all that is needed. For the vermifuge method, several hours or more may needed to gather materials.

## DEMONSTRATION TIME

1.5–2 hours

## DISCUSSION QUESTIONS

1. Most earthworm species found in farmed soils in the U.S. were not present in those soils 400 years ago. Where do you think they came from?
2. Compare your findings from different habitats. Which habitats had the most earthworms per sample area? Which had the highest diversity (greatest number of species)? Why?
3. Determine what ecological types of earthworm were present in each sample area (see Table 2, page 34). How do you think these results were influenced by soil management practices in those areas. Consider factors such as amount and type of soil disturbance, organic matter inputs, presence of surface organic layer, etc.
4. How do these findings relate to agricultural productivity and sustainability?
5. If you were in charge of management decisions for the farm soils that were sampled, would you alter any practices based on this information? Why?

# Demonstration 3: Assessing Earthworm Populations as Indicators of Soil Quality

## *step-by-step instructions for students*

### INTRODUCTION

*Earthworms are representative of the many organisms that make up soil food webs, and their abundance can be an indicator of soil biological activity.*

There are a number of ways to estimate how many earthworms are living in a particular field. Perhaps the simplest is the shovel-count: turn over a shovel-full of soil and count the worms present. Dig down 8 inches to a foot, and count every earthworm you can find in the shovel-full. Do this in half-a-dozen or more spots in each soil type on your land and come up with an average for each. If you find 5 to 10 worms per shovel-full, that represents a fairly healthy earthworm community. If this is done at about the same time each year the results will give some indication of how management practices are affecting earthworm populations.

Keep in mind that earthworm populations are very patchily distributed, and their location and abundance are heavily influenced by soil moisture, temperature, organic matter, time of year, and probably several other variables such as barometric pressure. For these reasons, a sufficient number of samples must be collected in order to accurately characterize earthworm populations in a particular field. Using more standardized sampling methods may also help.

Another method for sampling earthworms uses a vermifuge, or chemical irritant, which causes the earthworms to burrow to the soil surface, where they can be collected by hand. For many years the standard vermifuge has been a very dilute solution of formalin (about 8 ml formalin in 4.5 liters of water). However, recent studies have shown that mustard powder in water can be equally as effective.

Those interested in developing an even greater depth of understanding about earthworm ecology and how it interacts with farming may want to do more than just count numbers of earthworms present. Earthworms can be classified according to some simple physical characteristics that are directly related to their ecological roles in soil. Table 2 (next page) highlights the three types of earthworms.

Try using Table 2 to determine if you have more than one type of earthworm in your samples. Most California farm soils have endogeic earthworms, but epigeic and anecic species are rare. Epigeic species are more likely to be found in fields that have a permanent organic mulch on the surface. They may be added along with composts, but are not likely to thrive in the absence of an organic cover. Anecic species are desirable because of the work they do incorporating organic matter into the soil, mixing surface and deeper soil horizons, and creating deep channels for aeration, infiltration, and easy root penetration. Anecic earthworms could be introduced by direct inoculation, but transferring blocks of soil (one cubic foot each) from an area with a large earthworm population into a farm soil might work better.

Another idea is to set aside a small portion of a farm to be managed as an earthworm reservoir. If needed, the soil could be limed to bring it near pH 7, fertilized, irrigated regularly, and a cover crop established and cut periodically to provide an organic mulch as food and cover. A population of an anecic species could be introduced into this area and built up. Nightcrawlers can be purchased from bait dealers, who generally get them from nightcrawler harvesters in the Pacific Northwest.

From this reservoir, blocks could periodically be taken and introduced into the field. This might be done each year in the fall when earthworm activity is increasing. Remember to provide an organic mulch. The rate of spread would vary with species and conditions in the field. *Lumbricus terrestris*, the nightcrawler, is capable of traveling at least 19 meters on the soil surface in the course of one evening foray.

## MATERIALS NEEDED

Assemble materials as per instructor's outline

### SHOVEL-COUNT METHOD

1. For the shovel-count method, very little preparation is required. Identify sample areas, try to collect a similar soil volume at each location, and record results.

### VERMIFUGE METHOD

1. Select sample area
2. Place sample rings on the surface of the site and push them several inches into the soil.
3. Carefully clip vegetation and removed all litter from inside sample area.
4. Slowly sprinkle 4.5 liters of vermifuge into each sample area, distributing it evenly over the entire surface.

5. After all of the vermifuge solution infiltrates the soil, wait 10 minutes, and make a second vermifuge application (4.5 liters).
6. Collect all earthworms that surface inside the sample area.
7. After 10 minutes elapse since infiltration of the second vermifuge application, use a hand spade to dig through the surface layer of soil (~5 cm deep) and collected any more earthworms found there.
8. Rinse earthworms in water, drain, and store in containers inside an insulated cooler with ice packs (unless samples are to be counted in the field and returned to the sample area).
9. An alternate method that does not require a sample ring can be found in the USDA Soil Quality Test Kit Guide, which is available in the internet (see Resources section).

TABLE 2. THREE DIFFERENT TYPES OF EARTHWORMS

GROUP	WHAT THEY LOOK LIKE	WHERE THEY LIVE	WHAT THEY EAT	MEANING OF NAME	EXAMPLE
Epigeic	small; dark red or brown; fast growing move quickly	areas with a lot of organic matter: forest litter layer; manure piles; cool compost piles	large proportion of diet is organic matter	epi = on Gaia = earth	<i>Lumbricus rubella</i> , <i>Eisenia fetida</i> (red worm, manure worm)
Endogeic	small to medium; light or no pigmentation; slower moving	continous burrows in soil; often found in root ball; generally feed and defecate below ground	mixture of buried organic matter and mineral soil, decaying roots	endo = within Gaia = earth	<i>Allolobophora chlorotica</i> , <i>Aporrectodea caliginosa</i>
Anecic	large and very muscular; wedge-shaped tail; color on front end, less on tail end; slow growing	build permanent, vertical burrows that are very deep; raised midden of castings and residue marks burrow entrance	feed by pulling organic matter from surface down into burrow before ingesting	unknown	<i>Aporrectodea longa</i> <i>Lumbricus terrestris</i> (night-crawler)

# Demonstration 4: Soil Arthropods

## *for the instructor*

### OVERVIEW

*This demonstration introduces students to techniques for sampling soil arthropods and familiarizes them with their functional roles.*

*For this short demonstration, both of these exercises provide a hands-on, show-and-tell of soil arthropods. You should have keys to identification available, and some familiarity with what kinds of animals students are likely to find.*

### MATERIALS

- Cups (plastic drink cups work well)
- Small trowel
- Funnels (steep-sided funnels with no seams work well; inverted polypropylene Erlenmeyer flasks with bottoms removed are excellent. 500 millileter flasks for 5 x 5 centimeter cores, 2000 millileter flasks for compost or litter samples)
- Light source (4 to 20 watts only—7 watt “Christmas” style lights work well)
- Screen (to place in the bottom of funnel to keep sample material in the funnel)
- Jars
- Dissection microscope, hand lenses
- Soil Arthropod Data Sheets (appendix 6)

### PREPARATION

#### PITFALL TRAPPING

Select sample areas in different habitats. Try for a minimum of 3 or 4 samples per habitat. Traps can be set 24 to 48 hours in advance of the demonstration. Traps can also be collected before demonstration if time is at a minimum, although it would be useful to show students how traps were set.

Bury the cup so that the top edge is flush with the soil surface. To prevent cup from filling with soil during this process, it is helpful to bury 2 cups together, one inside the other. When you are finished burying them, remove the top cup, and the one underneath should be free of soil. Opening may be left open, or covered with a board, leaving enough room between the pitfall and cover for free access by surface roaming creatures. If collected frequently, pitfalls may be left empty, or filled partly with water, so that live specimens are obtained.

Pitfalls left in place for more than a day or two should have a preservative added. This prevents the creatures from devouring one another. Ethol glycol (antifreeze) is commonly used, as is 70% alcohol, or 10% formalin. Each of these possesses attractive properties for certain creatures.

### TULLGREN FUNNELS

Collect samples from various habitats and carefully place in funnels. If too much sample material falls through funnel, add more screens, or a piece of coarse cheesecloth.

Place a wide-mouth jar containing liquid under the funnel. Use water if you want to keep animals alive. Use alcohol (70%) with some glycerin added if you want to preserve specimens. Do not shake or disturb funnels, in order to keep sample jars as free of soil as possible. Let samples stand in funnels with no light for 1 day. Turn lights on and leave them on from second to seventh day.

Samples can be collected and extracted in advance of demonstration, although as with pitfall traps, it would be useful to demonstrate for students how samples were collected, and how extraction funnels work.

### PROCEDURE

Observe collections under magnification. If live collections are made, students have the opportunity to observe behavioral adaptations of the animals (e.g., springing springtails, fast-moving predators like centipedes, or mesostigmatid mites, slower-moving fungal grazers like oribatid mites and millipedes). Have simple keys available for help with identification. For a quantification exercise, have students count species, or functional groups, and calculate a diversity index for comparing habitats.

### PREPARATION TIME

1 hour or more, depending on which exercises are followed, and what materials are available or need to be obtained.

### DEMONSTRATION TIME

From just 0.5 hour for a brief show-and-tell, where students observe samples previously collected, to 1 to 2 hours if students are involved in collecting samples, observing, and quantifying.

### DISCUSSION QUESTIONS

1. Can you guess which animals might be predators? Which ones might be grazers?
2. What effects do each habitat that the samples were collected from have on the soil organisms found there? Think about sizes of creatures, diversity, food-web interactions, pigmentation, and so on.
3. Which habitats had greatest abundance? Which has greatest diversity? Why?
4. What effects do you think different soil management practices have on soil arthropods? Besides the various effects of organic matter inputs, think also about the influence of physical disturbance.

# Hands-On Exercise: Carbon and Nitrogen Mineralization

## *for students*

### OVERVIEW

*A major function of the soil food web is to convert organic matter into forms of nutrients that plants can use. The following is an exercise to estimate how much mineral N (nitrate and ammonium) is coming from organic inputs. This exercise is a simplification of organic matter composition and the complex processes that occur during decomposition. Use it as a learning aid.*

*(based on material from the UC Davis Sustainable Agriculture Farming Systems project)*

### SCENARIO

In one year, 12,000kg per hectare\* of organic matter (dry weight) are added to the soil of an organic farm. These materials include cover crop residues, manure, and crop residues from the previous year. Overall, carbon (C) accounts for roughly half the weight of the added organic matter.

**Ten percent** of the organic matter consists of **resistant** structural components (e.g., lignin in plant cell walls) that cannot be degraded by soil microorganisms. This fraction has a very high C:N ratio (100:1 or higher). It becomes part of the soil organic matter, thereby increasing structure and water-holding capacity of the soil.

**Sixty percent** of the organic matter consists of cell components (such as cellulose) that are **moderately decomposable** by soil microorganisms. The 60% fraction has a relatively high C:N ratio of 40:1. During decomposition of this fraction, microbes must respire 90% of the C (as CO<sub>2</sub>) in order to incorporate 10% of the

*\*Equivalent to about 5.4 tons per acre*

C into their cells. Similarly, microbes incorporate only 10% of the N from this fraction, so that the remaining 90% is released as mineral N. (Remember that soil microbes typically have adequate levels of N, but they are starved for C.)

**Thirty percent** of the organic matter consists of cell tissue components such as sugars, amino acids, and lipids, which are **easily decomposable** by soil microorganisms. The C:N ratio of this fraction is 20:1. Since microbes are more efficient in utilizing these compounds, they incorporate 20% of the C and give off only 80% as CO<sub>2</sub>. Microbes also incorporate 20% of the N from this fraction, while releasing 80% as mineral N.

### THE PROBLEM

Your task is to calculate how much nitrogen is mineralized, in order to determine if the amount of N will be adequate for crop production. Fill in the blanks in the chart on the next page with approximate amounts of C and N. Use the chart to calculate how much mineral N is released from the organic matter added over the course of one year.

<b>Resistant Fraction</b>	10%      100:1 C:N Total in this fraction 600 kg C/ha 6 kg N/ha	
<b>Moderately Decomposable Fraction</b>	60%      40:1 C:N Total in this fraction _____ C (kg/ha) _____ N (kg/ha)	_____ kg C per ha in biomass _____ kg C per ha respired as CO <sub>2</sub> _____ kg N per ha in biomass _____ kg N per ha in mineral N
<b>Easily Decomposable Fraction</b>	30%      20:1 C:N Total in this fraction _____ C (kg/ha) _____ N (kg/ha)	_____ kg C per ha in biomass _____ kg C per ha respired as CO <sub>2</sub> _____ kg N per ha in biomass _____ kg N per ha in mineral N

\_\_\_\_\_ TOTAL KG N MINERALIZED PER HECTARE

#### QUESTIONS TO PONDER

- What happens to the N incorporated in the soil biomass? Is this the end of the story?
- What is the fate of mineralized N/
- How would organic and conventionally fertilized farm soils differ with respect to the timing of mineral N release?
- Why is it important to consider three fractions for organic matter inputs?

## CARBON AND NITROGEN MINERALIZATION EXERCISE KEY

<b>Resistant Fraction</b>	10%      100:1 C:N Total in this fraction 600 kg C/ha 6 kg N/ha	
<b>Moderately Decomposable Fraction</b>	60%      40:1 C:N Total in this fraction 3600 C (kg/ha) 90 N (kg/ha)	360 kg C per ha in biomass 3240 kg C per ha respired as CO <sub>2</sub> 9 kg N per ha in biomass 81 kg N per ha in mineral N
<b>Easily Decomposable Fraction</b>	30%      20:1 C:N Total in this fraction 1800 C (kg/ha) 90 N (kg/ha)	360 kg C per ha in biomass 1440 kg C per ha respired as CO <sub>2</sub> 18 kg N per ha in biomass 72 kg N per ha in mineral N

153 TOTAL KG N MINERALIZED PER HECTARE





# Assessment Questions

1) What is soil?

2) What forms of life exist in soil ecosystems?

3) How would you define a “healthy” agricultural soil?

4) What is a soil food web?

5) What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizer and pest control agents on the soil ecosystem?

# Assessment Questions Key

- 1) What is soil?
  - *An ecological system consisting of inorganic minerals (sand, silt, clay, and nutrients), pore spaces, water, gases, organic matter, living organisms, and plants*
- 2) What forms of life exist in soil ecosystems?
  - *Bacteria, fungi, actinomycetes, millipedes, isopods, mollusks, insects, insect larvae, worms and many small vertebrate animals such as gophers, ground squirrels, moles, etc.*
- 3) How would you define a “healthy” agricultural soil?
  - *A soil with a set of desirable physical and chemical properties which has the capacity to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health. This would include many of the following general characteristics:*
    - a) *adequate rooting depth for the crop(s) to be grown*
    - b) *a 3–5% organic matter content*
    - c) *maintains stable soil aggregates*
    - d) *allows for rapid water infiltration without soil erosion*
    - e) *a low bulk density (good structure with minimal compaction)*
    - f) *pH between 6 and 7*
    - g) *an extractable nutrient profile within the optimal range of physiological tolerance for the crops to be grown*
    - h) *good water holding capacity and well-drained*
    - i) *high soil biological diversity and activity (soil respiration)*
    - j) *adequate supplies of labile organic matter with potentially mineralizable nitrogen*
    - k) *seasonal soil temperatures from 60–85°F*
- 4) What is a soil food web?
  - *The entire assemblage of soil organisms (producers, consumers and decomposers) in a soil ecosystem interacting among and between trophic levels*
- 5) What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizer and pest control agents on the soil ecosystem?
  - *Loss of SOM, reduction in soil aggregation, reduction in nutrient- and water-holding capacity, reduction in soil biological diversity and activity, increased pest and disease incidence*

# Resources

## PRINT RESOURCES

Coleman, David, and Dak Crossley. 1996. *Fundamentals of Soil Ecology*. San Diego, CA: Academic Press.

*The best textbook introduction to the subject that I know of. Gives an overview of the basics, and attempts to consider the applications.*

Dindal, Daniel, ed. 1990. *Soil Biology Guide*. NY: Wiley.

*A weighty tome, with chapters including taxonomic keys and basic biology/ecology on virtually all organisms found in soils.*

Doran, John, and Alice Jones, eds. 1996. *Methods for Assessing Soil Quality*. Special Publication # 49. Madison, WI: Soil Sci. Soc. America.

*Soil quality is the current buzzword in soil science circles. This volume explores the application of the idea to sustainable environmental management.*

Gershuny, Grace, and Joseph Smillie. 1995. *The Soul of Soil: A Guide to Ecological Soil Management*. Davis, CA: AgAccess.

*More hands-on and less academic than the above works, this book is aimed at plant growers and has lots of practical information.*

Gibbons, Boyd. 1984 (September). Do we treat our soil like dirt? *National Geographic*, pp 351-388.

*An overview of U.S. soils, from soil biota to bankrupt farmers, done in classic NG style, with lots of great photos and drawings.*

Gliessman, Stephen R. 1998. *Agroecology: Ecological Processes in Sustainable Agriculture*. Chelsea, MI: Ann Arbor Press.

*Provides a brief overview of the most commonly used conventional agricultural practices and the environmental and agroecological consequences of their use.*

Tugel, Arlene, Ann Lewandowski, and Deb HappevonArb, eds. 2000. *Soil Biology Primer, Revised Edition*. Ankeny, Iowa: Soil and Water Conservation Society.

*An excellent overview of soil biology, loaded with glossy photos and colorful chart. Available from [soils.usda.gov/sqi/SoilBiology/soil\\_biology\\_primer.htm](http://soils.usda.gov/sqi/SoilBiology/soil_biology_primer.htm).*

## WEB RESOURCES

### SOIL QUALITY

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Appropriate Technology Transfer for Rural Areas (ATTRA)

[www.attra.org/attra-pub/soil-lab.html#Soil%20Health](http://www.attra.org/attra-pub/soil-lab.html#Soil%20Health)

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

Illinois Soil Quality Initiative (ISQI)

[www.aces.uiuc.edu/~asap/resources/isqi/soil-health.html](http://www.aces.uiuc.edu/~asap/resources/isqi/soil-health.html)

Life in the Soil

[www-crcslm.waite.adelaide.edu.au](http://www-crcslm.waite.adelaide.edu.au)

Soil and Health Library

[www.soilandhealth.org/index.html](http://www.soilandhealth.org/index.html)

Soil Biological Communities

[www.blm.gov/nstc/soil/index.html](http://www.blm.gov/nstc/soil/index.html)

Soil Ecology Society

[vax.wcsu.edu/ses/ses.html](http://vax.wcsu.edu/ses/ses.html)

Soil Quality Information Sheets  
[soils.usda.gov/sqi/sqiinfo.html](http://soils.usda.gov/sqi/sqiinfo.html)

Soil Quality Institute—Agronomy Technical Notes  
[soils.usda.gov/sqi/agronomy.shtml](http://soils.usda.gov/sqi/agronomy.shtml)

Soil Quality Institute—NRCS  
[soils.usda.gov/sqi/](http://soils.usda.gov/sqi/)

Soil Quality Test Kit  
[soils.usda.gov/sqi/kit2.html](http://soils.usda.gov/sqi/kit2.html)

The Health of Our Soils: Toward Sustainable Agriculture in Canada  
[sis.agr.gc.ca/cansis/publications/health/intro.html](http://sis.agr.gc.ca/cansis/publications/health/intro.html)

The Soil Foodweb: Its Importance in Ecosystem Health, Elaine Ingham  
[www.rain.org/~sals/ingham.html](http://www.rain.org/~sals/ingham.html)

Soil quality and financial performance of biodynamic and conventional farms in New Zealand. 1993. J.P. Reganold, A.S. Palmer, J.C. Lockhart and A.N. Macgregor. *Science* 260: 344-349.  
[www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu)

University of California Sustainable Agriculture Research and Education Program (UC SAREP)  
[www.sarep.ucdavis.edu/soil/websites.htm](http://www.sarep.ucdavis.edu/soil/websites.htm)

#### **SOURCES OF SUPPLIES**

Fisher Scientific, Pittsburgh, PA  
(800) 766-7000

Scientific Industries  
227 Blue Bell Ave. Boulder, CO 80302  
(303) 443-7087

# Appendix 1: Major Organic Components of Typical Decomposer Food Sources

	PROTEINS	FATS	CARBOS	SIMPLE CELLULOSE	HEMI- CELLULOSE	LIGNIN	ASH
Oak leaf (young)	9	8	22	13	16	21	6
Oak leaf (old)	3	4	15	16	18	30	5
Pine needle	2	24	719	16	23	2	
Grass leaf	2	2	13	24	33	14	0
Corn stem	1	2	15	18	30	11	8
Wood	0	4	222	47	22	1	
Horse manure	7	2	524	28	14	9	
Bacteria	50 to 60	10 to 35	5 to 30	4 to 32	0	0	5 to 15
Fungi	14 to 52	1 to 42	8 to 60	2 to 15	0	0	5 to 12
Earthworm	54 to 72	2 to 17	11 to 17	0	0	0	9 to 23
Arthropods	38 to 50	13 to 26	14 to 31	5 to 9	0	0	0
Steer carcass	39	50	00	0	0	11	

# Appendix 2: Litter Bag Data Sheet (for Demonstration 1)

burial date:

location:

retrieval date:

details:

LITTER BAG #	HABITAT	% REMAINING (VISUAL ASSESSMENT)	AVERAGE PER HABITAT	OTHER OBSERVATIONS
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				

# Appendix 3: Litter Bag Data Sheet Example

burial date:  
retrieval date:

location:  
details:

LITTER BAG #	HABITAT	% REMAINING (VISUAL ASSESSMENT)	AVERAGE PER HABITAT	OTHER OBSERVATIONS
1	compost	5		
2	compost	25		
3	compost	80		
4	compost	90	50.0	
5	orchard soil	100		
6	orchard soil	100		
7	orchard soil	70		
8	orchard soil	90	90.0	
9	raised garden bed	97		
10	raised garden bed	99		
11	raised garden bed	72		
12	raised garden bed	95	90.8	
13	row crop	97		
14	row crop	95		
15	row crop	94		
16	row crop	96	95.5	
17	soil surface	100		
18	soil surface	100		
19	soil surface	100		
20	soil surface	99	99.8	



# Appendix 4: Soil Respiration Data Sheet (for Demo.2)

Soil Respiration (at Initial Field Water Content)							Date:	
Sample site	Ring height	Start time	End time	Soil temp °C	Draeger tube %CO <sub>2</sub> (n=1)	Soil respiration lbs C/A/day*	Draeger tube %CO <sub>2</sub> (n=5)	Soil respiration lbs C/A/day*
1						0.0		0.0
2						0.0		0.0
3						0.0		0.0
4						0.0		0.0
5						0.0		0.0
6						0.0		0.0
7						0.0		0.0
8						0.0		0.0

**Soil Respiration (at least 6 hours after irrigation or soil wetting)      Date:**

\* Soil respiration = PF x ((Soil Temp C + 273)/273) x (CO<sub>2</sub> % - 0.035) x 22.91 x Ring Ht = lbs CO<sub>2</sub> -C/acre/day  
 PF = Pressure Factor = 'raw' barometric pressure in inches Hg/29.9 inches.  
 Note: This adjustment is necessary at elevations > 3,000 ft.; otherwise PF = 1  
 H = 5.08 cm (if not measured)  
 Conversion: Degrees Celsius = 5/9 x (Degrees Fahrenheit - 32)  
 Notes:

# Appendix 5: Earthworm Data Sheet (for Demonstration 3)

DATE:

SAMPLE SITE	EPIGEIC EATHWORMS	ENDOGEIC EARTHWORMS	ANECIC EARTHWORMS	TOTAL EARTHWORMS	EARTHWORMS PER SQ METER
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

NOTES:

Epigeic: small; dark red or brown color; fast growing; move quickly  
Endogeic: small to medium; light or no pigmentation; slower moving  
Anecic: large and very muscular; wedge-shaped tail; color on front end, less on tail end; slow growing

# Appendix 6: Arthropod Data Sheet (for Demonstration 4)

1      2      3      4      5      6      7      8      9      10      11

---

sample site: \_\_\_\_\_

isopods \_\_\_\_\_

springtails \_\_\_\_\_

spiders \_\_\_\_\_

mites \_\_\_\_\_

earwigs \_\_\_\_\_

aphids \_\_\_\_\_

beetles \_\_\_\_\_

fly larvae \_\_\_\_\_

fly adults \_\_\_\_\_

ants \_\_\_\_\_

wasps \_\_\_\_\_

crickets \_\_\_\_\_

millipedes \_\_\_\_\_

centipedes \_\_\_\_\_

slugs & snails \_\_\_\_\_

# Part 3 Social and Environmental Issues in Agriculture

Unit 3.1 The Development of U.S. Agriculture

Unit 3.2 Social Issues in Modern Agriculture

Unit 3.3 Environmental Issues in Modern Agriculture

Unit 3.4 Introduction to Sustainable Agriculture



# 3.1 The Development of U.S. Agriculture

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# Introduction: The Development of U.S. Agriculture

## UNIT OVERVIEW

*This unit provides students with an historical context for current issues in the U.S. agrofood system. It chronicles the comparatively rapid development of American agriculture and food systems from subsistence farming to globalization. It takes a political economy approach to the analysis of American agriculture's development in order to illuminate the intersection of political, economic, social, ecological, and technological factors, innovations, and failures that have shaped this remarkable and complex system.*

The first lecture begins with an overview of general trends in the development of the United States agrofood system, including a quantitative analysis of structural and demographic changes in U.S. agriculture from approximately 1900–2000, drawing from the U.S. Census of Agriculture. This profile of the U.S. food system will serve as a reference point in Units 3.2–3.4 for discussion of the social and environmental consequences of this complex. The ways in which historical land use practices, settlement policies, and labor management schemes have influenced agricultural development in the U.S. are then covered, followed by a discussion of the increasing emphasis on science and technology that characterizes U.S. agriculture. This includes an overview of the federal policies responsible for the development of the U.S. agricultural research complex. This complex has generated the innovations in agricultural technologies that have shaped both the production and processing of food and fiber in America.

The second lecture begins with a discussion of the ways in which large-scale capital investment, enabled by advances in agricultural science and technology, has entered U.S. agriculture, and the structural changes that have resulted. Corn is examined as a case study of how science, capital, and policy interact in the context of agricultural development. The lecture outline concludes by identifying and discussing the effects of the confluence of policy, technology, and capital on agricultural development in terms of certain key characteristics and concepts such as overproduction and surplus, the cheap food policy, and the technology treadmill.

## MODES OF INSTRUCTION

> (2 LECTURES, 50 MINUTES EACH)

Two lectures cover the historical circumstances that have been largely responsible for the direction of development in the U.S. food and agricultural system from 1900–2000. References given in the outlines are described in the Resources section.



## LEARNING OBJECTIVES

### CONCEPTS

- The broad demographic changes in U.S. agriculture from approximately 1900–2000
- The changes in control over the means of production in the U.S. food system from approximately 1900–2000
- How historical land use practices, land settlement policies, and labor management schemes have influenced U.S. agricultural development
- U.S. federal policies that have been responsible for the development of the U.S. agriculture research complex and the innovations in technologies that have shaped the direction of development of U.S. agriculture
- The influence of investment capital on the adoption of capital-intensive agricultural technologies and the concentration of ownership in agricultural

# Lecture 1 Outline: The Development of U.S. Agriculture

## *for the instructor and student*

### **A. Overview of General Trends in U.S. Agricultural Development**

(statistics and graphs from U.S. Census of Agriculture and other sources; see also U.S. Census of Agriculture, [www.nass.usda.gov/census/](http://www.nass.usda.gov/census/))

1. Number of farms and farm size (see Gardner 2002, 51, 58-59)
2. Farm population (see Gardner 2002, 93, 99)
3. Market share of large vs. small farms (see Gardner 2002, 69)
4. Increase in part-time farmers and off-farm employment
  - a) 57% of all persons employed on U.S. farms in 1987 also did non-farm work for cash wages or salary
5. Increasing use of labor-saving technologies (see Gardner 2002, 13-17)
6. Increase in yields and productivity (see Gardner 2002, 20-22, 44)
7. Increase in purchased off-farm inputs (see Gardner 2002, 63; Cochrane 1993, 130-131)
8. Stagnation of net farm income (see Gardner 2002, 75)
9. Share of food dollar to farmers (see Gardner 2002, 129, 155; Cochrane 1993, 135)
10. Concentration in agricultural input firms (see [www.foodcircles.missouri.edu/consol.htm](http://www.foodcircles.missouri.edu/consol.htm))
11. Concentration in food processing firms (see [www.foodcircles.missouri.edu/consol.htm](http://www.foodcircles.missouri.edu/consol.htm))
12. Concentration in food retail firms (see [www.foodcircles.missouri.edu/consol.htm](http://www.foodcircles.missouri.edu/consol.htm))
13. Concentration of agricultural production units (farms): Decrease in number, increase in size

### **B. Land Use and Settlement** (see Cochrane 1993, chapters 4 and 5; Hurt 1994)

1. Agriculture was the dominant land use and economic activity of early U.S.
  - a) >90% of U.S. populace was involved in agriculture pre-1900
2. Early U.S.'s most abundant commodity was land
  - a) Encouraged extensive agricultural development
    - i. Since land was superabundant, few incentives for soil conservation or fertility management
      - Effect: Use hard, exhaust, move on
      - Example: Pre-Dust Bowl agricultural land-use practices
  - b) Early land settlement policies: Had effect of quickly populating landscape with small-scale agriculture, displacing native Americans and making it claimable by U.S.
    - i. Homestead Acts: Free land for those who "improved" it; tracts circumscribed by Township and Range settlement patterns
    - ii. Conscription acts: Trading land for military service, paying soldiers in land was common
    - iii. Railroad land grants establish infrastructure for distribution of food, fiber

- iv. Reclamation acts: Irrigation projects open up vast tracts of the Southwest and California for agriculture
- v. Exceptions: California, Southern U.S.—characterized by large landholdings from the start

### 3. Labor supplies and flows

- a) Slavery: Enabled exception to small-scale, family-scale agriculture that characterized early U.S. Allowed for large increases in the scale of production.
- b) New immigrants typically made up bulk of agricultural labor force
  - i. Waves of immigration in California (ethnic succession: first Chinese, then Japanese, then Dust-Bowl Okies and Arkies, then Filipinos, and currently Mexicans) resulting in a continuous supply of low-wage workers with little status or political power
  - ii. Immigration status and abundance of workers made exploitation the norm and organization difficult

## C. The Scientization and Rationalization of Agriculture (see Cochrane 1993, chapter 7; Hightower 1973, chapters 1–2; Gardner 2002, p. 183)

### 1. Pre-1860s

- a) Agricultural innovation and knowledge exchange was hands-on, in-situ, farmer-to-farmer, and the primary mechanism for knowledge exchange
- b) Locus of control of agricultural knowledge and innovation was on-farm
- c) Basic agricultural techniques and yields per acre had reached a plateau

### 2. Federal policies established the scientific agricultural enterprise

- a) U.S. Department of Agriculture (USDA, established in 1860): Devoted to improvement of agriculture based on scientific inquiry
- b) Morrill Act (1862, amended 1890): Established Land Grant Colleges of Agriculture to conduct research and development
- c) Hatch Act (1887): Established agricultural experiment stations to work on practical agricultural problems
- d) Smith-Lever Act (1914): Established cooperative extension service to diffuse innovations to farmers
- e) Reclamation Act (1902): Authorized the Secretary of the Interior to develop irrigation and hydropower projects in 17 Western States
- f) Adams Act (1920s): Provided a basis for the inclusion of agricultural economics within the research agenda of land grant universities
- g) Budgetary allocations to the U.S. agricultural research complex 1860–2000 (see Garner 2002, pp. 183–184)

### 3. The subsequent furious pace of technological developments

- a) Mechanization spurred early increases in productivity
  - i. Trends: see Gardner 2002, pp. 13–17
- b) Chemical crop protection and fertilizer
  - i. War technology: Peacetime by-products of weapons research
- c) Reclamation and irrigation increased productive capacity enormously
- d) Improved plant and livestock varieties, hybridization
- e) Continued pressure for extension of seasons to allow for year-round availability of commodities
  - i. Varietal research
  - ii. Shift in production localities

- f) Effects
  - i. Vast reduction in labor requirements on farms, which facilitated huge rural-urban migrations and provided labor for industrialization. More workers for the factories and greater financial security for workers.
  - ii. Enabled huge expansion of scale of agricultural production
  - iii. Encouraged specialization and monoculture; separated crop from livestock production
  - iv. Moved input production and processing off-farm
- 4. Summary: Federal policy and resources created the funding and infrastructure for research in the direction of developing agricultural technologies. These technologies encouraged increases in the scale of production, with social and environmental consequences (see Unit 3.2, Social Issues in Modern Agriculture, and Unit 3.3, Environmental Issues in Modern Agriculture).



# Lecture 2 Outline: Capital, Politics, and Overproduction

## *for the instructor and student*

### A. The Commodification and Capitalization of Agriculture

(see Goodman et al. 1987; Goodman 1991; Kloppenburg 1987; Heffernan 1998)

1. The historical barriers to capitalist development in agriculture (see FitzSimmons 1990)
  - a) The presence of “nature” in agriculture: The vagaries of season and the absence of control of environmental conditions influencing yield
  - b) The inherent riskiness of farming: Environmental conditions in agriculture, return on investment is unsure, high risk
  - c) The fixed amount and variable quality of land
2. The increasing role of private capital in U.S. agriculture
  - a) Private capital has difficulty directly controlling the act of farming/crop production
  - b) As technological developments move input production and food processing off-farm, investment capital moves into these areas (see Heffernan 1998; Goodman 1991; [www.foodcircles.missouri.edu/consol.htm](http://www.foodcircles.missouri.edu/consol.htm))
    - i. Seed companies
    - ii. Machinery manufacturers
    - iii. Chemical fertilizer and pesticide suppliers
    - iv. Post-harvest transportation and storage
    - v. Processing and value-adding
    - vi. Wholesale and retail
3. Cost/price squeeze
  - a) Farmers become “price-takers”; must take market price for products
  - b) Competitive advantage is gained by the economy of scale enabled by the adoption of capital-intensive technologies
  - c) Increasing private and corporate ownership of the agricultural inputs, food processing and retail sales sector of the economy begins to appropriate increasing proportion of food dollar, and thus power over the food system
  - d) Farmers are “sandwiched between a monopoly-controlled input sector and a monopoly-controlled output sector” (Lobao 1990, p. 27)
  - e) Dwindling share of food dollar to farmer
  - f) Farmers gradually lose power, autonomy, economic self-determination
4. As sector matures, concentration of input suppliers/processors/retailers into monopolies and oligopolies (see Heffernan 1998)

## B. Modern Corn: At the Nexus of Research, Capital, and Politics in Agriculture

(see Kloppenburg 1987)

1. The corn seed as a symbol
  - a) In it lies both productive and reproductive capacities
  - b) It is the beginning and end of the cycle of reproduction
  - c) Strategic point of control: Control of seed = control of the self-sufficiency (or market dependency) of farmers and farming
  - d) The story of modern corn is a story of a struggle for that control; and the use of agricultural research and science as a tool of private capital, facilitated by public policy
2. Pre-1920s: Farmers saved a portion of crop as seed to plant the next year
  - a) Maintained a degree of autonomy from purchased inputs
  - b) High degree of genetic diversity and regional variation
3. Hybridization
  - a) Developed in 1920s by Pioneer Hi-Bred, with help from USDA and U.S. patent protection laws
  - b) Doubled and tripled yields resulted from hybrid seed strains
  - c) Facilitated mechanization of production: Uniform height and maturation time
  - d) Consequence: Would not “reproduce true”—forced farmers to buy seed every year
  - e) Almost universally adopted by early 1930s
4. Contemporary developments in agricultural technology: Genetic engineering
  - a) Further application of agricultural science in the service of private capital
  - b) Created and sold as “technology packages,” e.g., Roundup Ready™ seed and Roundup™
  - c) Novel methods of intellectual property protection
    - i. Technology use agreements
    - ii. “Terminator” technology

## C. Chronic Surplus, Overproduction, Export Agriculture, and Global Food Trade (see Cochrane 1993, chapter 8; Friedmann 1993; Lobao 1990, chapter 1; Danbom 1995, chapter 11)

1. Surplus and overproduction: A core problem of the modern food system
  - a) Fueled by development of agricultural technology and labor-saving devices
  - b) Exacerbated by federal farm subsidies, commodity payments, price supports to largest producers
  - c) Keep crop prices paid to farmers chronically low
  - d) Those farmers not receiving subsidies are placed at an economic disadvantage
  - e) Farmers’ status as price-takers and the cost-price squeeze give them little margin for error
  - f) Overproduction has been constant since 1880s (with exception of war-time periods)
  - g) Slim profit margins discourage farmers from adopting conservation farming practices that do not show economic return or that require reinvestment of capital
2. The “cheap food policy:” Good for consumers, bad for farmers
  - a) Chronic overproduction keeps food prices low (for consumers)
  - b) Enables non-farm wages to be kept low; important for industrialization
3. Export agriculture
  - a) Surpluses exported, formed the basis for global food trade
    - i. Major source of revenue and catalyst for U.S. overseas economic development
    - ii. Overseas commodity markets of major strategic importance to U.S.

4. Those surpluses not exported formed basis of U.S. meat industry
5. The “technology treadmill”
  - a) Chronic low commodity prices force farmers to rely on economies of scale
  - b) Farmers must produce more to survive: “Get big or get out”
  - c) Creates a climate in which early adopters of capital-intensive, yield-increasing technologies are rewarded
  - d) Those who do not adopt technologies are driven out; leads to familiar pattern of bankruptcy and consolidation
6. The tyranny of the agricultural economists
  - a) Narrow efficiency criteria: Often food system policies and decisions are made based on exclusively economic logic and do not consider externalized costs of production
  - b) Smaller farms are by definition “less efficient” by economic calculus
  - c) Their disappearance, and their consolidation into larger farms, were logical and even welcome consequences of economic rationalization
  - d) This logic ignores social and ecological issues/consequences (see Units 3.2 and 3.3)





# Resources

## SUGGESTED READINGS FOR STUDENTS (DESCRIBED BELOW)

- Buttel, Frederick H. and Howard Newby, eds. 1980.
- Cochrane, Willard W. 1993.
- Danbom, David B. 1995.
- Friedmann, Harriet. 1993.
- Gardner, Bruce L. 2002.
- Heffernan, William D. 1998.

## PRINT RESOURCES

Buttel, Frederick H. and Howard Newby, eds. 1980. *The Rural Sociology of the Advanced Societies: Critical Perspectives*. Montclair, N.J.: Allanheld Osmun.

*A pivotal collection of essays covering a range of social and environmental issues in modern agriculture. This book and its contributors would help to define and direct a new, richly critical sociology of agriculture. Especially Newby and Buttel, "Toward a critical rural sociology;" and Buttel, "Agriculture, environment, and social change: Some emergent issues."*

Cochrane, Willard W. 1993. *The Development of American Agriculture: A Historical Analysis*. Minneapolis: University of Minnesota Press.

*The definitive critical history of U.S. agricultural development. Full of insightful analysis and commentary as well as exhaustive history. Introduces the concept of the "technology treadmill" as a major problem in U.S. agriculture.*

Danbom, David B. 1995. *Born in the Country: A History of Rural America*. Baltimore: Johns Hopkins University Press.

*An important history of the effects of agricultural policy and development on rural life and rural people. See especially Chapter 11, "The production revolution and its consequences."*

FitzSimmons, Margaret. 1990. The social and environmental relations of US agricultural regions. In *Technological Change and the Rural Environment*. London: Philip Lowe et al. London, David Fuller.

Friedmann, Harriet. 1993. The political economy of food: a global crisis. *New Left Review*: 29.

*A succinct history, overview and contextualization of trends in global food trade. Discusses national agriculture and trade policies in the context of international geopolitical relations; and their effects on agricultural development.*

Gardner, Bruce L. 2002. *American Agriculture in the Twentieth Century: How It Flourished and What It Cost*. Cambridge, MA: Harvard University Press.

*A straightforward, uncritical, but data-intensive and encyclopedic overview of trends in American agricultural development during the 20th century. Full of valuable charts and graphs. An excellent reference.*

Goldschmidt, Walter R. 1978. *As You Sow: Three Studies in the Social Consequences of Agribusiness*. Montclair, N.J.: Allanheld Osmun.

*A groundbreaking and often-cited study of two agricultural communities in California with different structures of farm ownership. Goldschmidt found that concentration in ownership and corporate control of farms had negative impacts on such indicators of social welfare as income distribution, civic participation, and quality of education.*

Goodman, David, Bernard Sorj, and John Wilkinson. 1987. *From Farming To Biotechnology: A Theory of Agro-Industrial Development*. Oxford, New York: Basil Blackwell.

*An integrated theory of the nexus of research, policy, technological development, and capitalist penetration in agricultural development. Considered a seminal work in modern political economy of agriculture.*

Goodman, David. 1991. Some recent tendencies in the industrial reorganization of the agro-food system. In *Towards a New Political Economy of Agriculture*. William Friedland, ed. Boulder, CO, Westview.

*A distillation and update of the concepts developed in From farming to biotechnology (Goodman et al. 1987); and an overview of the encroachment of industrial capital into the agrofood system.*

Heffernan, William D. 1998. Agriculture and monopoly capital. *Monthly Review* 50: 46 (July/August).

*An analysis of who controls the agro-food system. A discussion of the historical and modern trends toward oligopoly and monopoly that characterize firms operating in the agro-food sector, and the consequences for the structure and development of agriculture. Heffernan's specialty.*

Hightower, Jim, and Agribusiness Accountability Project. Task Force on the Land Grant College Complex. 1973. *Hard Tomatoes, Hard Times; A Report of the Agribusiness Accountability Project on the Failure of America's Land Grant College Complex*. Cambridge, MA: Schenkman Pub. Co.

*A high-profile critique of the research and education agenda of the land-grant university complex in the U.S. Hightower argues that the Land Grant Universities serve and promote large-scale, corporate agriculture at the expense of small-scale, family farmers, and have actively contributed to the decline in family-scale agriculture.*

Hurt, R. Douglas. 1994. *American Agriculture: A Brief History*. Ames, Iowa State University Press.

*A good, but uncritical, survey of American agricultural development with an emphasis on pre-World War II history.*

Kloppenborg, Jack R. 1988. *First the Seed: The Political Economy of Plant Biotechnology, 1492-2000*. Cambridge; New York: Cambridge University Press.

*A gripping and well-documented analysis of the "commodification of the seed." Kloppenborg starts from the thesis that the seed is an important locus of power and autonomy in agriculture, and goes on to show how control over the seed has been transferred from the public domain—farmers and peasants—to a handful of large private corporations; and this transferral's effects on the structure of the agrifood system.*

Lobao, L. M. 1990. *Locality and Inequality: Farm and Industry Structure and Socioeconomic Conditions*. Albany: State University of New York Press.

*A Marxian analysis of the structural economic conditions governing agricultural development.*

McConnell, Grant and American Farm Bureau Federation. 1969. *The Decline Of Agrarian Democracy*. New York: Atheneum.

*A history and analysis of agrarian populist movements in the U.S. Good discussion of farmers' resistance strategies in the face of increasingly powerful corporate control over the food system.*

Schafer, Joseph. 1936. *The Social History of American Agriculture*. New York: The Macmillan Company.

*A dated but entertaining history of pre-chemical American agriculture, with an emphasis on social organization.*

Worster, Donald. 1990. Transformations of the Earth: Toward an agroecological perspective in history. *Journal of American History* 76(4): 1087.

*A preeminent environmental historian's discussion of agriculture as the fundamental way in which humans relate to, transform, and are themselves transformed by their environments. A call for the reorientation of agriculture towards a more ecologically informed approach.*

## WEB RESOURCES

California Agriculture Teachers Association (CATA)  
Sustainable Agriculture Curriculum and PowerPoint  
Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see “Course Curriculum”)

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This sustainable agriculture education resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*



# 3.2 Social Issues In Modern Agriculture

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# Introduction: Social Issues in Modern Agriculture

## UNIT OVERVIEW

*This unit introduces the most significant social consequences of the development of U.S. agriculture. The lecture outlines offer multiple critical perspectives of the social impacts of the dominant conventional U.S. agricultural model. The unit's overarching goal is to convey to students a sense that discrepancies of power and risk exist between different actors in the food system, that these inequalities shape and constrain these individuals' worldviews and decisions, and that these trends have significant (and sometimes tragic) social consequences that must be considered in discussions of agricultural sustainability.*

Lecture 1 begins with a discussion of the commonly held misconceptions of the U.S. food system's structure and organization. The major components of the U.S. food system are then mapped out, and the changes in this system's structure over the past 100 years discussed.

Lecture 2 examines the social consequences of the current food system in greater detail, focusing on the following topics: farm structure, labor, the concentration of ownership within the larger food system, and consumer issues. The lectures conclude with a discussion of the major contradictions that exist within the U.S. agricultural system. Throughout, students will be encouraged to consider the multiple (and sometimes contradictory) meanings of the term "sustainability" in order to develop a more sophisticated understanding of the complex and various social impacts of the U.S. agricultural system.

## MODE OF INSTRUCTION

> (2 LECTURES, 50 MINUTES EACH)

The lecture outline covers the social consequences that have resulted from the evolution and current organization of the U.S. food system. References given in the outlines are described in the Resources section.



## LEARNING OBJECTIVES

### CONCEPTS

- The current food system in the United States is comprised of myriad actors, including: growers, laborers, labor unions, distributors, processors, retailers and restaurants, input suppliers, investors, consumers, policy makers, researchers, non-governmental organizations, etc.
- Between different actors within the food system there are significant discrepancies of resource allocation, economic and health risks, access to information, and therefore power
- The current food and agriculture system produces certain “externalities”—the social and ecological consequences (“hidden costs” of production) that have resulted from recent changes in the food system to which no actors are held legally or financially accountable
- The externalized social costs of production are, among others: increases in the concentration of ownership over the means of agricultural production; the associated declines in small-farm viability and the life quality indicators of rural agricultural communities; declines in the working conditions and life quality of agricultural laborers; continued consumer and farmworker exposure to unsafe levels of pesticides; and the persistence of hunger in the context of the overproduction of food
- The way food and agriculture problems are defined will determine the means to their solution (e.g., defining the problem of contemporary agriculture exclusively as one of production limits the focus of policy and research to yield, and thereby ignores other ecological and social problems associated with the current food system)
- The current structure of the U.S. food system is not inevitable or immutable. Policy, science, capital, and culture (i.e., political participation, consumer choices, etc.) combine to create and change the current system.

# Lecture 1 Outline: Agriculture and Food System Structure

## *for the instructor and student*

### A. Introduction: What Does Agriculture Really Look Like Today?

1. Popular misconceptions of what agriculture looks like
  - a) Describe the myth of the family farm (see Browne 1992)
    - i. That agriculture in the United States is a collection of small-scale family farms
    - ii. That these family farms are a vital part of our national heritage, and that farming is a way of life that preserves agrarian populist ideals, maintains a strong moral base for the nation, and nurtures healthy rural communities
    - iii. Farmers are good citizens and have high morals; as stewards of the land and producers of food, they pursue a way of life that benefits the rest of the country
    - iv. These images in part stem from a romanticized perception of early rural America as an exemplary democratic, egalitarian culture based on family farms
    - v. Family farms are perceived as subsistence systems and are a mix of farming, labor, and leisure
    - vi. That family farms seek to meet a diversity of needs at the farm or community scale
    - vii. There is a social transfer of skills and roles (often from parents to children)
  - b) This myth is used as justification for U.S. agricultural policy (see Browne 1992)
    - i. Current U.S. agricultural policy is heavily laden with rhetoric and legislation for preserving “family farming”
    - ii. Farmers’ organizations lobby for billions of dollars to be allocated as subsidies for large-scale producers of struggling commodities
    - iii. These powerful agricultural interests justify such subsidies on the basis of preserving the way of life maintained by the nation’s “family farmers”
    - iv. Subsidizing agriculture is argued to be an important component of preserving healthy rural economies and livelihoods and therefore preventing pressure on urban areas caused by outmigration from farming areas
2. Briefly introduce expanded conceptions of what “agriculture” actually looks like
  - a) Family and corporate farms contrasted
    - i. The American landscape has, over the past century, come to be dominated by corporate agriculture, most notably in California
    - ii. Corporate agriculture can be characterized by well-capitalized, large-scale, high-technology, vertically and horizontally integrated production and distribution systems where agricultural production sites are more like factories than farms
    - iii. While family farming can be perceived as a lifestyle (a means of protecting family independence and supporting a rural community’s economy), corporate farming approaches agriculture as a business enterprise and is primarily concerned with the bottom line
    - iv. Family farms historically relied on the labor of family members, while corporate farms hire workers during the short periods in which labor is needed. The success of corporate agriculture therefore depends on the presence of an expendable, cheap, temporary, and migratory labor force.
    - v. A focus on the bottom line limits corporate farms’ efforts to profit maximizing and excludes other environmental and social considerations.

- b) Small vs. large farms
    - i. Changes in farm size: The number of farms has declined from 6.3 million (in 1910) to 2 million today. However, the acreage in cultivation has remained relatively constant. (See Census of Agriculture.)
    - ii. Most of the farms that have disappeared are mid-size farms. Large-scale, industrialized farms primarily dominate today's agricultural landscape, represented by a decrease in the total number of farms and increase in the total acreage per farm, with overall acreage in production remaining constant.
    - iii. There are a large number of small-scale farms, but they tend to be economically insignificant to the economy of the larger food system and frequently not economically viable for farm operators themselves
  - c) Regional differences in farms
    - i. Regional variations exist and are significant. E.g., the industrialized specialty crop agriculture that characterizes California is extremely resource intensive, highly capitalized, large scale, and dependent on immigrant labor. This contrasts, for example, with the corn-soy-hog agriculture of the Midwest, which is similarly large in scale but not nearly as capitalized or as labor intensive.
3. Conclusion: Popular conceptions of "agriculture" do not accurately reflect today's reality. An understanding of the social impacts of the current agricultural system depends not only on a more accurate understanding of the social and ecological relationships that exist on the farm, but also within the larger food system.

## B. What Is a Food System?

1. Describe the U.S. food system
  - a) Map out the various players and their relationships to each other: Growers, laborers, labor unions, distributors, processors, retailers, input suppliers, land, capital, consumers, restaurants, government policy, non-governmental organizations, wildlife, etc. (see appendix, U.S. Food Systems Model)
  - b) Temporal change: Discuss how these divisions of inputs and labor are recent divisions within the U.S. agricultural system, with nearly all of these activities integrated into the farm just 100 years ago
2. Why are these layout descriptions important? We can study the points of tension and discrepancies of power that exist within the system in order to: (a) gain a more sophisticated understanding of the system's internal relationships, and (b) identify potential points of focus for social/political change.

## C. Changes in Farm Structure

1. Introduction: Characterize important changes in agricultural production in the U.S. in first half of 20<sup>th</sup> century (see Steinbeck 1939, chapters 1–12)
2. Brief review of major trends in U.S. agriculture
  - a) Scientization/technification of U.S. agriculture (see Cochrane 1979)
    - i. The shift from farmers to scientists as primary source of knowledge about agriculture. Attributed to the advent of the land grant complex and to a more general "scientization" trend developing in society.
    - ii. The primary problem identified in agriculture was underproduction
    - iii. Hence the promotion of mechanization, monocultures, chemical fertilizers, and chemical pesticides in a technological effort to increase efficiency and productivity in agriculture
    - iv. Farmer adoption of new agricultural technologies as a way of gaining a competitive advantage through increased efficiency and the economies of scale

- b) Capitalization of U.S. agriculture (see MacIntyre 1987)
    - i. Corporate capital infiltrated to assume production of these inputs (fertilizers, pesticides, seeds, machinery, etc.). New players entered the scene: input manufacturers, seed companies, etc.
    - ii. Continued adoption of technological innovations created technological dependence by farmers and further reinforced these new players' control over the food system
  - c) Important changes in land tenure during the 20<sup>th</sup> century (consult Census of Agriculture for data)
    - i. Decline in the number of farmers
    - ii. Increased average farm size
    - iii. An increase in corporate-owned vs. family-owned land
    - iv. An increase in farming leased land vs. owned land
3. The known and potential consequences of these trends
- a) Goldschmidt's Thesis: How different types of agriculture (corporate/large-scale vs. family-farm/smaller-scale) have different and significant consequences for the local community structure (see Goldschmidt 1947)
    - i. Communities dominated by large farms similarly tend to be associated with deteriorating social structure and decreased economic viability
  - b) Introduce the concept of chemicals and mechanization as labor saving and labor control strategies (see Friedland 1980)
    - i. Mechanization reduces labor costs
    - ii. Mechanization acts as a substitute for labor
    - iii. Mechanization acts as a control factor when labor strikes; it eliminates the threat of unionization
  - c) Land tenure matters (see Rosset and Altieri 1997; NRC 1989)
    - i. Farm size is important.
      - Small farms are frequently more productive per acre
      - Large farms often exhibit a low energy-use efficiency
      - Accountability: Owning land and depending on it for one's livelihood can engender a sense of responsibility for the consequences of production in order to ensure long-term economic viability. Contrast this with the case of large corporate farms, or leased lands where land is viewed as simply another component of the production process, and which can be leased off if production starts to fail.
      - Accountability is also linked with owner proximity: Local ownership imparts a sense of responsibility for the health and vitality of the local community and resources
      - Corporate profits don't stay in the local community. Small farms have a stronger "multiplier effect" on the local economy.
    - ii. Farm policies in the U.S. make small farms less economically viable
      - Market competition makes small farms less economically viable where declining crop prices squeeze some growers out of production and cause the others to expand their acreage in order to make up for lower per-acre profits. This results in fewer small-scale farmers and an increased number of large-scale farms. Furthermore, competition forces growers to focus on the bottom line at the expense of non-production goals (like sustainable land tenure).
      - Large growers also have more political clout and wealth and therefore receive preferential access to credit, irrigation, chemical fertilizers, pesticides, technical assistance, and marketing services
      - Farm subsidies—cash payments that augment the prices received by growers for producing basic commodities such as wheat, corn, and cotton—overwhelmingly favor the largest producers. Subsidies encourage large-scale monocultures, promote the specialization of equipment, and discourage crop rotations by supporting some commodities strongly.

- iii. Power. These issues of land tenure are not so much about farm size as they are about power. Highly capitalized interests in agricultural production have a vested interest in encouraging resource-intensive, industrialized agriculture. Their political and economic power helps maintain this current agricultural development trajectory.
    - Don't mistake farm size for power/accountability (see Moore Lappé et al. 1998, p. 96)
    - How are increases in productivity important if people are still going hungry?
    - Welfare programs designed to improve food security in U.S. are being cut
    - Number of people living in poverty is increasing. Number of hungry people in the U.S. increased 50% between 1985 and 1993 (see Allen 1997).
  - d) Overproduction of food
    - i. The U.S. has historically promoted a “cheap food” policy, thereby endorsing high levels of production at the expense of other goals (such as environmental protection or boosting workers' wages, for example)
    - ii. Externalities: The “hidden” costs of production, including water and air pollution, soil degradation, harm to non-target organisms, injustice, abuse, or inequalities to which no actor in the food system is held legally or financially accountable are termed externalities. Externalities effectively subsidize the “unsustainable” aspects of the production system that created them.
    - iii. Plentiful food lowers prices for consumers but also depresses prices for growers
4. Why have these changes taken place?
- a) Capital has moved in to capture profits at new points in the system (refer back to the U.S. Food Systems Map in the appendix)
  - b) Agricultural activities that previously took place on the farm and apart from financial transactions have come to be appropriated by off-farm capital interests (see Goodman, Sorj, and Wilkinson 1987)

# Lecture 2 Outline: Social Consequences of the Food System

## *for the instructor and student*

### **A. Concentration within the Larger Food System**

1. Concentration in distribution and retail: Grower-shippers and retail chains as powerful players in the food system
  - a) Consumer food prices go up and commodity prices paid to growers are going down. Thus these retail/shipping “middlemen” are retaining increasing profits and power.
  - b) Consolidation in the retail sector also acts as a market barrier for small growers, who cannot compete for market share with larger suppliers
2. Concentration of input suppliers
  - a) Seed companies: Top 10 seed firms control 30% of the US\$24.4 billion commercial seed market (see PANUPS 9/10/01)
  - b) Agrochemicals: Top 10 agrochemical corporations control 84% of the US\$30 billion agrochemical market (see PANUPS 9/10/01)
  - c) Biotechnology: Pharmacia/Monsanto’s gene technology accounted for 94% of the total area sown to genetically engineered (GE) crops in 2000 (see PANUPS 9/10/01)
3. Concentration in food processing
  - a) Discuss the consolidation trends described in Lyson and Raymer (2000). The ten largest U.S. based multinational corporations account for over half of the food and beverage sales in the U.S.
  - b) Implication: Production consolidation means consolidation of power and decision making. Such corporations seek large quantities of standardized and uniform products; they therefore “have considerable power in dictating how and where agricultural production takes place” (see Lyson and Raymer 2000, p. 200) as well as what is available in the marketplace.
  - c) Members of the boards of directors of these multinational corporations frequently overlap, thus exacerbating the problem of power concentration. Thus, much of the power in the food industry rests in the hands of relatively few individuals. These individuals tend to share common worldviews regarding the environment, labor, and food safety issues.
  - d) Example: The consequences of consolidation within the meat packing industry (see Pollan 2002)
  - e) Consequences of consolidation for growers: Smaller-scale growers are being paid less for farm products and paying more for farms and farm inputs, resulting in narrow to non-existent profit margins. This leads to business closure and further consolidation.

### **B. Farm Labor**

1. Contrasting descriptions of farm labor today: California and the rest of the U.S. (see Census of Agriculture; Allen 1994)
  - a) Size of labor force
  - b) Ethnic composition
  - c) Wages
  - d) Gender composition
2. Migrant farmworker lifestyle issues
  - a) Seasonality of work/migration patterns

- b) Health issues
    - i. Poor diet
    - ii. Physical stress and long hours of work
    - iii. Chemical exposure
    - iv. Lack of health insurance
    - v. Lack of affordable housing
    - vi. Family member separation
  - c) Typical work day description
  - d) Worker abuse
  - e) Farm labor contractors' roles—accountability, responsibility
    - i. Growers frequently and increasingly hire farm labor contractors to hire and manage field workers
    - ii. This effectively absolves growers of responsibility for abuses of workers that take place in their fields
    - iii. Relations with farm labor contractors frequently constitute a “black market” of laborers in which pay arrangements disappear from public scrutiny
3. Agricultural labor as “exceptional” in regards to policy
- a) Agricultural workers excluded from the Fair Labor Standards Act (FLSA) and from the National Labor Relations Act (NLRA)
    - i. These laws provide minimal standards of employment and collective bargaining rights for all other U.S. workers
    - ii. Agricultural workers are excluded from FLSA's overtime pay requirement
    - iii. Minimum age for agricultural workers is 12, whereas it is 14 for all other types of employment
    - iv. Unlike all other industries, farms with less than 11 employees are exempt from the protections of the Occupational Safety and Health Administration (OSHA), unless the grower operates a farm labor camp or if an on-the-job fatality occurs
  - b) Immigration policy has historically made exceptions for agricultural workers more than any other industry
    - i. For example, the Bracero program set up a pattern of migration that provided states in the Southwest U.S. with a migrant labor force in the first half of the 20<sup>th</sup> century
    - ii. Process was encouraged by U.S. and Mexican governments
    - iii. The extraction of labor has moved progressively south
4. Significance of U.S. labor policies
- a) Introduce Carey McWilliams' thesis on the ethnic succession of agricultural labor: That the U.S. government has designed immigration policies that introduce new (ethnic-based) group of workers who are willing to work for low wages and live in sub-standard conditions
    - i. Organizing efforts of immigrants are undermined through the repeated introduction of new groups of workers (of a different ethnicity) to replace “recalcitrant” workers who protest working conditions (see McWilliams 1935, Introduction)
  - b) Examples of this cycle: Chinese, Japanese, Dust-Bowl Okies, Arkies, Filipino, and Mexican immigrant labor throughout the 20<sup>th</sup> century
  - c) The newest ethnic group in California is the Mixtecs of southern Mexico, who are particularly vulnerable and powerless because of their lack of familiarity with English and Spanish, poorly developed support networks, and lack of familiarity with U.S. society/culture (see video El Norte in Resources section)
5. Why ethnic-based subgroups of laborers are so important
- a) Discourages collective organizing and bargaining



6. Why the size of the agricultural labor force is so important
  - a) Oversized labor pool keeps wages low by making workers compete with each other
  - b) Prevents workers from organizing: Constant influx of willing workers depresses wages and disrupts bargaining efforts
    - i. UFW membership has declined to ~10,000 (from an all-time high of 67,000 in 1973)
7. Why the seasonal nature of agricultural production is so important
  - a) Keeps workers migrating, which prevents them from settling, organizing, and making demands for higher wages or standards of living
  - b) Eliminates the responsibility from the growers of having to provide benefits
  - c) Social consequences
    - i. High unemployment rates in winter
    - ii. Less job security; less ability to establish rapport with employer
    - iii. Discrimination in society
    - iv. Difficulty in establishing oneself in a community

### C. Consumption Issues

1. Increased demand for fresh fruits and vegetables
  - a) Increased importance of long-distance shipping of fresh produce in order to provide year-round availability of most commodities
    - i. Food in the U.S. travels an average of 1,300 miles and changes hands half a dozen times before it is consumed (see Kloppenburg 1996, p. 34)
    - ii. Consequences: No consumer connection to site of production or mode of transport. No accountability for the social or ecological consequences of the production of any particular food item.
  - b) Increased importance in all areas of the world on producing high-value luxury export crops in lieu of producing subsistence crops
  - c) Implications for food security: The shift from subsistence agriculture to export/market production has led to greater market dependence for food. With the possibility of upsets in the market, peasant farmers place themselves at greater risk of hunger.
2. Cosmetic standards (see MacIntyre 1987)
  - a) These emerged in response to consumer (quality) demand and as a supply-control strategy (to keep prices reasonably high)
  - b) Consequence: Growers increase pesticide use in order to meet strict cosmetic standards for fresh produce and to outcompete their competitors
3. Pesticide residue standards
  - a) Consumer awareness of the severe ecological consequences of persistent organochlorine pesticides led to increased demand for lower pesticide residue tolerances in food
  - b) Consequence: Pesticide industry developed pesticides that are less persistent in the agricultural environment (but which are frequently more acutely/immediately toxic). This focus on final food product effectively removed attention from the site of production—and away from pesticides' impacts on workers.
4. Increased demand for processed foods
  - a) Implications for diet/health: Processed foods contain preservatives and chemicals that may pose human health problems and also contain fewer naturally occurring vitamins and minerals
  - b) Implications for power within the system
    - i. U.S. food processing corporations continue to retain the power within the system and provide less real “choice” for consumers
    - ii. Innovation in processed foods is geared towards high-profit, processor-driven convenience foods (see Lyson and Raymer 2000, p. 206)



## D. Contradictions: Redefining “The Problem” in U.S. Agriculture

1. U.S. agricultural research and policy
  - a) U.S. agricultural research and policy have historically defined the problem of hunger in terms of underproduction, with yield-improving technological developments advanced as solutions to this problem
  - b) Environmental and social issues are seen as separate from, external to, and independent of food production or hunger
2. Hunger in the context of overproduction: A fundamental contradiction within the U.S. food system
  - a) Does a food policy that purportedly prioritizes increasing productivity over all other (ecological and/or social) goals make sense?
  - b) There is not a direct correlation between agricultural productivity and poverty/hunger reduction. Increased food production per acre has not yet alleviated hunger in the U.S. or globally (see Moore Lappé 1998). 20% of children in the U.S. are hungry or malnourished.
  - c) There are racial dimensions to the phenomenon of hunger as well: 76% of hungry in U.S. are people of color (Allen 1994)
  - d) Hunger is as much an issue of power as it is an issue of food. Hunger is an issue of food distribution more than it is necessarily about food productivity per acre.
3. Overproduction in the context of environmental degradation
  - a) Given that maximum productivity today (through high use rates of pesticides, synthetic fertilizers, etc.) has significant human health risks and ecological costs over the long run, then: How rational is a food policy that prioritizes short-term production goals at the expense of the long-term resource base?

## E. Conclusion

1. Options, Power
  - a) Our current food system is a human creation, not an inevitable natural phenomenon
  - b) The shape and impacts of our agricultural system are not immutable, but we do not have any institutional framework for rewarding food systems that promote long-term social sustainability
  - c) Developing institutional frameworks that financially reward food systems that promote greater social justice will be necessary for change to take place toward long-term social sustainability
  - d) Recognition of human agency (the role and action of humans) infuses these discussions with responsibility and accountability
  - e) Such recognitions of agency also require recognition of power and resource inequalities that exist between different groups and individuals in society

# Resources

## SUGGESTED READINGS FOR STUDENTS (DESCRIBED BELOW)

- Lappé, Francis Moore, Joseph Collins, Peter Rosset, and Luis Esparza. 1998.
- Lyson, Thomas, and Annalisa Raymer. 2000.
- Pollan, Michael. 2002.
- Rothenberg, Daniel. 1998.
- Steinbeck, John. 1939.

## PRINT RESOURCES

Allen, Patricia. 1994. The Human Face of Sustainable Agriculture: Adding People to the Environmental Agenda. Sustainability in the Balance Series. Issue Paper No. 4. November 1994. Santa Cruz, CA: Center for Agroecology and Sustainable Food Systems, University of California, Santa Cruz

Allen, Patricia. 1997. Finding Food Security in the 1990s. *The Cultivar*. Vol. 15, No. 2 (Summer 1997). Santa Cruz, CA: Center for Agroecology and Sustainable Food Systems, University of California, Santa Cruz.

*This clear, short article discusses the food security implications of welfare reform and offers suggestions for how the sustainable agriculture movement can offer solutions to many of the problems resulting from dismantled social welfare programs. Available from CASFS ([www.ucsc.edu/casfs](http://www.ucsc.edu/casfs)).*

Allen, Patricia. 1999. Reweaving the food security safety net: Mediating entitlement and entrepreneurship. *Agriculture and Human Values* 16: 117-129.

*Interesting discussion of how agricultural sustainability initiatives frequently overlook the needs of low-income consumers.*

Allen, Patricia, ed. 1993. *Food for the Future: Conditions and Contradictions of Sustainability*. New York: John Wiley and Sons.

*Collection of articles investigating the various definitions of and attempts to achieve agricultural sustainability, with an explicit consideration of social, political, economic, and ethical issues. Contributors include Patricia Allen, Miguel Altieri, Frederick*

*Buttel, Katherine Clancy, Kenneth Dahlberg, Harriet Friedmann, David Goodman, Kathleen Merrigan, James O'Connor, Michael Redclift, Tom Regan, Carolyn Sachs, Neill Schaller, Lori Ann Thrupp, and Garth Youngberg.*

Browne, Willam P., Jerry R. Skees, Louis E. Swanson, Paul Thompson, and Laurian Unnivher. 1992. *Sacred Cows and Hot Potatoes: Agrarian Myths and Agricultural Policy*. Boulder: Westview Press.

*Discusses how the myth of the family farm is used as a justification for U.S. agricultural policy but is disconnected from reality.*

Census of Agriculture ([www.nass.usda.gov/census/](http://www.nass.usda.gov/census/))

*U.S. government statistics, compiled every seven years. This web site is very user friendly and provides data at various scales; creates useful maps from any given data set.*

Cochrane, Willard W. 1979. *The Development of American Agriculture: A Historical Analysis*. Minneapolis: University of Minnesota.

Conover, Ted. 1987. *Coyotes: A Journey through the Secret World of America's Illegal Aliens*. New York: Vintage Books.

*Fascinating, first-person account of a U.S. graduate student who lived, worked, and traveled for several years throughout the southern United States with migrant workers from Mexico.*

Friedland, William H. 1980. Technology in agriculture: Labor and the rate of accumulation. In *The Rural Sociology of the Advanced Societies, Chapter 7*, Buttel, Fred, and Howard Newby, eds. Montclair, N.J., UK: Allanheld, Osmun.

*Friedland discusses the relationship between labor and technological developments in agriculture, and stresses that frequently the strongest reasons for adoption of new agricultural technologies are as a form of social control and to suppress unionization efforts.*

Friedland, William H. 1981. *Manufacturing Green Gold*. Cambridge, MA: Cambridge Univ Press.

*A classic work describing how agricultural industry structure is related to the social relations of production and technological change.*

Goldschmidt, Walter R. 1947. *As You Sow: Three Studies of the Social Consequences of Agribusiness*. New York: Harcourt, Brace.

*Groundbreaking study of the different ways in which different types of farms affect the nearby communities.*

Goodman, David, Bernard Sorj, and John Wilkinson. 1987. *From Farming To Biotechnology: A Theory of Agro-Industrial Development*. Oxford, New York: Basil Blackwell.

*An integrated theory of the nexus of research, policy, technological development, and capitalist penetration in agricultural development. Considered a seminal work in modern political economy of agriculture.*

Kloppenborg, Jack, J. Hendrickson, and G.W. Stevenson. 1996. Coming in to the foodshed. *Agriculture and Human Values* 13: 33-42.

*Addresses the importance of proximity and accountability, and how the distance involved in the conventional food system disables a consumer's sense of responsibility for the social and ecological consequences associated with their food.*

Lappé, Francis Moore, Joseph Collins, Peter Rosset, and L. Esparza. 1998. *World Hunger: Twelve Myths. Second Edition*. New York: Grove Press.

*This book by Food First (Institute for Food and Development Policy) deconstructs in clear and accessible language twelve of the most common myths about hunger, food, and agriculture. Food First does an excellent job not only of explaining how the problem of hunger cannot be solved simply by increasing short-term production, but also of making these complicated issues understandable to the general public. Chapters 1, 4, 5, 6, and 7 are particularly recommended.*

Lyson, Thomas, and Annalisa Raymer. 2000. Stalking the wily multinational: Power and control in the U.S. food system. *Agriculture and Human Values* 17: 199-208.

*Discusses multinational corporation's newfound control over the U.S. food system; the degree of concentration of control within the leadership of these firms; and the implications of this consolidation for growers, workers, and consumers.*

McWilliams, Carey. 1935. *Factories in the Fields: The Story of Migratory Farm Labor in California*. Berkeley: University of California Press.

*Excellent and critical historical analysis of farm labor in California. Special emphasis is placed on the ways in which ethnicity and the seasonality of labor demand combine with industrial capitalism's infiltration of agriculture to create an unjust labor system.*

MacIntyre, A.A. 1987. Why pesticides received extensive use in America: A political economy of agricultural pest management to 1970. *Natural Resources Journal* 27(3): 533-578.

Martin, Philip L. and J. Edward Taylor. 2000. For California farmworkers, future holds little prospect for change. *California Agriculture* 54(1): 19-25.

*Briefly discusses the ways in which immigration policy has played a role in California farm labor history, the importance of the size of the agricultural labor force, and the social consequences of the highly seasonal demand for agricultural labor.*

Martin, Philip L. 1989. California's Farm Labor Market. California Institute for Rural Studies (CIRS) Working Paper #4. [www.cirsinc.org/pub/labor.html](http://www.cirsinc.org/pub/labor.html)

*Good review of the basic statistics about California's farm labor market from one of the leading researchers on such issues in the state; perhaps should be read with the more recent CIRS publication on this topic by Villarejo and Runsten (1998), listed below.*

Mitchell, Don. 1996. *The Lie of the Land: Migrant Workers and the California Landscape*. Minneapolis: University of Minnesota Press.

*Combines the fields of geography and labor history in this excellent look at the human costs associated with agricultural production in California. He uses historical analysis of farm labor in California between 1913 and 1942 in order to contrast the image of the bountiful agricultural landscape with the invisible injustices endured by the labor force that made that abundance possible.*

PANUPS. 2001. Handful of Corporations Dominates Commercial Agriculture. Pesticide Action Network Updates Service. 9/10/01. [panna.igc.org/resources/panups/panup\\_20010910.dv.html](http://panna.igc.org/resources/panups/panup_20010910.dv.html)

*Short report of consolidation within agricultural industry.*

Pollan, Michael. 2002. Power Steer. *New York Times Magazine*. 3/31/02.

*Enlightening investigative article navigating the U.S. beef industry.*

Rosset, Peter, Joseph Collins, and Francis Moore Lappé. 2000. Lessons from the Green Revolution: Do We Need Technology to End Hunger? *Tikkun Magazine* 15(2) (March/April 2000): 52-56.

*Good Food First connection of the issues of hunger, agricultural technology, ecology, income, and power.*

Rothenberg, Daniel. 1998. *With These Hands: The Hidden World of Migrant Farm Workers Today*. Berkeley: University of California Press.

*A fascinating collection of interviews, studied with the author's thoughts and background research, of migrant farmworkers in the U.S. today. Interviews were conducted with farm laborers, their families, growers, farm labor contractors, border control agents, residents of agricultural communities, and union workers. This wide variety of interviews gives the reader an education on the power relations and structure of employment in U.S. agriculture, as well as a fair treatment of a very wide set of perspectives and first-person testimonies of the difficult racial, class, and citizenship problems associated with migrant labor.*

Schlosser, Eric. 2001. *Fast Food Nation: The Dark Side of the All-American Meal*. Boston: Houghton Mifflin.

*Vivid, descriptive account of the meat processing and retail industry in the U.S.*

Steinbeck, John. 1939. *The Grapes of Wrath*. New York: Viking Penguin Books.

*At minimum, the first twelve chapters are recommended for their poignant and compelling discussion of the human and environmental impacts of agricultural modernization. The parallels between the experiences of the characters in this novel and today's migrant laborers should not be overlooked.*

Villarejo, Don, and Dave Runsten. 1998. California's Agricultural Dilemma: Higher Production and Lower Wages. California Institute for Rural Studies Publication #011. [www.cirsinc.org/pub/dilemma.html](http://www.cirsinc.org/pub/dilemma.html)

*Good treatment of the contradictions surrounding production, wages, and unions in California agriculture.*

Wright, Angus. 1990. *The Death of Ramon Gonzalez: The Modern Agricultural Dilemma*. Austin: University of Texas Press.

*An excellent, highly recommended discussion of the human and ecological consequences of agricultural pesticide use. This compelling, readable story is interwoven with political economic analysis of agricultural technology and development in both the U.S. and Mexico.*

Zabin, Carol, Michael Kearney, Anna Garcia, Dave Runsten, and Carole Nagengast. 1993. Mixtec Migrants in California Agriculture: A New Cycle of Poverty. California Institute for Rural Studies Publication #009. [www.cirsinc.org/pub/mixtec.html](http://www.cirsinc.org/pub/mixtec.html)

*Describes Mixtecs from the state of Oaxaca, who comprise the largest indigenous group from Mexico currently working in West Coast agriculture. Documents the living and working conditions of Mixtec farmworkers in West Coast agriculture and analyzes the effect their entry has had on mestizo Mexican (of mixed European and indigenous heritage) farmworkers who have a longer history of work in California agriculture.*

## WEB RESOURCES

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see “Course Curriculum”)

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This sustainable agriculture education resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

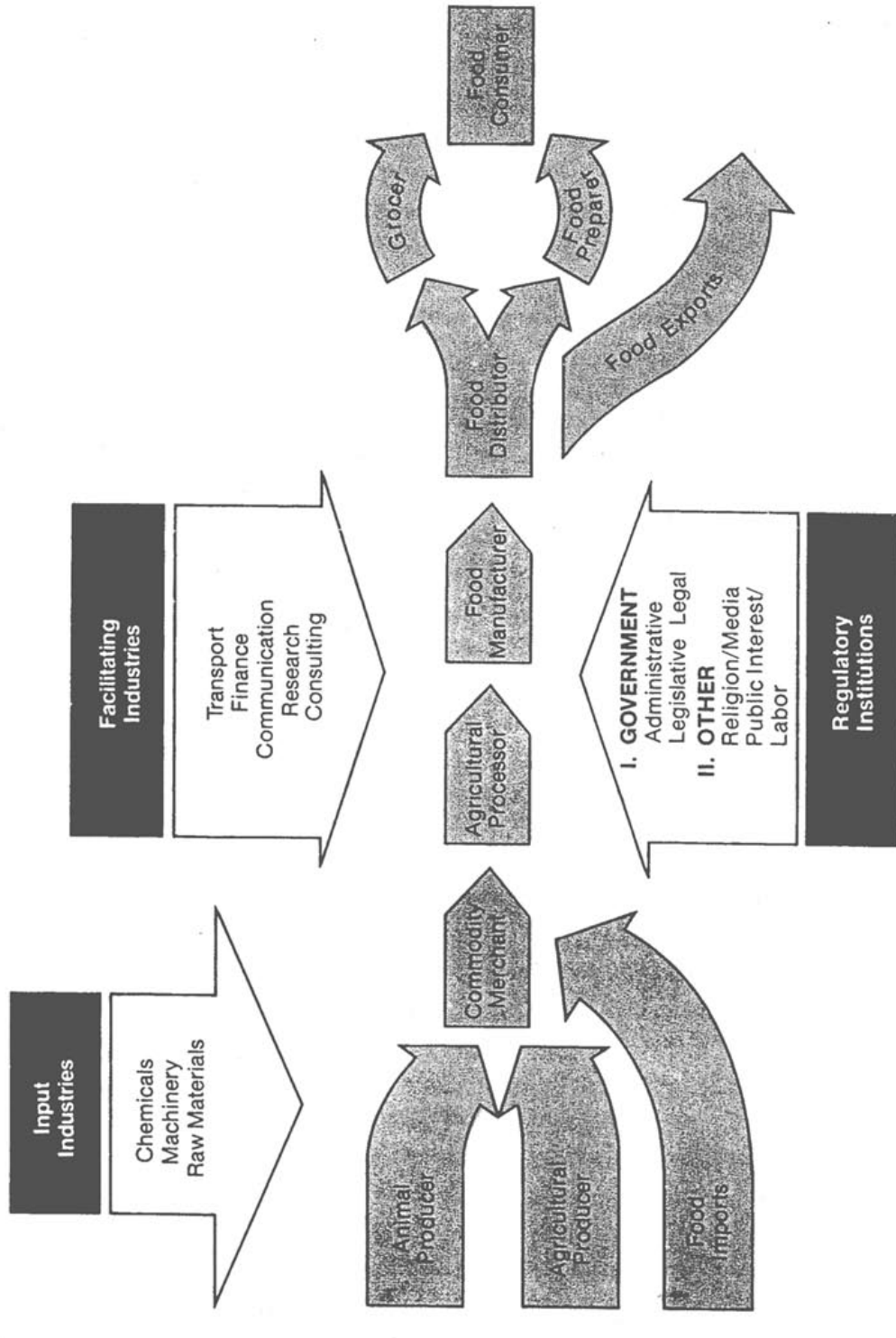
## VIDEO

El Norte. 2000. By Gregory Nava and Anna Thomas. Artisan Entertainment. (2 hours, 19 minutes)

*El Norte provides a case study in the phenomenon of ethnic succession of the agricultural labor force, migrating from Guatemala to the United States. It was nominated for an Oscar following its original 1984 release.*



# Appendix: U.S. Food System Model





# 3.3 Environmental Issues in Modern Agriculture

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# Introduction: Environmental Issues in Modern Agriculture

## OVERVIEW

*This unit introduces students to the most common agricultural practices employed in conventional production, and the major agricultural, environmental, and human health concerns that have arisen as a result of their use over the last century. Lecture 1 provides a framework of analysis to understand the factors driving change in modern agricultural systems—technology and capital—and an explanation of how changes in production have impacted environmental and human health. Lecture 2 includes an overview of alternative agricultural practices and concludes with an examination of the necessary policy and economic changes needed for their widespread adoption.*

Note: It is important to convey to students that many “conventional” farming operations, though not operating under National Organic Program organic certification, often integrate many of the “sustainable agriculture” practices outlined in this manual. Further, it is important to discuss that mere adherence to the minimum requirements of organic certification does not necessarily constitute sound agricultural practices. Students should understand that agriculture itself (whether “certified organic” or “conventional”) is one of the most extensive and environmentally disruptive land use practices that human beings currently employ.

Additionally, it is important to stress that it is often market pressures and the need to maintain a competitive advantage/economic viability that have encouraged individual farmers to adopt agricultural technologies that have later proven to have negative environmental or human health consequences. Lastly, though environmental degradation often results from the simple misuse or over-application of agricultural technologies (e.g., synthetic N-P-K fertilizers), certain agricultural technologies (e.g., GMOs and pesticides) currently pose either an unknown or well-substantiated environmental quality and/or human health risk.

## MODES OF INSTRUCTION

### > LECTURES (2 LECTURES, 50 MINUTES EACH)

Two lectures cover the socioeconomic factors that shape conventional modern agricultural production; key elements of modern agriculture and their environmental and human health impacts; and critical interactions between natural and agroecosystems. The lectures also present the set of alternative farming practices that have been used to avoid risks to environmental quality and human health. The lectures conclude with a discussion of the policy, regulatory, and economic factors that reinforce the conventional agriculture model and the policy and economic changes that need to take place in order to develop more sustainable production systems. References given in the outlines are described in the Resources section.

## LEARNING OBJECTIVES

### CONCEPTS

- The environmental impacts of modern agriculture as the consequence of the path of technological development taken in this country
- The “technology treadmill”: The technological package of modern agriculture as a system with its own internal logic, fueled and maintained by the techno-scientific and socioeconomic systems in which it is situated
- The development of agricultural mechanization, agricultural chemicals, and agricultural biotechnology in this light
- The major environmental impacts and human health risks of modern agriculture: water, soil, and air, biological diversity, and human health
- The barriers to adoption of conservation measures that would reduce these risks
- The set of organic/sustainable farming practices that are used to avoid risks to environmental quality and human health
- The policy and economic changes that need to take place in order to develop more sustainable production systems

# Lecture 1 Outline: Technological Innovations

## *for the instructor and student*

### **A. The Shaping of Conventional Agriculture: Technological Innovations, Investment Capital, and the Technology Treadmill (see FitzSimmons 1986; Heffernan et al. 1999)**

1. The initial resistance of agriculture to the forces of capitalism
  - a) Crop production as high-risk investment: Capital investors initially reluctant to invest in agriculture with productivity and profit being tied to biological processes and variables of natural environment
2. New agricultural technologies and capitalist investment
  - a) As new agricultural technologies were developed and introduced into agriculture, capitalist investors found it more profitable to invest in the technologies rather than crop production itself
  - b) Consequences
    - i. Farmers become dependent upon constantly evolving inputs of agricultural technology
    - ii. Agricultural technologies require substantial financial investment, thus requiring many farmers to obtain loans to reinvest in technology
    - iii. Capital investors and technology manufacturers control agricultural technology
    - iv. The restructuring of farm economics: New technology requires access to capital (loans, credit) for investment. This favors larger, well-capitalized farmers or farming corporations and puts smaller farmers at a competitive disadvantage, who often have to sell out, contributing to the growth in farm size and the loss of more small farms.
3. “The technology treadmill”
  - a) The technology treadmill defined: The self-reinforcing cycle of technological dependency, driven by the application of technology and investment capital to agriculture
    - i. Competition in the marketplace encourages the adoption of new agricultural technologies that allow for increases in efficiency or increases in the scale of production
    - ii. Increased efficiency, increases in the scale of production convey a competitive advantage through the economies of scale
    - iii. Crop prices are driven down because of efficiencies in production and the reduced costs per unit produced
    - iv. This drives some small producers out of business because they cannot access the credit needed to invest in the latest technology that is now essential in competing in the market place
    - v. Concurrently, this encourages producers to further increase the scale of production to have the size of operations necessary to cover their debts incurred through purchases of technology inputs
    - vi. The agricultural technologies used in expanding the scale of production have had significant social and environmental consequences

### **B. Technological Innovations and Practices Used in Conventional Agriculture**

1. Fossil fuel use in conventional agriculture
  - a) Fossil fuel was first used on the farm to replace human labor and animal power. It was a great labor-saving device, but tractors laid the foundation for monocultural production and long distance shipping of agricultural products.

- b) The influence of fossil fuel
  - i. Economically subsidized in many ways: Highways; lower prices for larger volumes of fuel used; externalized environmental costs (e.g., CO<sub>2</sub>, oil spills, etc.)
  - ii. Inexpensive fossil fuel power makes long-distance, cross-country, and international transportation of food and fiber cost effective. Cost effectiveness of international import agriculture is further assured by lower costs of production in developing nations due to lower environmental and social justice standards.
  - iii. Local and sustainable food systems cannot compete against large-scale agriculture with economically efficient long-distance food transport and the suite of externalized costs
- 2. Monoculture cropping systems (see Kimbrell 2002)
  - a) Monoculture defined: The planting of genetically similar or uniform crop varieties over large tracts of land, sometimes without rotation to other crops in space or time
  - b) Scale of monocultures: Monocultures can occupy hundreds to thousands of acres of land
  - c) Known and potential agroecological risks
    - i. Agriculture as environmental degradation: With 600 million hectares worldwide, and 943,000 acres of arable land under cultivation in the U.S., it is the most extensive terrestrial-based activity
    - ii. Agriculture has resulted in the conversion and degradation of grassland, woodland, and wetland ecosystems in the U.S. and around the world
    - iii. Highly simplified agricultural ecosystems maintain large carrying capacity for “pest” organisms and low carrying capacity for natural predators of agricultural pests
    - iv. Narrow and therefore vulnerable crop gene-pool
    - v. Dependency on biocides to control pests
    - vi. Soil loss and siltation of waterways through wind and water erosion in the absence of cover crops
    - vii. Uninterrupted pest/host relationship resulting in buildup of pest and pathogen populations
- 3. Hybrid seed (see Kloppenburg 1988)
  - a) History of seed production: Historically, seed has been selected by the farmers from the crop plants that produced well in a given area. This assured a locally adapted crop gene pool.
  - b) Though rapidly changing, this is still the practice in most of the world today
  - c) The development of off-farm selective breeding programs
    - i. Geneticists began controlled breeding of corn varieties in the first half of the 20th century to improve yields.
    - ii. Hybrid seed varieties—a product of a forced cross between homogeneous inbred lines—have superior traits, such as uniformity in growth and yield, uniform ripening, better taste, consistent germination, and processing and shipping qualities
    - iii. Traits in hybrid seeds can only be assured during the first generation, requiring farmers to buy hybrid seeds annually
    - iv. This created a huge economic opportunity for seed companies by generating input dependence by farmers on these high-yielding seeds
    - v. It also meant that entire counties or states could have near-uniform and therefore vulnerable crop genetics
  - c) The adoption of hybrid seed
    - i. Government agencies and seed companies conducted extensive campaigns to “modernize” farmers by persuading them to buy “improved” seeds
    - ii. Farmers who were resistant, either because they suspected efforts to make them buy off-farm inputs, or because they simply saw no reason to change, were ridiculed

- iii. As early adopters began to profit from improved seeds, they were able to outcompete their neighbors
    - iv. Early adopters of agricultural technologies began to buy their neighbors out, encouraging the concentration of ownership
  - d) Known and potential agroecological risks
    - i. The loss of genetic diversity of crop plants
    - ii. They may lack traits that have other ecological functions, such as disease resistance
    - iii. Narrow genetic base and therefore vulnerable to pests and pathogens
    - iv. Dependency on pesticide use
    - v. Loss of biodiversity of sexually reproduced crop plants
    - vi. Input dependence by farmers
- 4. GE: Genetically Engineered organisms (see [www.etcgroup.org](http://www.etcgroup.org); [www.centerforfoodsafety.org](http://www.centerforfoodsafety.org); [www.actionbioscience.org/](http://www.actionbioscience.org/); Kimbrell 2002)
  - a) What are genetically engineered (GE) organisms?
 

Genetic engineering (GE) is the transfer of genes from one organism to another through means that do not occur without human intervention. This involves isolating and then moving genes within and without different species by recombinant DNA techniques and other manipulation of the genetic construct outside the traditional practices such as sexual and asexual breeding, hybridization, fermentation, in-vitro fertilization and tissue culture. Also define agricultural biotechnology.
  - b) Examples of GE technologies
    - i. Bt-producing crops (advantages, risks)
    - ii. Terminator technology (advantages, risks)
    - iii. Herbicide-resistant crops (advantages, risks)
    - iv. Vitamin-producing crops (advantages, risks)
    - v. GE animals (advantages, risks)
  - c) Claims about GE crops
    - i. Feeding the world: Malnutrition and hunger are largely problems of maldistribution of food and poverty, not of underproduction
    - ii. Reducing pesticide use: Herbicide use may be encouraged as GE crop plants have higher tolerances for herbicides
  - d) Worldwide increase in the use of GE technology
    - i. Herbicide-resistant crops (HRCs) and insect-resistant crops (Bt crops) accounted for 59 and 15 percent respectively of the total global area of all transgenic crops in 2000
    - ii. Worldwide, the areas planted to transgenic crops increased more than twenty-fold in the past six years, from 3 million hectares in 1996 to nearly 44.2 million hectares in 2000.
    - iii. In the U.S., Argentina, and Canada, over half of the acreage (on average) for major crops such as soybean, corn, and canola are planted in transgenic varieties
  - e) Known and potential agroecological and human health risks
    - i. Potential human allergens: Viral vectors and antibiotic markers are used to verify successful trans-genetic engineering
    - ii. Potentially unknown viruses, toxins, and pathogens could be created by vector-mediated horizontal gene transfer and recombination
    - iii. The “escape” of trans-genetic genes via wind and insect pollination to wild plant weeds of the same species resulting in irreversible genetic pollution
    - iv. Additional farmer dependency on technological inputs
    - v. Ethical questions around intellectual property rights of germplasm

- vi. Loss of genetic diversity of crop plants through the abandonment of regional selection of sexually reproduced seed
  - vii. Loss of effectiveness through rapid evolution of resistance of biocontrol pesticides for organic systems: Example, Bt corn
  - viii. Transfer of genes/contamination of non-GMO and certified organic crops
  - ix. Reduction of the fitness of non-target organisms through the acquisition of transgenic traits via hybridization
  - x. The rapid evolution of resistance of insect pests such as to Bt
  - xi. Soil accumulation of the insecticidal Bt toxin
  - xii. Disruption of natural control of insect pests through intertrophic-level effects of the Bt toxin on natural enemies of agricultural pests
  - xiii. Unanticipated effects on non-target herbivorous insects (e.g., monarch butterflies) through deposition of transgenic pollen on foliage of surrounding wild vegetation
- f) GMOs as a crisis of democracy
- i. FDA has made the regulatory determination that they are “substantially equivalent” to non-GMO foods and that minimal testing needs to be done, and they need not be labeled. Simultaneously, industry has pursued patent rights for GMOs.
  - ii. GMOs sold and in widespread use before long-term studies on ecological and human health risks were conducted
  - iii. Question: Do individuals have the right to be informed of the potential environmental quality and human health risks associated with GMO as with other products (e.g., tobacco, alcohol, gasoline)?
  - iv. Farmers and populace have not been informed of the environmental, human health, or economic risks of GMO crops
5. Synthetic pesticides: Herbicides, insecticides, rodenticides, and fungicides (see Benbrook 1996; Kegley 1999, 2000; Reeves 1999; Kimbrell 2002)
- a) Pesticides as “biocides”: A pesticide is any substance or mixture of substances used to destroy, suppress, or alter the life cycle of any target organism. A pesticide can be a naturally derived or synthetically produced substance. Pesticides are not able to discriminate between target and non-target organisms with similar physiology.
  - b) Origins of synthetic biocides: Developed in WWI and WWII as warfare agents and later applied to agriculture
  - c) How pesticides work: The physiology of biocides (see [www.epa.nsw.gov.au/](http://www.epa.nsw.gov.au/))
    - i. Physical toxicity pesticides: Block the cellular processes of target organisms in a purely mechanical way. Examples include spray oils that clog the respiratory mechanism of insects
    - ii. Metabolic system inhibitors: There are many inhibitory pesticides in this category, such as rotenone and cyanide, that disrupt respiratory functions in animals; herbicides that inhibit seed germination or plant growth (especially at the root and shoot tips); and fungicides that inhibit germination of spores.
    - iii. Protein synthesis and enzyme disruption: Proteins such as enzymes control many important cell functions. Many pesticides aim to disrupt enzyme processes or denature proteins. Examples include inorganic copper compounds, dithiocarbamate fungicides, phosphono amino acid herbicides such as glyphosate, and organophosphate insecticides.
    - iv. Hormonal system interference: Several pesticides simulate or otherwise interfere with hormones to disrupt hormone cycles. Examples are the phenoxy herbicides that interfere with plant growth hormones and insect growth regulators that interfere with cuticle formation in insects during moulting.

- v. Nervous system disruptors: These pesticides affect mainly animal groups such as insects, nematodes, and rodents. Some are narcotics such as some fumigant pesticides. Others disrupt the movement of nerve impulses, such as the organophosphate, carbamate, and pyrethroid pesticides.
- vi. Photosynthetic inhibitors: Pesticides that disrupt photosynthesis prevent the plant from producing or storing energy and ultimately kill the plant. Examples include the triazine, substituted urea, and uracil herbicides.
- vii. Some pesticides work in more than one way and fall into more than one of these categories. The modes of action of many pesticides are not fully understood.
- d) Current trends in sales and use of biocides in agriculture (see Kegley 2000)
  - i. California: ~200 million pounds of active ingredients/year.
  - ii. 1991–1998: 40% increase in pesticide use with most toxic pesticide use remaining high
  - iii. U.S.: 800 million pounds active ingredients/year
  - iv. Misleading terms: Active ingredients and “inert” ingredients. Pesticide formulation may contain 99% inert ingredients. Many have adverse health effects and may be active ingredients in other pesticide formulations.
- e) Trends in crop losses: Relatively constant, despite increased use of biocides (see Gould 1991)
- f) Known and potential environmental and human health risks (see Kegley 1999, 2000; Reeves 1999; Moyers 1993)
  - i. Toxicity to non-target organisms, including natural enemies of agricultural pests
  - ii. Surface and groundwater pollution: Toxicity to aquatic wildlife and humans through drinking water
  - iii. Bio-accumulation in wildlife populations
  - iv. Effects on the physical environment (e.g., methyl bromide and ozone depletion)
  - v. Acute poisoning and occupational exposure of farmers and agricultural workers with known endocrine-disrupting compounds, known and suspected carcinogens and nerve toxins. (3 million human pesticide poisonings, and 220,000 deaths attributed to pesticides worldwide/year.)
  - vi. Dietary exposure to endocrine-disrupting compounds, known and suspected carcinogens and nerve toxins
  - vii. Potential synergistic effects of exposure to environmental toxins with similar mechanisms of toxicity
  - viii. Soil degradation: Reduce biological activity and diversity
  - ix. Developed resistance and resilience in pest populations
  - x. Dietary exposure and the safety of existing tolerance levels
  - xi. Pesticides disproportionately affect predaceous “beneficial organisms” over pests, creating resurgence in populations of pest organisms
- g) Estimates on financial costs to mitigate environmental damage
  - i. In the U.S., environmental costs are estimated in the range of \$1–8 billion, depending on assumptions; worldwide estimates range up to \$100 billion annually (Pimentel 1993)
- h) The “logic” of pesticide use and the externalization of costs
  - i. For every \$1 spent on pesticides there are \$3 in economic effect. It is estimated that for each dollar spent on pesticides, approximately \$1 of environmental damage and an unknown cost to human health are caused. These costs of production are not compensated for by the farmer or agrochemical company.
- i) Legislation restricting the use of biocides (see Benbrook)
  - i. The Food Quality Protection Act of 1996 (see [www.epa.gov/opppsp1/fqpa/](http://www.epa.gov/opppsp1/fqpa/))
  - ii. Shortcomings of the FQPA (see [www.ecologic-ipm.com](http://www.ecologic-ipm.com))



## 6. Synthetically compounded N-P-K fertilizers

- a) What is synthetically compounded fertilizer? Synthesizing ammonia from nitrogen and hydrogen gas involves submitting nitrogen and hydrogen to at least 3,000 pounds per square inch of pressure, in the presence of osmium as a catalyst. Industrially produced synthetic ammonia is the principal source of the commercially available, industrially produced nitrogen and is the principal starting point from which all of the different kinds of industrially produced, so-called nitrogen “fertilizers” are made.
- b) Known and potential agroecological and human health risks (see Gliessman 1998; U.S. Geological Survey 1998 )
  - i. The overapplication of synthetic N, P, and K nutrients are the most extensive form of “nonpoint source (runoff) pollution” in the U.S.
  - ii. The overapplication has greatly altered the global N and P cycles with unknown consequences (Gliessman 1998)
  - iii. Surface water contamination: N-P-K, eutrophication, and increased biological oxygen demand (see Carpenter et al. 1998; Miller 2001; U.S. Geological Survey 1998)
  - iv. Energy intensive production (see Miller 2001; [edis.ifas.ufl.edu/](http://edis.ifas.ufl.edu/))
  - v. Drinking water contamination: Nitrate poisoning. Elevated nitrate levels in drinking water wells are common in agricultural areas and have resulted in a rare infant disease called methemoglobinemia (“blue-baby syndrome”; see [www.cdffa.ca.gov](http://www.cdffa.ca.gov))
  - vi. Excess nitrogen in crops can lead to increased susceptibility to pests and pathogens and poor post-harvest handling (Young, 1999)
  - vii. Soil degradation: Increased loss of soil organic matter; decreased soil biological activity and diversity; reduced aggregation and aggregate stability and the decline in desirable physical properties; increased soil erosion by wind and water; reduced nutrient availability through biological activity; increase susceptibility to pests and pathogens; increased dependence on synthetic chemical fertilizers and pest control agents to maintain productivity (Magdoff 2000).

## 7. Confined Animal Feeding Operations (see [www.cdc.gov](http://www.cdc.gov) and [www.usda.gov](http://www.usda.gov))

- a) The increased number and size of Confined Animal Feeding Operations 1882–1987
  - i. Decrease in very small (<50 Animal Units, AU) and small farms (50–300AU) from 435,000 to 313,000 farms
  - ii. Medium size farms (300-1000 AU) grew by 4,400 farms
  - iii. Large farms (1000 + AU) doubled to 4,000 farms
- b) Such concentration of reclaimable nutrients results in significant nutrient pollution of air, water, and groundwater (e.g., nitrate contamination and eutrophication of surface waters)

## 8. Agricultural water use (see [www.pbs.org/kteh/cadillacdesert/home.html](http://www.pbs.org/kteh/cadillacdesert/home.html); Reisner 2002)

- a) In the Western U.S. roughly 90% of water diversion and supply goes to agriculture
- b) There are about 75,000 dams nationwide, and about 1500 in California
- c) Environmental consequences of dams and water diversion
  - i. Dams degrade aquatic and riparian ecosystems by altering natural river flows, preventing flood flows necessary for the maintenance of habitat and wetlands, disrupting natural water temperatures, and reducing water quality
  - ii. Average annual flows in Central Valley rivers of California have been reduced by as much as 80% on the San Joaquin River below Friant Dam and as much 35% on the Sacramento River below Shasta Dam
  - iii. In California dams block 90% of the anadromous fish habitat

- d) Groundwater depletion (see [water.usgs.gov/ogw/gwrp/stratdir/future.html](http://water.usgs.gov/ogw/gwrp/stratdir/future.html))
    - i. The overdraft of groundwater is resulting in the depletion of underground aquifers resulting in increased costs of harvest and eventual loss of resource
    - ii. Groundwater depletion in coastal areas may result in saltwater intrusion and salt contamination of ground water
    - iii. Land subsidence
  - e) Salinity problems (see [www.heinzctr.org/ecosystems/index.htm](http://www.heinzctr.org/ecosystems/index.htm))
    - i. Salinity results from the accumulation of salt in the soil, resulting from the use of irrigation in poorly drained soils
    - ii. High soil salinity may result in the interference of water uptake and circulation leading to moisture stresses in crop plants
    - iii. It is estimated that 40% of irrigated lands in the U.S. are affected by elevated salinity
9. The environmental consequences of international trade liberalization policies (see Korten 2001). International trade liberalization policies (e.g., NAFTA and GATT) allow capital investors and U.S. and European food corporations to secure profits through the production of agricultural products in less developed nations (LDN). Costs of production in LDNs are much lower due to LDNs having lower environmental quality and social justice standards. These inexpensive products with many associated externalized costs are imported to the U.S. and Europe and sold at very low prices at large retail outlets.
10. Summary: Conventional agriculture, soil degradation, and the technology treadmill (see Magdoff 2000)

Market competition and the absence of laws restricting the use of agrochemicals encourage the adoption of new agricultural technologies that allow for increases in the efficiency and scale of production (e.g., monocultures, pesticides, synthetic N-P-K fertilizers, hybrid and GMO seeds). Large-scale monocultures create a large carrying capacity for “pest” organisms and low carrying capacity for natural predators of agricultural pests by simplifying the agroecosystem and surrounding plant communities. This results in the population growth of pest organisms and the inability of natural predators of insect pests to effectively prevent pest outbreaks. Pesticides are therefore applied in an attempt to control pest populations.

Pesticides disproportionately affect predaceous natural enemies of insect pests, resulting in the resurgence of insect pest populations and the development of genetic resistance of pests to pesticides. Pesticides become less effective and the intensity of pesticide use increases. The overuse of synthetic nitrate fertilizer may result in excessive vegetative growth and poor post-harvest quality, both of which are highly susceptible to pests. Pesticides are therefore applied in an attempt to control pest organisms.

Synthetic N-P-K fertilizers do not replace the organic matter necessary to maintain the soil biological diversity and activity needed to maintain disease suppression and desirable physical properties of agricultural soils. The use of synthetic fertilizers and the absence of sound crop rotation and cover cropping may encourage soil erosion and compaction, reduce the water- and nutrient-holding capacities of soil, and result in poor growing conditions for crops, leading to an increased susceptibility to both pests and pathogens. Intensive use of fertilizers, new pesticides, and tillage are then required to maintain productivity of such systems. This often results in further soil degradation and the unintentional exposure of agriculture workers, wildlife, and the general public to elevated levels of pesticides and nitrates in food and ground-water.

Agriculture itself (whether “certified organic” or “conventional”) is one of the most extensive and environmentally disruptive land-use practices, where terrestrial plant and animal communities are converted to row crops and enormous amounts of water are diverted to supply needed irrigation water. Irrigation water has led to elevated salt levels, which may result in the interference of crop plants to access and regulate moisture. Water diverted from rivers has resulted in the degradation of these aquatic ecosystems through the erection of dams. Overdraft of underground aquifers for agricultural use has led to the depletion of this resource, and in coastal areas, to the intrusion of saltwater into agricultural wells.

GMO crops pose an unknown environmental and human health risk, reduce the diversity of crop genetics and, where adopted, create further input dependence for farmers. Hybrid seed reduces the diversity of crop genetics and creates further input dependence for farmers.

# Lecture 2 Outline: Alternatives to Conventional Agriculture

## *for the instructor and student*

### A. Viable Alternatives to Conventional Agriculture: Sustainable and “Organic” Agriculture Practices (see National Research Council 1989; Magdoff 2000; Units 1.1 and 1.8 of this manual)

1. Soil fertility management: Maintenance of optimal soil chemical properties
  - a) Nutrient budgeting based on balancing nutrient inputs with outputs: Matching crop demand with nutrient contribution of inputs. This approach attempts to assure that nutrient needs are met without creating nutrient excesses and their associated problems (e.g., nutrient runoff, leaching/nonpoint source pollution, pest susceptibility, and poor post-harvest quality).
  - b) Practices
    - i. Cover crops: Non-market crops, some of which are used to fix atmospheric nitrogen and carbon; cycle nutrient inputs and sub-soil nutrients (e.g., N and P respectively); stimulate soil biological activity; prevent nutrient leaching
    - ii. Compost: Depending on compost feedstock, can be a source of N-P-K and micronutrients; stimulates soil biological activity necessary for nutrient release
    - iii. Naturally occurring soil amendments and fertilizers: Supplies nutrients
    - iv. Proper irrigation: Prevents leaching of mobile nutrients
2. Soil fertility management: Soil physical properties
  - a) Perennial cover crop rotation: Allows soil to remain undisturbed and aggregate formation to proceed
  - b) Properly timed and quantity of tillage: Prevents compaction of soil and unnecessary oxidation of soil organic matter (SOM)
  - c) Cover crops: Prevent soil erosion; stimulate soil biological activity; allow soil to rest and aggregate formation to proceed
  - d) Compost: Stimulates soil biological activity, diversity, and aggregate formation
  - e) Proper irrigation: Prevents soil erosion
3. Non-toxic pest management
  - a) Sound soil fertility management (see above)
  - b) Polycultures: Diversity of crop plants maintains more even carrying capacity for pests and beneficial insects
  - c) Biocontrol of pest organisms, e.g., using releases of predaceous, parasitic, and parasitoid insects to reduce pest populations
  - d) Farmscaping: Non-crop vegetation used to encourage habitat for beneficial organisms and/or encourage pests away from market crop (trap crop)
  - e) Cover crops: Rotating crops interrupts pest-host cycle and attracts natural enemies of agricultural pests; stimulates soil biological activity; allopathic control of pests
  - f) Compost: Stimulates soil biological activity and diversity that encourage disease- suppressive qualities of soils
  - g) Mating disruption: Pheromone releases timed with mating periods
4. Open-pollinated seed varieties: Maintain viability of regionally adapted (i.e., disease resistant) crop cultivars

## B. Making Agriculture Practices in the U.S. More Environmentally Sound

(see Youngberg et al. 1993; Lockeretz 1997; Hassanein 1999)

1. Recognize what has driven change in agriculture over the past century: A complex interaction of social forces that have different impacts under different ecological conditions
2. Second step: To recognize the primary instruments of change have been investment capital and technological developments
  - a) Behind these instruments are a host of social structures that have influenced our relationship to food and food production: Capitalist economics, national policies, changes in the agricultural workforce, reduction in food costs and increased availability of foods, changes in diet preferences, and attitudes toward the role of food in culture
3. To effect change, advocates will have to work intensively in particular areas but link up with others working on a broad range of reforms
4. Economics
  - a) Support of policy initiatives that encourage local economic development that allows social and environmental values to be incorporated into the price structure of foods
5. Policy, science, technology, and education
  - a) Continued educational efforts in informing consumers of the relationship between personal food choices, the food systems these choices support, and the associated social and environmental consequences
  - b) Citizen participation in U.S. agricultural public policy (e.g., Farm Bill) in support of funding federal programs that financially support the adoption of conservation farming practices
  - c) Citizen encouragement of agricultural public policies to fund federal programs for alternative agriculture, environmental, and food system research in U.S. agricultural colleges
  - d) Consistent and sustained pressure on the public institutions that direct research trajectories (e.g., Land Grant institutions)
  - e) Integration of conservation farming education into Cooperative Extension services
6. Policy: See Policy Initiatives in Unit 3.4, Sustainable Agriculture and Sustainable Food Systems (page 12)
7. The importance of human values in shaping agriculture
  - a) Recognize that attitudes toward food are shaped by broad social circumstances such as the cost of living, changes in the roles of women in society, food products advertising, the number of persons directly involved in food production, knowledge of food and agricultural systems and their social, environmental, and health consequences
  - b) With knowledge of food and agricultural systems and the associated social, environmental, and health consequences individuals may be compelled to emphasize locally produced seasonal and organic foods
  - c) Education on food costs and fast foods may encourage more Americans to spend less money on food outside the home
  - d) Re-emphasizing eating as a social act that builds family and community can assist the necessary changes in diet, the local agricultural economy, and the broader food system

# Resources

## SUGGESTED READINGS FOR STUDENTS (DESCRIBED BELOW)

- Carpenter et al. 1998
- Funders Agriculture Working Group. 2001.
- Gliessman, Stephen R. 1998. Chapters 1-2.

## PRINT RESOURCES

Altieri, Miguel A., ed. 1995. *Agroecology: The Science of Sustainable Agriculture*. Boulder, CO: Westview Press.

*Miguel Altieri is one of the pioneers in developing the discipline of agroecology, and this was the first text to lay out its major premises. Rather than present techniques for production, this text proposes an agricultural paradigm based on the science of ecology. The (second) edition contains updated essays, and still provides a thoughtful overview.*

Benbrook, Charles M. 1996. *Pest Management at the Crossroads*. Yonkers, New York: Consumers Union.

*The clearest summary of environmental, health, policy and economic issues surrounding pest management in the U.S. Its chapters introduce IPM—with an emphasis on biointensive IPM, review of pesticide use and risk, and discussion of economic and policy obstacles to the adoption of IPM.*

Carpenter, Stephen, Nina F. Caraco, David L. Correll, Robert W. Howarth, Andrew N. Sharpley, and Val H. Smith. 1998. *Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen*. Issues in Ecology 3. Available from [www.esa.org/issues.htm](http://www.esa.org/issues.htm)

*Provides an introduction to the ecological impacts of nutrient run-off. Although the article's scope is much broader than agriculture, it explains the biochemical processes that occur when excess nutrients enter waterways; appropriate for non-science majors.*

Cooper, Ann. 1999. *Bitter Harvest: A Chef's Perspective on the Hidden Dangers in the Foods We Eat and What You Can Do About It*. New York: Routledge.

*Describes the health risks of modern industrial food and lax government oversight of food safety.*

Conway, Gordon R., and Jules N. Pretty. 1991. *Unwelcome Harvest: Agriculture and Pollution*. London: Earthscan.

*An exhaustive overview of the relationship amongst agrochemicals, environmental impacts, and social consequences from a global perspective.*

DANR (Division of Agriculture and Natural Resources). 1992. *Beyond Pesticides: Biological Approaches to Pest Management in California*. Oakland: University of California Division of Agriculture and Natural Resources.

*A thorough analysis of the production-related problems of pesticide reliance in California; proposes increased funding for research and extension of biological methods of pest management in the state.*

FitzSimmons, Margaret. 1986. The new industrial agriculture: The regional integration of specialty crop production. *Economic Geography* 62 (4):334-353.

Funders Agriculture Working Group. 2001. *Roots of Change*. San Francisco: FAWG. Available at [www.fawg.org](http://www.fawg.org).

*Produced by private foundations interested in funding sustainable agriculture initiatives in California, describes in very simple, non-technical language the environmental problems of conventional agriculture and the potential of sustainable agriculture as a force for change.*

Gliessman, Stephen R. 1998. *Agroecology: Ecological Processes in Sustainable Agriculture*. Chelsea, MI: Ann Arbor Press.

*The first textbook aimed at undergraduates to teach the basic principles of agroecology.*



Hassanein, Neva. 1999. *Changing the Way America Farms: Knowledge and Community in the Sustainable Agriculture Movement*. Lincoln, Nebraska: University of Nebraska Press

Heffernan, William D., Mary Hendrickson, and Robert Gronski. 1999. *Consolidation in the Food and Agriculture System*. National Farmers Union: www.nfu.org

*Provides the clearest and most compelling evidence of the concentrated economic control that a small number of transnational corporations have over the processing and distribution of foodstuffs.*

Kegley, Susan, Lars Neumister, and Timothy Martin. 1999. *Disrupting the Balance: Ecological Impacts of Pesticides in California*. San Francisco: Californians for Pesticide Reform. www.igc.org/cpr/publications/publications.html

*Reports in considerable detail the continuing impacts of agrochemicals on California's ecosystems.*

Kegley, Susan, Stephan Orme, and Lars Neumister. 2000. *Hooked on Poison: Pesticide Use in California 1991–1998*. San Francisco: Californians for Pesticide Reform. www.igc.org/cpr/publications/publications.html

*Drawing from California's pesticide database, reports patterns of pesticide use in the state by chemical, crop, and county.*

Kimbrell, Andrew, ed. 2002. *Fatal Harvest: The Tragedy of Industrial Agriculture*. Washington DC: Island Press.

*A coffee table-sized book with many short essays and large photos describing the environmental and social consequences of our modern agricultural system. Provides a thorough identification of the range of consequences from this system. A lower-cost version without photos has all the essays, and would be an appropriate reader for undergraduates.*

Kloppenborg, Jack. 1988. *First the Seed: The Political Economy of Plant Biotechnology*. Cambridge: Cambridge University Press.

*A brilliant historical analysis of seeds, plant breeding, genetic diversity, and the appeal of biotechnology to capitalism.*

Korten, David C. 2001. *When Corporations Rule the World*. 1294 Blue Hills Avenue, Bloomfield, CT 06002, U.S.A.

*A central text in the emerging global Living Democracy Movements. Addresses the social and environmental consequences of economic globalization.*

Lockeretz, William, ed. 1997. *Visions of American Agriculture*. Ames: Iowa State University Press.

*A selection of writings by experts on social and economic evolution in the agricultural sector.*

Miller, G. Tyler, Jr. 1998. *Living in the Environment*. Belmont, CA: Wadsworth Publishing Company.

*Undergraduate-level textbook in environmental science. Addresses prevalent environmental issues including problems in modern conventional agriculture and alternatives.*

National Research Council. 1989. *Alternative Agriculture*. Washington, D.C.: National Academy Press.

*This book was significant because of the scientific legitimacy it accorded to the emerging sustainable agriculture movement. Its methodology was criticized by both conventional and alternative agriculture advocates. Although its findings and recommendations are not particularly provocative by today's standards, it marked an important milestone in efforts to promote alternative approaches to production.*

—. 1993. *Soil and Water Quality: An Agenda for Agriculture*. Washington DC: National Academy Press.

*Provides the most scientifically thorough discussion of the soil and water conservation challenges facing agriculture in the U.S. Although written by scientists, its target audience is policymakers. Clear and well-organized.*

Pimentel, David, et al. 1993. Environmental and economic impacts of reducing U.S. agricultural pesticide use. In *The Pesticide Question: Environment, Economics, and Ethics*, D. Pimentel and H. Lehman, eds. New York: Chapman & Hall.

Pollan, Michael. 2002. Power Steer. *New York Times Magazine* March 31.

*Describes the modern beef production system, and its human health and environmental impacts.*

Pretty, Jules N. 1995. *Regenerating Agriculture*. London: Earthscan.

*Would serve well as a textbook for a sustainable agriculture class with a global perspective. Pretty does a good job integrating technical, social, and political changes that need to be put in place to make a transition to more environmentally friendly agriculture.*

Reeves, Margaret, Kristin Schafer, Kate Hallward, and Anne Katten. 1999. *Fields of Poison: California Farmworkers and Pesticides*. San Francisco: Californians for Pesticide Reform. Available at [www.igc.org/cpr/publications](http://www.igc.org/cpr/publications)

*The most complete discussion of California farmworker poisonings. Critiques the weak reporting and even weaker enforcement of farmworker protection laws.*

Robbins, John. 1987. *Diet for A New America*. Walpole NH: Stillpoint.

*Discusses the human and environmental health impacts of modern agriculture and diet.*

Röling, N.G., and M.A.E. Wagemakers. 1998. *Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty*. Cambridge: Cambridge University Press.

*Essays explore in detail the social changes necessary to make the technical changes possible for sustainable agriculture. The emphasis and case studies are focused on Europe and the developing world, but the principles are relevant to all.*

Schlosser, Eric. 2001. *Fast Food Nation: The Dark Side of the All-American Meal*. Boston: Houghton Mifflin.

*Contains great chapters on food safety, meat packing, and the implications of a fast food diet.*

U.S. Geological Survey. 1998. *Water Quality in the San Joaquin-Tulare Basins: California 1992-1995*. Reston, Virginia: USGS Circular 1159.

[water.usgs.gov/pubs/circ1159](http://water.usgs.gov/pubs/circ1159).

———. 1999. *The Quality of Our Nation's Waters: Nutrients and Pesticides*. Reston, Virginia: USGS Circular 1225.

———. 2000. *Water Quality in the Sacramento River Basin, California, 1994-1998*. Reston, Virginia.

*Reports describe a thorough investigation into the water quality in U.S. and California rivers and streams.*

Youngberg, Garth, Neill Schaller, and Kathleen Merrigan. 1993. *The sustainable agriculture policy agenda in the United States: Politics and prospects*. In *Food for the Future*, Patricia Allen, ed. New York: John Wiley.

## WEB RESOURCES

Action Group on Erosion, Technology and Concentration (formerly RAFI)

[www.etcgroup.org](http://www.etcgroup.org)

*Dedicated to the conservation and sustainable advancement of cultural and ecological diversity and human rights. Supports socially responsible developments of technologies useful to the poor and marginalized and addresses international governance issues and corporate power.*

Benbrook Consulting Services

<http://pewagbiotech.org/events/0204/benbrook.php3>

*Viewpoints on biotechnology by previous National Academy of Sciences agriculture director.*

Bullfrog Films

[www.bullfrogfilms.com](http://www.bullfrogfilms.com)

*Source of films on environmental issues.*

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*



#### Californians for Pesticide Reform

[www.pesticidereform.org](http://www.pesticidereform.org)

*A coalition of over 170 public interest groups dedicated to protecting human health and the environment from the dangers of pesticide use.*

#### Center for Food Safety

[www.centerforfoodsafety.org/](http://www.centerforfoodsafety.org/)

*Analyzes biotechnology issues.*

#### Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This sustainable agriculture education resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

#### Extension Toxicology Network

[ace.orst.edu/info/extoxnet/](http://ace.orst.edu/info/extoxnet/)

*A source of objective, science-based information about pesticides developed by toxicologists and chemists within the Extension Service of the land-grant universities; written for the non-expert. Information fully searchable and selectively retrievable.*

#### Food Quality Protection Act (FQPA)

[www.ecologic-ipm.com/fqpa.html](http://www.ecologic-ipm.com/fqpa.html)

[www.ecologic-ipm.com/viewwand.html](http://www.ecologic-ipm.com/viewwand.html)

*Viewpoints on the FQPA.*

#### Heinz Center

[www.heinzctr.org](http://www.heinzctr.org)

*The Heinz Center is a non-profit institution dedicated to improving the scientific and economic foundation for environmental policy through multisectoral collaboration among industry, government, academia, and environmental organizations.*

#### Pesticide Action Network

[www.panna.org](http://www.panna.org)

*An excellent web site containing the most recent compilations of studies on pesticide use in California and the U.S.*

#### UC Sustainable Agriculture Research and Education Program

[www.sarep.ucdavis.edu](http://www.sarep.ucdavis.edu)

*An excellent web site for the discussion of the social, political, ecological, and agronomic aspects of “sustainable agriculture.”*

#### U.S. Geological Survey

[water.usgs.gov/nawqa/wcp/index.html](http://water.usgs.gov/nawqa/wcp/index.html)

[water.usgs.gov/nawqa/nutrients/maps.html](http://water.usgs.gov/nawqa/nutrients/maps.html)

[water.usgs.gov/pubs/FS/FS-116-99/](http://water.usgs.gov/pubs/FS/FS-116-99/)

*Accessible reports and maps on the water quality impacts of non-point source pollution from agriculture. These are appropriate for undergraduate students, and their maps make nice overheads for lectures.*

#### U.S. Geological Survey

[water.usgs.gov/ogw/gwrp/stratdir/future.html](http://water.usgs.gov/ogw/gwrp/stratdir/future.html)

*The USGS Ground-Water Resources Program’s efforts to examine and report on critical issues affecting the sustainability of the nation’s groundwater resources.*

## VIDEOS

In Our Children's Food. 1993. PBS FRONTLINE special. Hosted by Bill Moyers (56 minutes).

*Covers human health and environmental risks associated with pesticide exposure. Follows the politics of the development of the National Academy of Sciences' children's study: Pesticide residues in the diets of infants and children.*

On American Soil. 1985. Produced by the Conservation Foundation (28 minutes).

*Award-winning film on the "next critical environmental issue" we see the nature and extent of the soil erosion problem in America today. Explains the economic circumstances influencing the adoption of conservation farming practices. Available from:*

[www.bullfrogfilms.com](http://www.bullfrogfilms.com)

Race to Save the Planet: Saving the Environment and Feeding the World. 1990. WGBH/PBS video.

*Explores the human side of international environmental issues in agriculture and the delicate balance between progress and the preservation of the environment.*

Diet for a New America. 1991. KCET /PBS video. Hosted by John Robbins (60 minutes).

*From the John Robbins book of the same name. Discusses the human and environmental health impacts of modern agriculture and diet.*

Playing with Poison. 2001. CBC's The Nature of Things. Force Four Entertainment (64 minutes).

*American anthropologist investigates the side effects on children of pesticide use in Mexico's Yaqui Valley, one of Mexico's largest agricultural areas. Available from:*

[www.bullfrogfilms.com](http://www.bullfrogfilms.com)



# 3.4 Sustainable Agriculture and Sustainable Food Systems

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# Introduction: Sustainable Agriculture and Sustainable Food Systems

## UNIT OVERVIEW

*This unit draws on information presented in Units 3.1–3.3 to help students understand efforts to promote greater sustainability in U.S. food and agriculture systems. The first lecture presents a short history of efforts resisting agriculture’s modernization, a process that has been driven by increasingly capitalist relationships and the application of new technologies in agriculture. The lecture summarizes early U.S. agrarian populism and efforts to resist the “scientization” of agriculture through the authority of expert knowledge associated with the Land Grant University complex. It then presents the origins of the organic agriculture movement, and describes the impact that Rachel Carson’s Silent Spring had on society and public policy. The resurgence of U.S. agrarian populism offered by Jim Hightower and Wendell Berry is then covered. The first lecture concludes with an introduction to the concept of “sustainability” in the literature and public discourse.*

The second lecture reviews some of the current initiatives to promote alternative visions of the U.S. food and agriculture system. It first explains various definitions and dimensions of “agricultural sustainability,” and explores the problems associated with this term. Students will be exposed to the criticism of the way that proponents of “sustainable agriculture” have tended to limit discussions of this issue to farms and farmers, ignoring the broader social context of the food system of which the farm is one part. The lecture then introduces the concept of agroecology pioneered by Steve Gliessman and Miguel Altieri, and the application of ecological principles to the design and management of agroecosystems. The definition and requirements of certified organic food production and the growth and development of the “Organic” food industry over the last ten years are then discussed. This section further addresses concerns over the replication of social and environmental problems caused by the introduction of capitalist relations and federal standards to organic production.

The concepts of the “foodshed” and “community food security” are then introduced as examples of how sustainability advocates have both idealized sustainable agriculture as well as actively worked toward localizing food systems and creating more integrated relationships between producers and consumers. The lecture concludes with a discussion of the difficulties and necessity of policy change needed to move toward greater agricultural sustainability.

## MODES OF INSTRUCTION

### > LECTURES (2 LECTURES, 50 MINUTES EACH)

Two lectures cover the historical populist movements that have attempted to resist the industrialization of agriculture in the U.S., and introduce the contemporary sustainable agriculture movements. References given in the outlines are described in the Resources section.

## LEARNING OBJECTIVES

### CONCEPTS

- The current food and agriculture system is not inevitable; many people and social movements have been working for decades to promote social justice and resource protection in this system. These efforts contest the direction the food system has taken.
- The outline of U.S. agrarian populism, its influence on U.S. culture, and its limited contemporary purchase
- The importance of knowledge questions in the search for sustainable alternatives
- The history of policy initiatives trying to promote more socially just and environmentally responsible forms of agriculture in the U.S., and the challenges facing any effort to promote sustainability at the national level
- The usefulness and limitations of applying the term “sustainability” to agrofood systems
- The value, complexity, and limitations of the agroecological paradigm
- The growth of organic food production and the role that U.S. government regulations have played in creating opportunities for organic agriculture that betray the original ideals of the organic farming movement
- The “third way” initiatives in promoting ecologically rational use of agrochemicals in conventional systems
- The different efforts to “localize” the food system and the role they play in promoting sustainability

# Lecture 1 Outline: A Brief History of Resistance to the “Modernization” of Agriculture

## *for the instructor and student*

### **A. The Current Food System Is Not Inevitable and Reflects Dominant Social Values — Alternatives Will Need To Be Rooted in the Expression of Alternative Values (see Thompson 1997)**

1. The food system in the U.S. is an extreme example of industrialized agriculture (see Unit 3.1)
  - a) The scale of modern U.S. agriculture
  - b) The concentration of ownership in modern U.S. agriculture
  - c) The use of high technology and industrial processes in modern agriculture
2. European countries are farther ahead of the U.S. in developing alternatives to industrial agriculture for a variety of reasons
  - a) European Union (EU) is less export dependent. Europe exports more processed foods and the U.S. more raw agricultural commodities. The U.S. uses proportionally more land to export the same value of goods
  - b) European cultures place more value on locally and regionally produced, culturally specific products (i.e., food is more closely tied with specific cultures and traditions)
  - c) Such social values are reflected in agricultural public policies that counter trends in the industrialization of the food system
  - d) The U.S. by contrast has placed more value on convenience and uniformity of foods
  - e) In the U.S., the need for alternatives is not recognized due to a limited understanding of the food system
  - f) The European subsidy policies appear to be more effective in targeting the money to farmers, including small farmers
  - g) Also, various European government policies favor organic agriculture
  - h) Minimal financial assistance for the adoption of conservation farming practices in the U.S.
3. For more than a century critics have protested problematic trends in U.S. agriculture mentioned in previous lectures
  - a) What kind of food system would we have today if their advice had been heeded?
  - b) Imagination is necessary to create alternatives. You cannot create a food system that you cannot imagine.
  - c) Values other than capitalism and profit will need to be injected into discussions and decisions about agriculture and food to achieve any viable alternatives

### **B. Early U.S. Agrarian Populism (see Danbom 1997; McConnell 1959)**

1. Major periods of struggle: 1866–1890; 1920s–1930s
  - a) Common theme of two periods: Efforts to protect small, independent farmers from predatory practices of capitalism
2. First period took place as capital from the Eastern seaboard began to dictate economic choices to homestead small holders in the Upper Midwest
  - a) Issues included transportation, economic concentration
  - b) Agrarian populist movements that grew out of this resistance
    - i. Grange network: Served as local forums for farmers to meet and discuss cooperative action for the common good of local agriculture



- ii. Farmers Alliance: A political effort to promote farmer-owned cooperatives and policies that supported them
  - iii. Populist Party: A political party that ran candidates; it had a vision of agriculture more in line with Jeffersonian democracy, and resisted the political power of railroads and powerful corporations
3. Second period: Agricultural depression foreshadowed national depression
    - a) New Deal responses included: alternative, communal farms; price supports; acreage reduction programs
    - b) Soil Conservation Service (now Natural Resources Conservation Service, NRCS) grew out of this era also
  4. Today: Is agrarian populism possible with the abolishment of subsistence and small-scale farming?
    - a) Solutions must include cooperative action, but with <2% of the population on farms, it must include more than farmers

### C. Resistance to the “Scientization” of U.S. Agriculture (see chapter 2 in Hassanein 1999)

1. Historically, farmers have been the source and guardians of knowledge about agriculture, although this has recently changed
2. The development of the land grant system, experiment station, and agricultural extension system with a technological and production-centered research agenda
  - a) More scientific methods were brought to bear in agriculture, but with them specialized technologies and practices that marginalized farmers. Their “unscientific” knowledge and lack of financial resources left them in an inferior economic and political position.
  - b) Supporters of the land grant system popularized the notion of farmers as stubborn, ignorant, and foolish, “unscientific.” This notion took hold in the popular and political imagination.
  - c) Most agricultural scientists during the middle part of the 20th century saw their work as unquestionably good, advancing the frontiers of modern society. They were by and large blind to the negative impacts of their work.
3. There were three responses by farmers to this development
  - a) Following the program proposed by the land grant complex: Those who had access to land, capital, and technology were able to grow and outcompete their neighbors, often buying them out in the process
  - b) A second group has rejected the entire land-grant/cooperative extension project, creating an alternative knowledge base for agriculture. The organic farming movement is an example of this (see Vos 2000).
  - c) A third approach is that of selectively adopting land-grant/cooperative extension advice, and perhaps working to make this system more responsive to the contemporary needs of growers
4. Criticism of the land grant complex
  - a) What are the worldview assumptions underlying modern agricultural science? Emphasis on technology where existing relationships of political and economic power are not questioned.
    - i. Example: The issue of world hunger is often understood solely as a problem of underproduction and not maldistribution of an already overabundant food supply
  - b) Whose interests has public agricultural science served?
    - i. It has repeatedly served the financial well being of those with the most capital

#### D. Early Organic Movement (see Vos 2000)

1. In England, Lady Eve Balfour and Sir Albert Howard were early leaders; in the U.S., J.I. Rodale along with Rodale Press
2. They were critics of the industrialization of agriculture, arguing that soil health, food quality, and human health were integrally related
3. Their ideas were fused with a more general critique of agriculture and society by the counter-culture movement during the 1960s and 1970s to create the organic farming movement

#### E. *Silent Spring* and Widespread Calls for Change

1. Its thesis: Massive, ignorant, needless poisoning of the biosphere
2. Why was *Silent Spring* so powerful?
  - a) It was an irrefutable critique of the chemical paradigm in agriculture
  - b) It was an effective critique of the entire enterprise of modernization and better living through technology
3. Social and political impacts of *Silent Spring*
  - a) People began to question the role of science and technology in agriculture and created a popular concern about the the environmental and human health risks associated with many modern technologies
  - b) EPA was created, in part to provide a more objective agency for evaluating pesticide impacts
  - c) Increased public funding and support for integrated pest management (IPM)
4. Fixed the problems of modern agriculture in the popular imagination. Created political space for alternatives.

#### F. Critics in the 1970s (see Berry 1977)

1. Jim Hightower and *Hard Tomatoes Hard Times*: Calling for public accountability for public universities and institutions
2. Wendell Berry: A contemporary form of agrarian populism
3. On the margins, a few critics call for land reform in the U.S., especially associated with publicly funded irrigation works, but these arguments never really find much credence in Washington D.C.
4. *A Time to Choose*: The Bergman (President Carter's Secretary of Agriculture) report on problems in American agriculture

#### G. Alternative Agriculture and the Development of the Concept of Sustainability

1. 1989: The National Research Council publishes *Alternative Agriculture*
  - a) This was a surprising critique of the model agricultural paradigm
  - b) The report was controversial for its message and method
2. The Brundtland Commission of the UN begins to popularize the notion of sustainability
  - a) This UN commission laid the foundation for the 1992 Rio conference on sustainable development and brought this term into general use
  - b) As a result, the term "sustainable agriculture" gains popularity
  - c) "Sustainability" is a powerful, yet almost undefinable term



# Lecture 2 Outline: Imagining Alternatives

## A. Problematizing the Concept of Sustainable Agriculture: What Does Agricultural Sustainability Mean? What Does It Look Like? (see Allen and Sachs, 1991; [www.sarep.ucdavis.edu/concept.htm](http://www.sarep.ucdavis.edu/concept.htm))

1. Common conceptions of sustainable agriculture and their limitations
  - a) Exclusively production oriented, agronomic in nature and farm-centric in focus
  - b) The problems are inaccurately framed as only technical problems and thus requiring only technological solutions
  - c) Fails to recognize the influence of social institutions on the soundness of farming practices and the food system
  - d) Fails to equally recognize both the social and environmental problems resulting from the dominant agricultural model
2. Questioning objectives of sustainable agriculture: “What is it that we want to sustain, or change?”
  - a) Whose needs should be emphasized?
  - b) Which of their needs should be prioritized?
    - i. Consumers and cheap food prices?
    - ii. Environmental quality?
    - iii. Fair prices to growers?
    - iv. Low pesticide residues in foods?
    - v. Workers: Wages, working conditions, or year-round employment?
3. Sustained over what time frame?
  - a) Long-term versus short-term planning
4. What scale does this term get used at?
  - a) Field?
  - b) Farm?
  - c) Watershed?
  - d) Region?
  - e) Nation?
  - g) Globe?
  - h) The unit of analysis largely determines what needs to be sustained
5. Comprehensive definitions of agricultural sustainability
  - a) Many advocates for sustainable agriculture recognize the need to integrate at least the following indicators: ecological, economic, and social (see [www.sarep.ucdavis.edu/concept.htm](http://www.sarep.ucdavis.edu/concept.htm))
  - b) Environmental quality
    - i. How do we define “environmental quality”?
  - c) Social equity
    - i. How do we define social justice?
  - d) Human health
    - i. How do we define human health?
  - e) Economic viability of small farmers
    - i. How do we define economic viability of small farmers?
  - f) Life quality of rural agricultural communities
    - i. How do we define life quality of rural agricultural communities?
  - g) What we define as goals in sustainable agriculture will influence the means and outcomes

## B. Agroecology: Altieri and Gliessman (see [www.cnr.berkeley.edu/~agroeco3/](http://www.cnr.berkeley.edu/~agroeco3/))

1. Agroecology defined: Applying the principles of ecology to the design and management of sustainable agricultural ecosystems
2. Altieri defines agroecology as: A scientific discipline that uses ecological theory to study, design, manage, and evaluate agricultural systems that are productive but also resource conserving
3. Strong emphasis on enhancing biological diversity of both the soil ecosystem and terrestrial plant associations in and around agricultural production systems
4. Advantages
  - a) Looks at farms as agroecosystems that are subject to human disturbances
  - b) Encourages returning more autonomy to the farmer through farmer as expert
  - c) Emphasizes understanding, managing, and enhancing ecological processes for soil fertility and pest management in order to reduce reliance on costly and damaging external inputs
5. Problems
  - a) How big is the system? How big an agroecosystem can be measured or managed?
  - b) What happens if the farm is ecologically sustainable, but not commercially viable?

## C. Organic Agriculture

1. Organic agriculture today (see [www.ams.usda.gov/nop/](http://www.ams.usda.gov/nop/))
  - a) Defined: A system of agriculture that encourages healthy soil and crops through such practices as nutrient and organic matter recycling, crop rotations, proper tillage, and the strict avoidance of synthetic fertilizers and pesticides for at least three years prior to organic certification
2. Organic agriculture is currently the fastest-growing sector of the food market
  - a) Compounded annual growth (CAG) of 22.74% over last ten years
  - b) Now ~\$9 billion/year industry world wide
  - c) By 2005, sales are expected to reach nearly \$20 billion
3. The development of the organic movement and the National Organic Standards (see Vos 2000)
  - a) The rationale behind organic certification: To assure consumers that food has been produced in accordance with a specific set of conservation farming practices
  - b) The rationale behind the national organic standards: To make the certification standards for export/import agriculture more uniform
4. Shortcomings of organic production and criticisms of the national organic standards (see Pollan 2001)
  - a) Production practices of most organic growers fall far short of the agroecological and the organic ideal (see Guthman 2000)
    - i. Off-farm inputs: Chilean nitrate, guanos, mined materials
    - ii. Energy use: Organic agriculture does not necessarily use less energy, and may in fact use more
    - iii. Weed control measures: Relies heavily on poorly paid hand labor. Which method is more sustainable?
  - b) Who serves to benefit most from the National Organic Program (NOP): Food processors?
  - c) NOP maintains less stringent standards than previous third-party certifying agencies
  - d) NOP places small growers at an economic disadvantage by requiring practices that require expensive equipment
    - i. Example: Compost production requirements
  - e) The effectiveness of the National Organic Standards Board as an advisory council for USDA remains questionable
5. The “organic industrial complex”: The replication of industrial model of agriculture in organics (see Buck et al. 1997; Howard 2003)
  - a) The organic commodity chain is identical to that of conventional agriculture

#### D. Alternative Agriculture: A Third Way? (see Swezey and Broom 2000)

1. Integrated Pest Management and “agricultural partnerships”: Initiatives to develop management systems for industrial agriculture that do not prohibit the use of agrochemical inputs. Systems are based on agroecological principles and the gathering of appropriate local knowledge of a farming system.
2. Agricultural partnerships are based on a critique of the conventional extension system, which tends to treat growers as passive recipients of knowledge. Influenced by the “farmer-to-farmer” approach to knowledge generation practiced in the developing world.
3. In California these partnerships have reduced the environmental impact of agriculture, and show genuine promise of influencing a large number of growers in some cropping systems
4. Shortcomings of approach: Does not raise questions about the social problems resulting from the current organization of the food and agriculture system

#### E. Re-localizing a Food System (see Allen 2004; Clancy 1997; Kloppenburg et al. 1996)

1. Strategic choices: Sustainability advocates balancing their interest in improving the environmental performance of agriculture with other problems in the food system
2. “Localizing” the food system: Connecting local growers with local eaters
  - a) Promoted as a way to reduce hunger and enhance the economic viability of smaller farms that adopt conservation farming practices
3. Criticisms of the modern food system (see Clancy 1997)
  - a) The modern food system as a “dis-integrated” food system
    - i. Consumers have lost a relationship with the production of their foods
    - ii. Growers have lost contact with the eaters that consume the food they grow
    - iii. There are enormous hidden costs associated with the global food system and cheap food
4. Efforts to promote local food systems through a more agriculturally literate society
  - a) Local food initiatives (see [www.caff.org](http://www.caff.org))
  - b) Supportive institutions that can facilitate grower-eater relationships mediated by values other than cheap food and markets
    - i. Examples: Food policy councils, which help institutions and individuals recognize the advantages of buying local foods, and facilitate interactions with farmers
  - c) Policies in support of a more integrated food system
    - i. Examples: Farm-to-school salad bars, which allow local growers to sell to supportive institutions
5. “The Foodshed” as an organizing principle for local action (see [www.foodshed.wisc.edu](http://www.foodshed.wisc.edu)). Or a “foodbelt”: A greenbelt around an urban area designated for growing foods for local consumption (which is what Europe has done for centuries, simply because it makes sense).
  - a) Questions posed
    - i. Where does our food come from?
    - ii. How is it produced?
    - iii. Does the production of the food I consume enhance or maintain the health of surrounding social and ecological communities?
6. The emergence of the community food security movement (see [www.foodsecurity.org](http://www.foodsecurity.org))
  - a) Fundamental assumptions: That all people have a right to access local, nutritious, culturally appropriate, non-emergency food
  - b) Links anti-hunger efforts with sustainable agriculture, economic development, and social justice advocacy

## F. Policy Initiatives (see Youngberg et al. 1993; Marshall 2000)

1. Large-scale economic reforms that advocates have not been able to figure out how to implement in the U.S.
  - a) Land reform: Making small-scale production possible for those without access to large amounts of capital
  - b) Market reform: Preventing large growers, large manufacturers, and intermediaries from taking advantage of small-scale producers
2. Sustainability at a national scale: Making policies serve this vision.
  - a) Greater enforced restrictions on the domestic and international use of pesticides and synthetic fertilizers
  - b) Ban on the use of GE organisms until long-term studies provide conclusive evidence on environmental quality and human health risks
  - c) Legislation leading to the eventual elimination of all toxic pesticides
  - d) Increased federal funding for research on organic and sustainable soil fertility and pest management practices
  - e) Increased federal funding for research on the development of economically sustainable regional food systems
  - f) Increased funding for regional and local food security initiatives
  - g) Increased funding for extension work in training farmers in alternative production practices
  - h) Increased access to low-interest credit for farmers to use in transitioning from conventional agriculture to certified organic production practices
  - i) Anti-trust legislation discouraging the concentration of ownership in the food system
  - j) Federal small farm subsidies to increase the adoption of conservation farming practices
  - k) Initiate program to assess the true cost of socially just and environmentally sound production practices: “True cost accounting”
    - l) Identify actors within the food system responsible for the externalized costs of production (e.g., pesticide manufactures, farmers)
  - m) Internalize the true costs of production by readjusting price structure of agricultural products to better represent actual costs of production
3. The U.S. Farm Bill
  - a) The influence of the U.S. Farm Bill in shaping U.S. agricultural policy
  - b) Recent conservation farming policies and language in the U.S. Farm Bill
  - c) Critical perspectives on “agricultural sustainability” in the U.S. Farm Bill
4. Obstacles to these initiatives
  - a) Political forces are deeply invested in the current agricultural model
  - b) The cheap food dilemma
5. Local policies and initiatives: Sometimes local groups can effect small-scale change. Advocates still need to engage national policy, but there are some opportunities at the local level.
  - a) Land use policy: Designating food belts
  - b) Directing public institutions to buy from small or local sources

## **G. Summary and Conclusion: How Do We Promote Sustainability in the Agriculture and Food System?**

1. To be effective, any effort has to understand the complexities of agriculture: It is framed by economic, social, and biological processes. All three need to be taken into account.
2. Effective social change generally includes oppositional and alternative efforts: Evolving reforms and promoting a revolutionary vision at the same time
3. Modern agriculture has been shaped directly by the advance of capitalist social relations and the application of science and technology to production practices. Behind these forces are a whole range of social forces. Policy reform is important, but ultimately, addressing these broader forces must be part of efforts to promote a more sustainable agriculture and food system.





# Resources

## SUGGESTED READINGS FOR STUDENTS (DESCRIBED BELOW)

- Allen, Patricia. 2004.
- Clancy, Kate. 1997.
- Danbom, David. 1997.
- Kloppenburg et al. 1996.
- Pollan, Michael. 2001.

## PRINT RESOURCES

Allen, Patricia. 2004. *Together at the Table: Sustainability and Sustenance in the American Agri-food System*. University Park: Pennsylvania State University Press.

*Examines the growth and development of alternative food system initiatives in the U.S., including: The growth of organic farming and the development of the USDA National Organic Program; the growth in popularity of direct marketing relationships such as farmers' markets and community-supported agriculture (CSA); the growth of urban agriculture and community garden programs; the increase in natural and social science research programs focused on sustainable food and farming systems.*

Allen, Patricia. 1993. *Food for the Future: Conditions and Contradictions of Sustainability*. New York: Wiley and Sons.

*Challenged definitions of sustainable agriculture that did not incorporate social issues, such as justice, gender, ethnicity, or class. If advocates do not heighten their awareness of the social forces pressing on conventional agriculture, they run the risk of reproducing the same social problems in alternative agriculture. This book had a significant impact on academic thinking in the sustainable agriculture movement. The chapter by Allen and Sachs is particularly important and influential.*

Allen, Patricia, and Carolyn Sachs. 1991. *What Do We Want to Sustain? Developing a Comprehensive Vision of Sustainable Agriculture*. Sustainability in the Balance, Issue Paper No. 2. Santa Cruz, CA: Center for Agroecology & Sustainable Food Systems, UC Santa Cruz. Available at [www.ucsc.edu/casfs](http://www.ucsc.edu/casfs), or from CASFS.

*A critique of definitions of sustainable agriculture that are limited only to what happens on the farm. Challenges its readers to reformulate definitions of sustainable agriculture to include gender, race, class, and issues in society at large. More appropriate for lower-division students than Allen 1993 (see above).*

Allen, Patricia, and Martin Kovach. 2000. The capitalist composition of organic: The potential of markets in fulfilling the promise of organic agriculture. *Agriculture and Human Values* 17:221-232.

*Explores the problems and possibilities associated with the increasing demand for organic agriculture.*

Berry, Wendell. 1977. *The Unsettling of America: Culture & Agriculture*. San Francisco: Sierra Club Books.

*A classic in contemporary agrarian philosophy written in an accessible style. Berry critiques the dominant industrial agriculture paradigm with his common sense prose, exposing the social, economic and ecological damage it caused. For this course, chapters 3, 4, and 9 are most appropriate. "The Ecological Crisis as a Crisis of Agriculture" describes the way conservationists and capitalists both objectify land and split it off from human culture. "The Agricultural Crisis as a Crisis of Culture" describes the social implications of a culture's alienation from the soil. "Margins" relates several stories of farmers who are intentionally creating alternatives.*

Bosso, Christopher J. 1987. *Pesticides and Politics: The Life Cycle of a Public Issue*. Pittsburgh: University of Pittsburgh. Chapter 2, The Pesticides Paradigm, pages 21-45, and chapter 4, The Apotheosis of Pesticides, 61-79.

*This book describes the enduring impact Silent Spring had on U.S. agriculture and pesticide policy.*

Buck, Daniel, Christina Getz, and Julie Guthman. 1997. From farm to table: The organic vegetable commodity chain of northern California. *Sociologia Ruralis* 37 (1):3-20.

*Describes the role that organic certification has had in shaping organic agricultural production and how the distribution of this produce has begun to mimic that of the conventional food system. Places these developments in the broader framework of agrarian political economy.*

Carson, Rachel. 1962. *Silent Spring*. New York: Houghton Mifflin Co.

*This book probably did more to instigate the environmental movement of the 1960s than any other. Unintentionally, it appears to have contributed to the alienation of the U.S. public from agricultural issues. Chapters 1 and 2 provide an overview of the chemical agriculture mindset, and chapters 3 and 4 introduce toxic agrochemicals and their environmental impacts. Chapter 17 describes alternative trajectories for human-environment relationships.*

Clancy, Kate. 1997. Reconnecting farmers and citizens in the food system. In *Visions of American Agriculture*, W. Lockeretz, ed. Ames: Iowa State University Press.

*Discusses the major factors that have weakened the links between farmers and the rest of the U.S. population. Clancy then provides criteria that must be met for a more integrated food system, including a more agriculturally literate society, local food security, and supportive institutions and policies. An ideal chapter for a beginning discussion of what needs to happen off the farm to promote social sustainability.*

Danbom, David. 1997. Past visions of American agriculture. In *Visions of American Agriculture*, W. Lockeretz, ed. Ames, Iowa: Iowa State University Press.

*Introduces the history of conflicting views of U.S. agriculture: Agriculture as enterprise vs. agriculture as social enterprise. Provides a helpful introduction to the history of American agrarian populism.*

Guthman, Julie. 2000. Raising organic: Grower practices in California. *Agriculture and Human Values* 17:257-266.

*This article is based on Julie Guthman's field work investigating the actual practices of organic growers in California. She discovered that organic farms usually comply with organic regulations, but still fall short of the agroecological ideal, with larger farms and mixed organic/conventional farms least likely to fulfill this ideal. Describes the way in which organic certification has helped the organic farming sector grow and become more like conventional agriculture.*

Hassanein, Neva. 1999. *Changing the Way America Farms: Knowledge and Community in the Sustainable Agriculture Movement*. Lincoln, Nebraska: University of Nebraska Press.

*Describes the emergence of alternative networks of agricultural knowledge among dairy farmers in Wisconsin, with a special emphasis on issues of gender. Chapter 2, "Knowledge questions in the sustainable agriculture movement," provides an excellent overview of how farmers resisted the hegemony of Land Grant University scientists.*

Howard, Sir Albert. 1947. *The Soil and Health*. New York: Schocken Books.

*This is an early classic in the organic movement, presenting many of the underlying ecological and philosophical principles still relevant today.*

Howard, Phil. 2003. Consolidation in food and agriculture: implications for farmers and consumers. CCOF Magazine Winter 2003/04, Volume XXI, Number 4. Available online: [www.ccof.org/magazine.php](http://www.ccof.org/magazine.php)

*Provides a concise qualitative and quantitative description of the concentration of ownership in the U.S. agri-food system and how these consolidation trends are being replicated in the organic food industry*

Kloppenborg, Jack, John Hendrickson, and George W. Stevenson. 1996. Coming into the foodshed. *Agriculture and Human Values* 13 (3):33-42.

*Explores the conceptual and practical opportunities of organizing agricultural production around “foodsheds.” Just as bioregionalists propose watersheds as an organizing framework for activism, so agricultural activists are working for local economies of food. Students often respond with enthusiasm to the imaginary this article proposes.*

Marshall, Andrew. 2000. Sustaining sustainable agriculture: The rise and fall of the Fund for Rural America. *Agriculture and Human Values* 17:267-277.

*Marshall details the challenges facing any policy initiative in support of sustainable alternatives, and the political and economic obstacles such an initiative must overcome. Helpful complement to Youngberg et al.*

National Research Council. 1989. *Alternative Agriculture*. Washington, DC: National Academy Press.

*The highest-ranking report up to that time to legitimize alternatives to the high-input, high-chemical-use model.*

Pollan, Michael. 2001. Behind the Organic-Industrial Complex. *New York Times Magazine* May 13. [www.nytimes.com/2001/05/13/magazine/13ORGANIC.html](http://www.nytimes.com/2001/05/13/magazine/13ORGANIC.html)

*This investigative journalism piece reached a wide audience, and brought the disturbing news that the organic ideal in the minds of many alternative consumers is very far from the reality of the contemporary organic food processing and distribution system. Useful to read side by side with the Kloppenborg et al. article.*

Rosset, Peter A., and Miguel A. Altieri. 1997. Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. *Society and Natural Resources* 10 (3):283-295.

*Critiques efforts to make conventional agriculture more sustainable, claiming that only a fully integrated agroecological farming system is truly sustainable.*

Swezey, Sean L., and Janet C. Broome. 2000. Growth predicted in biologically integrated and organic farming. *California Agriculture* 54 (4):26-36.

*Describes the growing interest in promoting biologically integrated farming systems in California, a “third way” farming system that draws from knowledge gained by organic systems, reducing yet not fully abandoning agrochemical usage. A provocative companion to Rosset and Altieri.*

Thompson, Paul B. 1997. *Agrarian values: Their future place in U.S. agriculture*. In *Visions of American Agriculture*, W. Lockeretz, ed. Ames, Iowa: Iowa State University Press.

*Thompson develops the two main currents in U.S. agriculture proposed by Danbom (see above), describing the values and ethics inherent in each, and how activists might secure a future for more communitarian ethics in the future of U.S. agriculture.*

Vos, Timothy. 2000. Visions of the middle landscape: Organic farming and the politics of nature. *Agriculture and Human Values* 17:245-256.

Youngberg, Garth, Neill Schaller, and Kathleen Merrigan. 1993. The sustainable agriculture policy agenda in the United States: Politics and prospects. In *Food for the Future*, P. Allen, ed. New York: John Wiley.

*Reviews the impact and implications of sustainability for agricultural policy making. Describes the difficulty of translating the values and visions of sustainable agriculture into concrete policy, and the tendency for political leaders to adopt the discourse of sustainability yet little more. A useful roadmap for charting a course towards improved policy efforts.*

## WEB RESOURCES

### Agroecology in Action

[www.agroeco.org/](http://www.agroeco.org/)

*Miguel Altieri's website has several useful summary essays about agroecology and agroecological principles. The section titled "Agroecology and Modern Agriculture" has the essays most relevant to this chapter.*

### California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

[www.ccagcans.com/cansdefault.html](http://www.ccagcans.com/cansdefault.html)  
(see "Course Curriculum")

*The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.*

### California Sustainable Agriculture Working Group

[www.calsawg.org](http://www.calsawg.org)

*This is a coalition of California organizations working for sustainable agriculture in this state.*

### Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems (CASFS)

[zzyx.ucsc.edu/casfs/instruction/esa/index.html](http://zzyx.ucsc.edu/casfs/instruction/esa/index.html)

*This sustainable agriculture education resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.*

### National Campaign for Sustainable Agriculture

[www.sustainableagriculture.net/index.htm](http://www.sustainableagriculture.net/index.htm)

*The National Campaign for Sustainable Agriculture is an umbrella organization for many local groups working for more sustainable agricultural policies in the U.S.*

### SAREP: What is Sustainable Agriculture?

[www.sarep.ucdavis.edu/concept.htm#Top](http://www.sarep.ucdavis.edu/concept.htm#Top)

*Provides a nice overview of the key themes in sustainable agriculture, especially as they relate to California. Presents information on natural resources, production practices, and the social and economic context of sustainability issues.*

### SAREP: Biologically Integrated Farming Systems

[www.sarep.ucdavis.edu/bifs/](http://www.sarep.ucdavis.edu/bifs/)

*A portion of the SAREP web page that introduces one form of agricultural partnerships, Biologically Integrated Farming Systems, and provides additional information on them.*

### Union of Concerned Scientists

[www.ucsusa.org/agriculture/index.html](http://www.ucsusa.org/agriculture/index.html)

*The Union of Concerned Scientists runs a "Food and Environment" Campaign, whose goal is: To create a food system that encourages innovative and environmentally sustainable ways to produce high-quality, safe and affordable food, while ensuring that citizens have a voice in how their food is grown.*

## VIDEOS

Goodbye Mrs. Ant. 1992. A BBC-TV production in association with Lionheart Television International, Inc. Northbrook, IL: Coronet Film & Video (58 minutes).

*An overview of the ecological impact of agricultural chemicals on the environment, and the Silent Spring-inspired efforts to regulate them. A good review of the popularity of DDT and the scientific enterprise that supported it.*

My Father's Garden. 1995. Miranda Productions Inc.; producer, Abigail Wright; director, Miranda Smith; writer, Nathaniel Kahn (58 minutes).

*Weaves together the personal stories of the loss of family farms, the role of chemical pesticides in changing the structure of American agriculture, and Fred Kirschmann's efforts to make his farm ecologically and economically sustainable. Available from:*

[www.bullfrogfilms.com](http://www.bullfrogfilms.com)

The Living Land. 1998. Foundation for Global Community (27 minutes).

*A thoughtful set of interviews with John Jeavons, Wes Jackson, Alice Waters, and Mas Masumoto on the values and practices of alternative agriculture. Available from:*

[www.globalcommunity.org/cgvideo/land.htm](http://www.globalcommunity.org/cgvideo/land.htm)

