1.10

Managing Weeds

Introduction: Managing Weeds

UNIT OVERVIEW

Managing weeds with organically acceptable techniques is one of the biggest challenges and potentially highest labor inputs 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; garden-scale considerations are also discussed. Demonstrations address both mechanical and hand-weeding techniques and tools used in a garden or small farm setting, as well as weed identification skills. The supplement provides more detailed information on weed control options for small-scale, mixed vegetable organic operations.

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, POWERPOINT

See *casfs.ucsc.edu/about/publications*, and click on Teaching Organic Farming & Gardening.

LEARNING OBJECTIVES

CONCEPTS

- The biology of weeds
- The need for managing weeds in cropping systems

SKILLS

- How to identify weeds
- How to design a cropping rotation specifically for weed management
- How to plant, cultivate, and irrigate crops to reduce weed pressure
- How to assess a cropping system for potential weed problems

Lecture 1: Weed Biology

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?

A. 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

B. 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

C. 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 Gurshuny)
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

D. 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) Brushes
      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: Cultural Weed Management Practices

Pre-Assessment Questions

1. What steps can be taken to minimize weed seed dispersal?
2. How can crop rotations be used to minimize weed pressure?
3. What tools do growers use to mechanically control weeds?

A. Weed Prevention Strategies (see also Supplement 1, Strategies for Improved Weed Management on Small-Scale, Diverse Farms)

1. Improve soil tilth, aeration, water infiltration, and fertility to optimize crop growth and minimize weed pressure. Healthy 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 131ºF+ 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

B. 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. Quickly smothers weeds 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. (See Unit 1.6, Selecting and Using Cover Crops.)

C. 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.
3. Avoid tilling perennial weeds such as Johnson and Bermuda grass
   a) Cutting and burying perennial weeds such as Johnson and Bermuda grass with a disc or rototiller will exacerbate a weed problem by facilitating the propagation and spread of their rhizomes

D. 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 (see Supplement 1 and Appendix 3, Planting to Moisture). Planting such large-seeded crops to moisture and allowing the crop to become established prior to any irrigation prevents germination of weedy competitors and provides a shade canopy to further inhibit weed growth.
2. Though soil and climate dependent, many of the crops listed above can grow to near maturity without irrigation, if not completely dry-farmed (see Supplement 4, Overview of Dry Farming in Unit 1.5, Irrigation—Principles and Practices)
3. 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. At a garden scale, planting in straight lines allows for ease and efficiency of hoeing.
4. 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.
5. 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.
6. Keep weed cultivations (either tractor mounted or hand held) shallow. This will avoid bringing up new weed seeds from lower soil horizons.
7. Pay close attention to soil moisture, tilth, and weed growth to optimize timing of cultivation. Both in the field and in garden settings, cultivating weeds at the right soil moisture (~50%–60% 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.
8. "Dirting": 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 "dirting" technique will effectively smother newly germinated weeds within the plant row.

E. Irrigation Techniques to Minimize Weed Pressure (see also Unit 1.5)

1. Pre-irrigate beds and lightly cultivate (either mechanically in the field or by hand in the garden) prior to planting to destroy newly germinated weeds (see Appendix 4, Pre-Irrigation to Minimize Weed Pressure). 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.

F. Fallow Period for Perennial Weed Control

1. Fallow period defined
   a) A period of time (generally a portion of a growing season up to three growing seasons) that ground is not in crop production, but rather left bare and cultivated for weed control, or left to sit in cover crop to control weeds and improve soil health. Fallow periods are often integrated into crop rotation and crop planning strategies. E.g., in the Northeast, farmers often take fields out of production for 1–2 years, and leave them fallow in a perennial cover crop such as clover, then bring them back into crop production in year 3.
2. 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 to desiccate and/or freeze

G. Flame Weeding Techniques and Strategies

1. Flame weeding defined
   a) Flame weeding involves direct application of a flame to newly emergent weeds. "Flaming" kills the weed by heating the water in the cells and bursting the cell walls. The technique dates back to the 1930s (prior to the advent of conventional herbicides), when row crop growers used kerosene as a fuel source. Today, flame weeding is done with propane. Flame weeders range from hand-held wands and human-powered push carts that span a garden bed for garden-scale applications, to multi-row, tractor-mounted units used in row crop fields.
2. How to flame weed
   a) 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
   b) 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. Results of flame weeding
   a) Flame weeding can provide effective control of newly emergent broadleaf weeds

4. Limitations of flame weeding
    a) Flame weeders are only effective on very small, newly germinated broadleaf weeds with no surface moisture (dew) on leaves
    b) On heavier soils, timing of re-entry with a tractor-mounted flame weeder can be challenging, as weed emergence is directly related to soil moisture. Using a flamer when the weeds are just emerging but the soil is too wet can result in significant soil compaction from tractor and implement wheels.
    c) Flame weeding should not be done during extremely dry, windy conditions due to fire danger
    d) At $3,500–$5,000, tractor-mounted flame weeders are a significant investment

H. Soil Solarization

1. Soil solarization defined
    a) Soil solarization is the process of covering the soil with a plastic tarp during the hottest time of the year. The top 12–18 inches of soil heat up enough to kill many types of weed seeds and seedlings, along with some pests and disease-causing organisms.
2. 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 solarizaton
    a) Solarization controls many annual weeds, and is especially effective in controlling winter annuals
3. Limitations of 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
    d) Soil solarization requires the use of petroleum-based plastic tarps that cannot be reused and are challenging to recycle

I. Weed-Suppressive Mulches

1. Weed-suppressive mulches defined
    a) Mulching involves covering the soil with organic or synthetic materials to keep weed seeds from germinating by blocking light and preventing seed-soil contact
2. Types of mulches
    a) Dark plastic mulches can be used as a weed-suppressive mulch in many cropping systems
        i. Example: Strawberries
    b) Organic mulches such as straw, woodchips, sawdust, or cardboard
        i. Examples: Tomatoes are often mulched with straw. Fruit trees are often mulched with woodchips. Cardboard covered by a layer of woodchips can suppress weeds, particularly in perennial plantings.

c) Living mulches: Intercropping with a cover crop in main season crop can prevent erosion and limit weed growth. Living mulches are important in low- and no-till systems to suppress weed growth during the cropping season (see Unit 1.2, Garden and Field Tillage and Cultivation).

3. Results of weed suppressive mulches
   a) Effectively inhibit growth of most weeds if applied as a thick layer (3" or more if using organic materials)
   b) Keeps soil cool
   c) Minimizes water loss
4. Limitations of weed suppressive mulches
   a) Potential problems with fungal diseases, especially if applied too close to stems or tree trunks
   b) May harbor snails, slugs, and other pests
   c) Labor intensive to apply
   d) Purchasing mulch increases input costs

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 & 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. Environmental Factors Conducive to Weeding

1. Briefly review weed prevention strategies and environmental factors conducive to weeding (see Lecture 2, Cultural Weed Management Practices)
   a) Soil moisture at 50% field capacity
   b) Sunny and windy conditions are ideal

B. Tools and Techniques for Hand Weeding at the Garden and Small-Farm Scale

1. 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
2. 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
      i. Discuss safety and ergonomics
   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. Glaser Colinear hoe
      iv. Hand tools, such as tined cultivators, hand hoes, and knives
3. 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.). 2001. *Steel in the Field: A Farmer's Guide to Weed Management Tools*. Handbook Series Book 2. Burlington, VT: Sustainable Agriculture Network. *www.sare.org/Learning-Center/Books/Steel-in-the-Field*

Includes drawings and explanations of numerous tractor implements used for mechanical weed management in sustainable cropping systems. Grower narratives give information on specific applications.

Ditomaso, Joseph M. 2007. *Weeds of California and Other Western States*. Publication 3488. Oakland, CA: University of California Division of Agriculture and Natural Resources

This encyclopedic yet easy-to-use 2-volume set covers 262 individual entries, including a full description of 451 spe-cies and another 361 plants compared as similar species, representing 63 plant families. Includes color photos of seeds, seedlings, flowers and mature plants.

Finney, Denise M., and Nancy G. Creamer. 2008. *Weed Management on Organic Farms. Special Topic: Cultivation Practices for Organic Crops*. Center for Environmental Farming Systems. North Carolina Cooperative Extension Service. *www.cefs.ncsu.edu/resources/organicproductionguide/weedmgm-tjan808accessible.pdf*

Excellent 28-page publication on weed control strategies for organic farms based on weed characteristics and an integrated cropping strategy. Details various weed prevention strategies, addresses cultivation practices, includes photos of cultivation implements, and discusses options such as weed geese and organically approved herbicides.

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 311 California weed species.

Gershuny, Grace. 1997. *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, flamers, soil sterilization, mulches, beneficial organisms, and chemical control of weeds.

Sullivan, Preston. 2003. *Principles of Sustainable Weed Management for Croplands*. National Center for Appropriate Technology (NCAT).

15-page publication discusses several alternatives to conventional tillage systems, including allelopathy, intercropping, crop rotations, and a weed-free cropping design.

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-BASED RESOURCES

California Weed Science Society (CWSS)

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.

eXtension. Bring Existing Weeds Under Control Before Planting Weed Sensitivie Crops.

www.extension.org/pages/18549/bring-existing-weeds-under-control-before-planting-weed-sensitive-crops#.VGE5DPTF9dE

eXtension. Design the Cropping System and Select Tools for Effective Weed Control

www.extension.org/pages/18531/design-the-cropping-system-and-select-tools-for-effective-weed-control

Webinar presentations by Mark Schonbeck of the Virginia Association for Biological Farming

eXtension. Weed Identification Tools and Techniques

www.extension.org/pages/32635/weed-identification-tools-and-techniques#.VMgQWGTF_v5

Online guide offers tools and techniques for identifying weed species. Includes a basic illustrated glossary of plant identification terms.

UC Cooperative Extension, Ventura County: An Alternative Weed Control – Mulching

ceventura.ucanr.edu/Com_Ag/Subtropical/Citrus/Weeds/An_Alternative_Weed_Control_-_Mulching_/

UC Cooperative Extension specialist Nick Sakovich describes the advantages of organic mulches in orchard systems.

UC Integrated Pest Management Program

www.ipm.ucdavis.edu

Contains extensive information on IPM, including weed identification and management.

University of Vermont Extension

www.uvm.edu/vtvegandberry/factsheets/orgweedconrtol.html

The fact sheet Ten Steps Toward Organic Weed Control provides a concise, practical ten-step approach to controlling weeds in diverse organic vegetable systems, based on small- and medium-scale Vermont growers' experiences.

Western Society of Weed Science (WSWS)

www.wsweedscience.org

WSWS works to promote weed science research and education; site includes job announcements, upcoming meetings, and links to additional weed management information.

SUPPLEMENT 1

Strategies for Improved Weed Management on Small-Scale, Diverse Farms

Good weed management is critical to the financial success of small-scale diverse organic farms. In most cases, labor costs associated with hand weeding vegetable crops can be avoided or minimized by following a set of production practices outlined below. These practices are designed to both control weeds in the short term and diminish weed pressure over time by reducing the weed seedbank.

Avoiding Weed Seed Set

The most effective way to minimize weed pressure is to never let a weed set seed in the production system, where it will add to the weed seedbank and compete directly with your crops once conditions are right for germination. For this reason it is critical to reduce the seedbank as much as possible, both prior to planting out your crops in order to start the season with a "clean slate," as well as following harvest. This can be especially challenging for small-scale producers in highly diverse cropping systems—particularly growers with limited access to effective tractor-mounted implements for tillage, bed forming, planting, and follow-up cultivation.

Commonly, a few "escaped" weeds that have grown along side your crop will continue to mature and set seeds after the crop has been harvested and prior to crop mow-down and tillage. In diverse systems this is particularly problematic because crops of various maturation windows are often sown in blocks, making it difficult to get in and till two lines of a quick-maturing crop that is directly adjacent to a crop with a longer maturation rate. For this reason it is essential to plan production blocks that are as uniformly matched, in terms of maturation, as possible.

If different maturation times within a block are unavoidable, then it is especially important to use set row configurations that match your implement selection to allow for post-harvest mowing and tilling of specific crop rows within a production block in order to minimize weed set following harvest. Tools that facilitate knock-down of specific rows within a block include the flail mower, the under-cutter, and either a bed recycling disc or a rototiller. All of these tools need to be closely matched to your bed configuration to minimize damage to adjacent crops and to effectively destroy escaped weeds.

Cover Cropping and Smother Cropping

A much-overlooked practice that can effectively limit weed seed production is the timely and careful preparation of cover crop seedbeds and the use of fast-growing cover crops planted at higher than normal seeding rates. These dense stands of cover crops (often referred to as "smother crops") can effectively outcompete weeds for light, water, and nutrients. Examples of highly competitive cover crops include cereal rye, mustard, and Sudan grass. Sudan grass is not cold tolerant and requires high temperatures for good growth, so it may not be suitable for cooler climates even during summer months.

Timing in terms of soil preparation, soil temperature, and soil moisture is critical when planting fall cover crops (see Unit 1.6, Supplement 2, Cover Crop Selection, Planting Tips, Tools and Techniques for additional details). Timing is especially important on farms with heavier soils in areas that receive high winter rainfall. Good soil preparation prior to planting cover crops is needed to provide adequate infiltration and deep percolation of winter rains.

Early rains can set back cover crop planting times; on the positive side they often provide the benefit of germinating the first flush of weeds. If timing is good the cover crop can be planted into well-prepared soil following the first significant rainfall event. The challenge, especially on heavier ground, is finding the right window to get back on the ground, till out the germinated weeds, and plant the cover crops without risking compaction issues related to tractor traffic.

The other challenge associated with fall planting is that as the soil starts to cool down in the fall the winter weeds have a distinct germination advantage compared to the cover crop seed. Generally speaking, the later the cover crop is planted the higher the potential for weed problems. The optimal time to plant

fall cover crops here on the Central Coast is in the last two weeks of October. Although it can be difficult for small, diversified growers to make time to plant cover crops while also dealing with the demands of irrigation, harvest and sales, good weed management related to fall cover cropping will save time overall.

Note that a less-than-optimal stand of winter cover crop can allow for extensive weed growth and subsequent weed seed production. These weed seeds can persist in the seed bank for years, adding significantly to weed management costs over time.

Legume-cereal cover crops are often popular cover crops with small scale diverse organic farms, but can also exacerbate weed management if they are planted at standard seeding rate (i.e., 125 lb/acre) that allow weed seed production. Typical legume-cereal mixes should be planted at two times or higher seeding rates to suppress weeds effectively. However, planting these mixtures at higher rates that will suppress weeds can significantly increase the cost of cover cropping. See *www.youtube.com/watch?v=WREmHajFbc* for additional information.

Crop Rotation

Crop rotation can be an effective tool for minimizing weed pressure on small-scale farms. There are numerous examples of effective crop rotations and the concepts involved in the design of a good rotation are fairly straightforward. If you are familiar with the weed issues in specific areas of your farm you can simply avoid planting crops that are "weed challenged" in areas that have higher weed pressure. In other words don't plant carrots on the same block in which the "escaped" amaranth set seed last season. Instead, plant corn and potatoes in that block or plant a highly competitive "smother" crop (see above).

Fallowing

Fallow periods are absolutely critical for the eradication of problem perennial weeds in organic systems. The best example is either summer or winter fallow to control Bermuda grass and/or Johnson grass. Both of these perennial grasses have shallow rhizomes that can be easily controlled through desiccation from exposure to summer sun or freezing temperatures.

Note that discing and/or rototilling to try and control Bermuda or Johnson grass are strongly discouraged. Cutting and burying the weeds will simply facilitate the propagation and spread of their rhizomes.

Though difficult to eradicate entirely, morning glory, oxalis, and nutsedge plants can be effectively reduced in vigor over time through fallow periods in conjunction with tillage and/or undercutting to continually reduce the plants' photosynthetic capability. This will eventually drain the plants' rooting structure of the carbohydrate reserve it needs to propagate and grow. Eradication of these weeds can take many years of persistent fallow management coupled with the intensive use of smother crops.

Irrigation Frequency and Duration

Irrigation techniques can have an impact on weed growth and development. In general, weed seeds germinate more readily when surface soil is kept closer to field capacity; thus frequent, shallow overhead irrigations often results in higher weed seed germination. Watering less often and deeper can reduce weed seed germination. For the same reason, good uniformity of application is critical for good weed management.

Pre-Irrigation

Numerous field trials have demonstrated the efficacy of pre-irrigation as a way to reduce the weed seed bank in organic farming. A draw back to pre-irrigation is that it creates additional costs related to water use, labor, and land out of production. In heavier soils pre-irrigation is sometimes impractical due to the potentially slow dry down time.

It can also be difficult to apply enough water during pre-irrigation to effectively germinate the majority of the weed seeds within the seedbed. Often weed seeds will germinate more readily in soil moisture conditions at or near field capacity.

If a grower can form beds and apply adequate irrigation water for good seed bank germination, there are two common ways to manage weeds after they emerge: flaming, and very shallow cultivation, preferably with an under cutter followed by a crust breaker. It is critical to destroy the weeds when they are newly emerged, and they need to desiccate adequately for good kill prior to planting the cash crop.

Minimizing soil disturbance is also important when attempting to mechanically destroy newly emerged weed seed; the more the soil is disturbed, the higher the risk of bringing new weed seed up from lower in the soil into a position favorable for germination.

Pre-irrigation to "flush" weeds prior to planting crops is usually done in the springtime heading into summer production or in late summer heading into fall production. The challenge with this timing is that soil temperatures are difficult to predict: spring soil temperatures can remain low enough during pre-irrigation that the summer annual weeds aren't stimulated to germinate; similarly, in the late summer the soil temperatures are still too high to germinate the fall annual weeds.

Drip Irrigation

Drip irrigation can be a tremendous aid in minimizing weed pressure, as the surface wetting from the drip emitters is limited to a small percentage of the overall soil surface. Where there is no surface wetting there is little opportunity for weed seed germination and growth. Use of drip irrigation is particularly effective in areas with limited summer rainfall.

Drip irrigation can also be used for pre-irrigation, but there are significant labor costs associated with laying out and retrieving the drip lines. However, in intensive small-scale mechanized production systems with limited water resources, pre-irrigation with drip is an effective weed management tool. Soil compaction is minimized, and it is easier to get a more thorough weed flush since the grower can easily maintain field capacity to optimize weed seed germination within the area to be planted without sacrificing the ability get back into the field for crop planting.

Planting to Moisture (see Appendix 3)

This often-overlooked planting technique is an effective way to minimize weed competition when planting large-seeded crops such as corn, beans, squash, and some cover crops, especially in California's Mediterranean climate. Here is a suggested sequence for planting to moisture:

1. Form beds
2. Pre-irrigate
3. Wait for weed flush and re-work beds with rolling cultivator
4. Knock dry soil off bed tops and precision plant large seeds into residual moisture
5. Lay drip line in seed line after crop emergence
6. Wait as long as possible for crops to establish prior to first irrigation
7. Cover drip line with rolling cultivator prior to first irrigation and before crop is too tall to cultivate

Planting large-seeded crops to moisture also minimizes the risk of soil borne pathogens (damping off complex) that can affect their development. Damping off is more likely to occur when seeds are "irrigated up" with either overhead irrigation or drip irrigation.

In addition, planting to moisture eliminates surface crusting caused by soil surface wetting. When the moisture is right the crops respond favorably and the weeds don't have enough moisture to germinate, leaving the production block effectively weed free.

Flame Weeding

Although not commonly practiced on large-scale organic farms, flame weeding ("flaming") can be an effective and economical way to manage weeds on small, diverse farms and in large market gardens. When done correctly, flame weeding is fast, efficient and inexpensive relative to the cost of hand weeding.

Flame weeding provides just enough heat uniformly across the bed top to quickly heat and expand the moisture in the cell walls of the just-emerged dicot weeds, killing the dicot seedlings. Using a backpack flamer, a small grower can knock out the weeds that have germinated just prior to crop emergence, and easily diminish weed pressure in carrots and garlic crops, which often emerge after weeds have germinated.

Note that because the growing point of grasses is below the soil surface, flame weeding is not considered effective for control of grass weeds.

Transplanting (see Unit 1.4, Transplanting and Direct Seeding)

The use of transplants in a farming system has major benefits in terms of weed management. Direct seeding of small-seeded crops can be extremely challenging when weed pressure is high due to the high rate of competition and the difficulty and precision required to remove the competing weeds. Using transplants gives the grower a jump on the weeds and will often be the difference between a crop's success and failure.

Blind Cultivation

Blind cultivation refers to the use of shallow soil disturbance (cultivation) just prior to or right after the emergence of large-seeded crops (e.g., corn, squash) or cover crops. This disturbance is often ad-

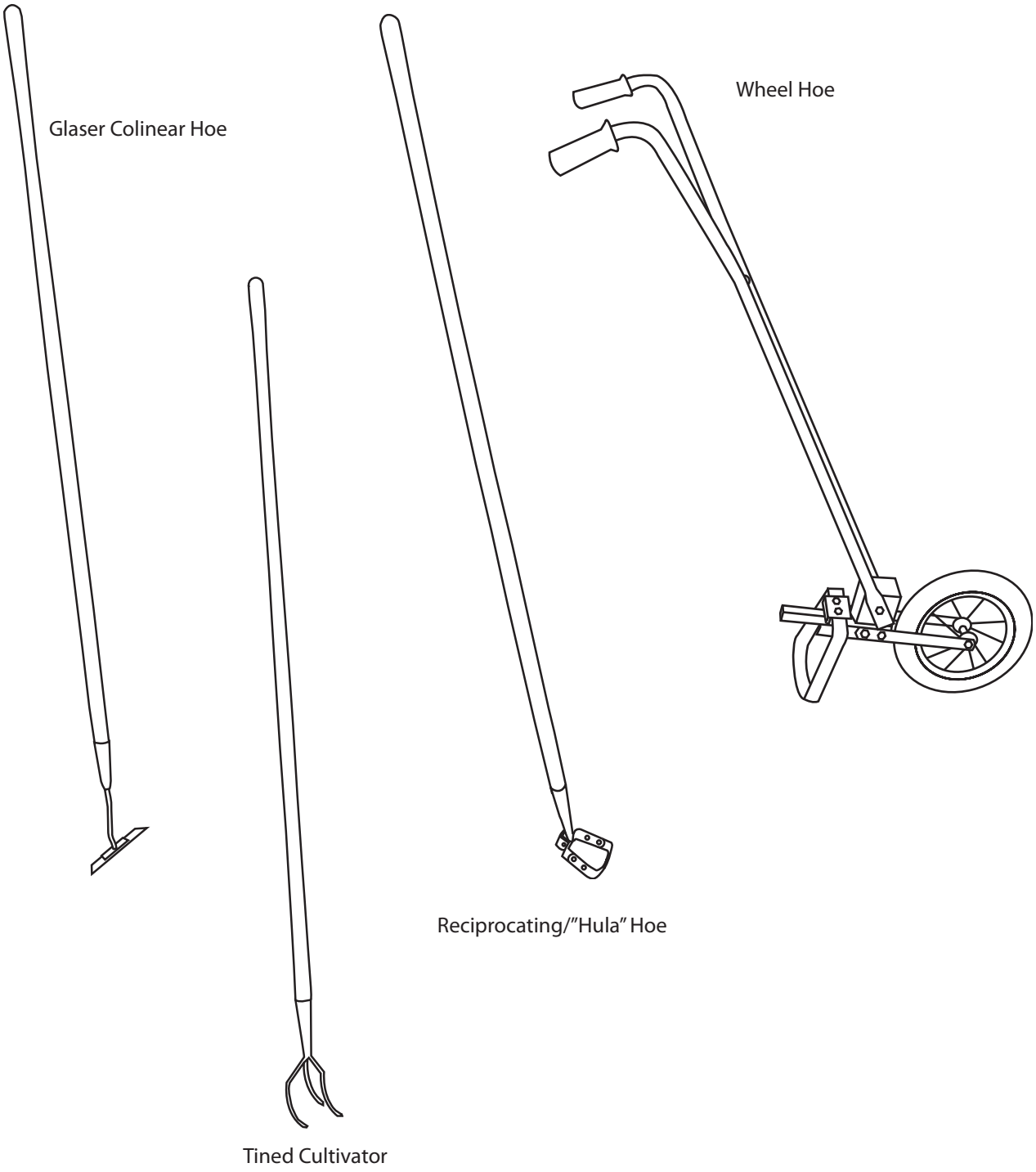
equate to kill newly germinated weeds while leaving the larger-seeded crops relatively undisturbed. The larger-seeded crops can more readily recover from the disturbance because they are planted deeper and/or have stronger stems and roots.

Tine weeders, including "finger weeders," and rotary hoes are used for this method of weed control. Timing in terms of the growth stage of the crop and weeds is critical, often coming down to a narrow "window" of hours; soil conditions must be perfect, with minimal crusting or "cloddy-ness." Some soils are simply not conducive to this practice. The main objective of blind tillage is to get the weeds in the "white thread" stage, just before they emerge from the soil.

Stale Seedbeds

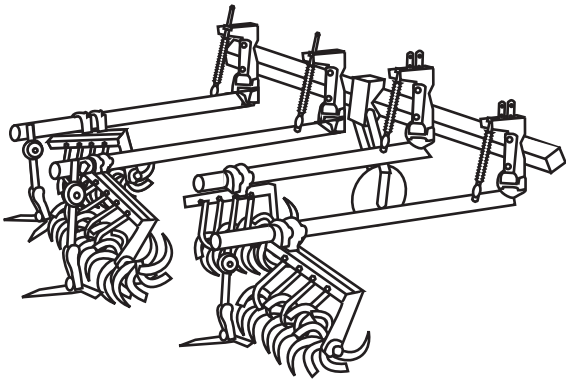
A "stale" seedbed is a seedbed that is prepared well in advance of the intended planting date. While "on hold" for planting the bed is either rained on or irrigated to germinate weeds, then lightly tilled to kill the weeds just prior to planting. The technique is most often used in East Coast vegetable production.

Appendix 1: Hand Tools for Weed Management

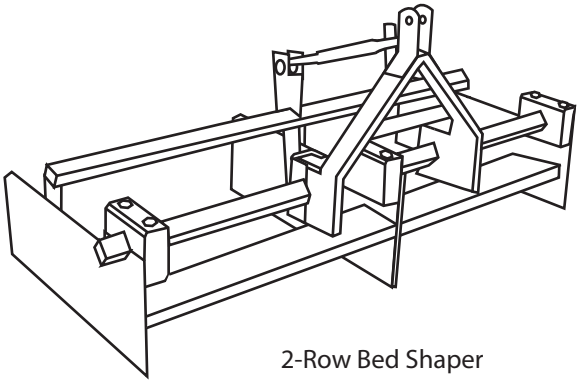


Illustrations by Cathy Genetti Reinhard; not to scale

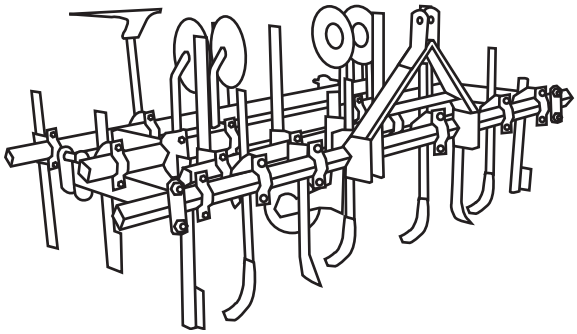
Appendix 2: Tools for Mechanical Weed Management



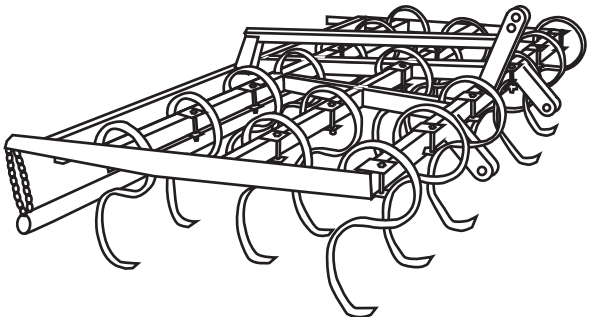
Lilliston Cultivator



2-Row Bed Shaper



3-Bar Cultivator

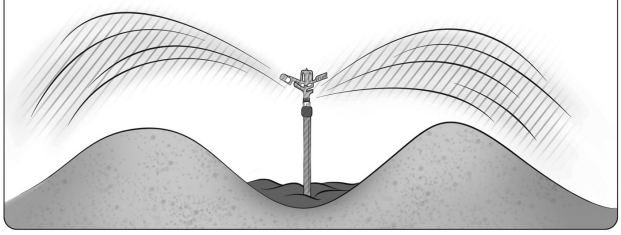


Spring-toothed Harrow

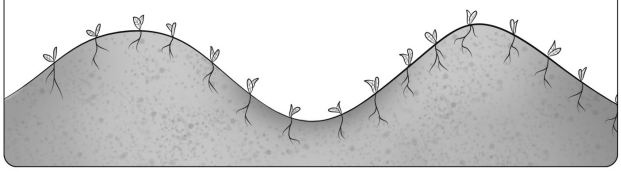
illustrations by Cathy Genetti Reinhard; not to scale

Appendix 3: Planting to Moisture

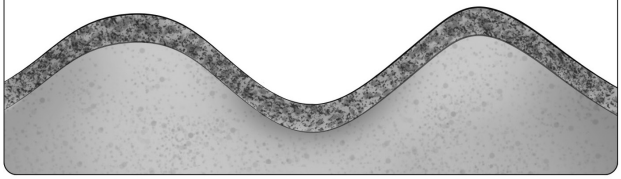
1. Pre irrigate



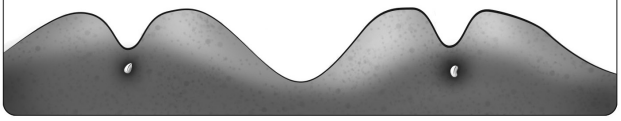
2. Germinate weeds



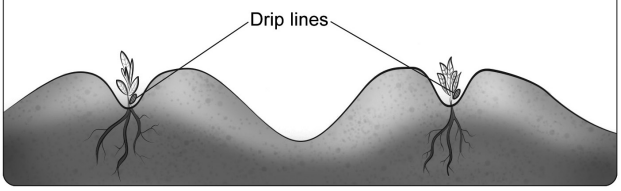
3. Cultivate (rolling cultivator)



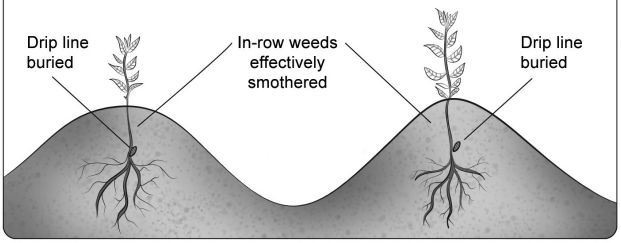
4. Knock bed top off. Plant to moisture.



5. First cultivation (sweeps, knives and reverse disc hillers)



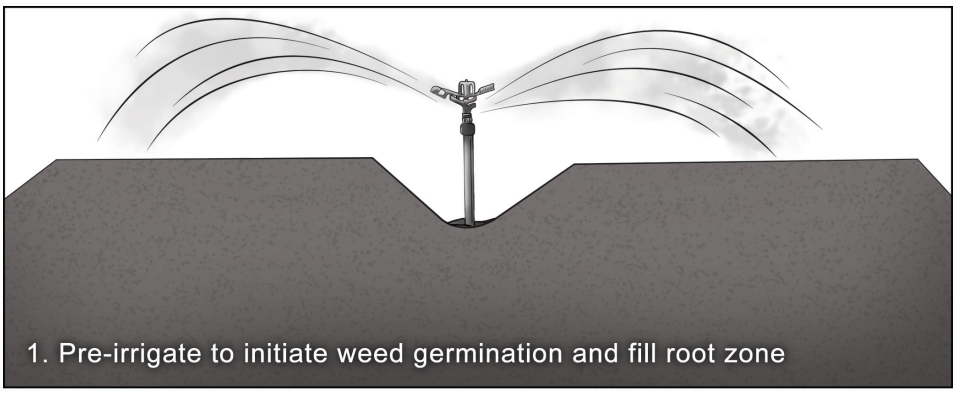
6. Second cultivation (rolling cultivator reforms bed)

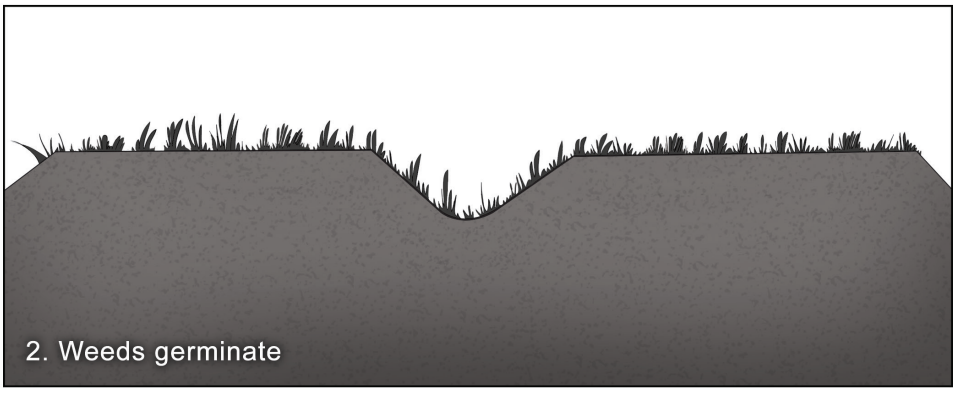


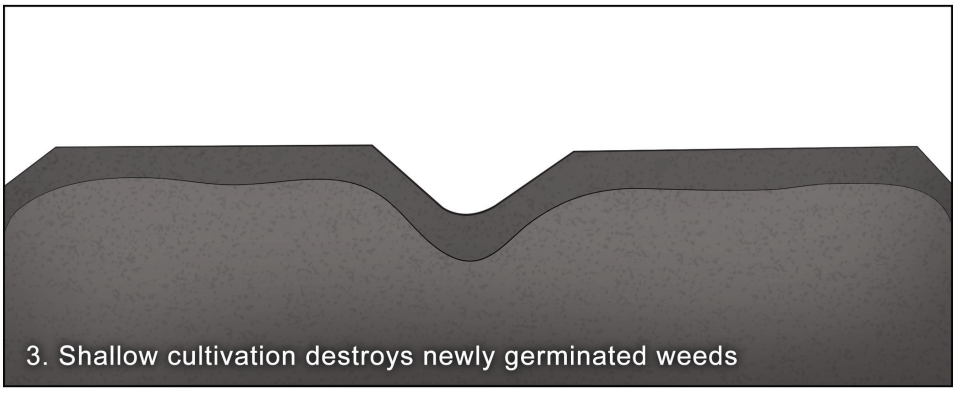
Illustrations by José Miguel Mayo

Appendix 4: Pre-Irrigation to Minimize Weed Pressure

When beds are pre-irrigated, the resulting "flush" of weeds can be easily controlled with shallow cultivation prior to crop planting and subsequent irrigation.

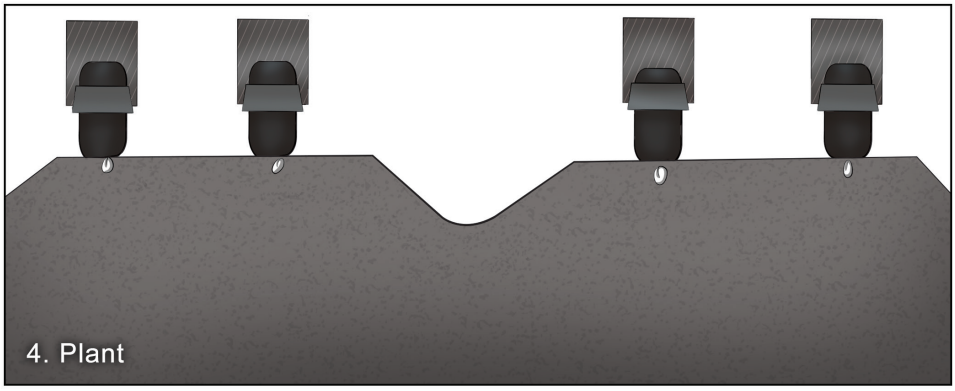


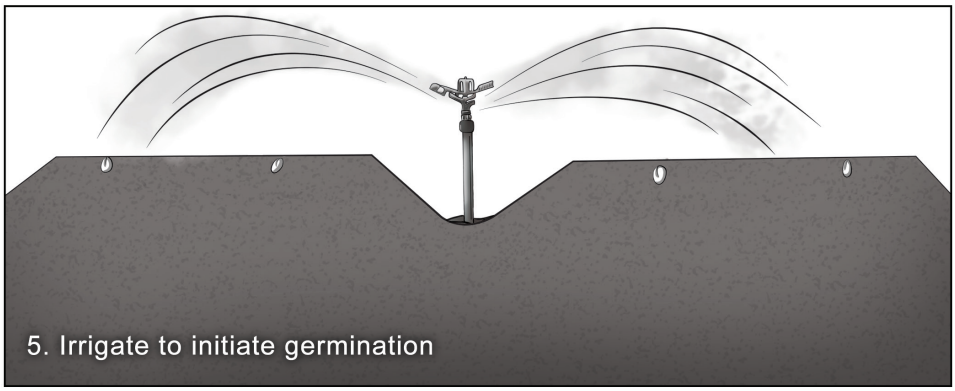


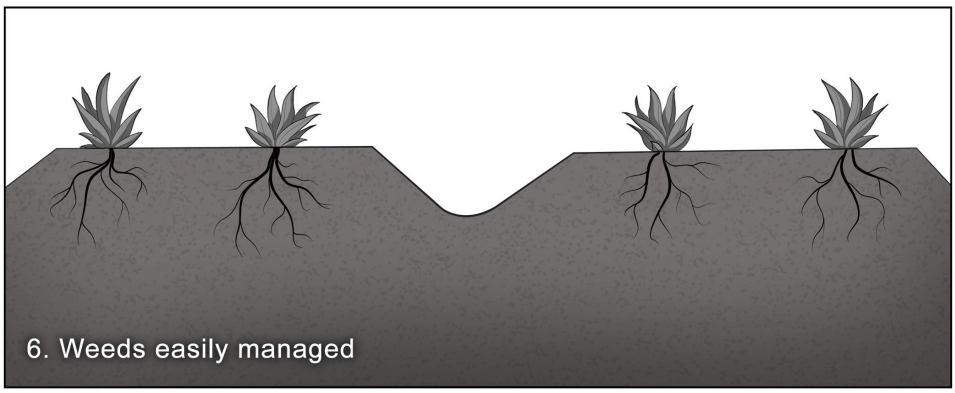


Illustrations by José Miguel Mayo

Appendix 4 (cont'd): Pre-Irrigation to Minimize Weed Pressure







Illustrations by José Miguel Mayo

Appendix 4 (cont'd): Pre-Irrigation to Minimize Weed Pressure

Note that in contrast to the sequence illustrated on pages 426–427, if seeds are planted prior to the initial irrigation, weeds and crop plants will germinate together, increasing the amount of labor and cost required to control weeds.

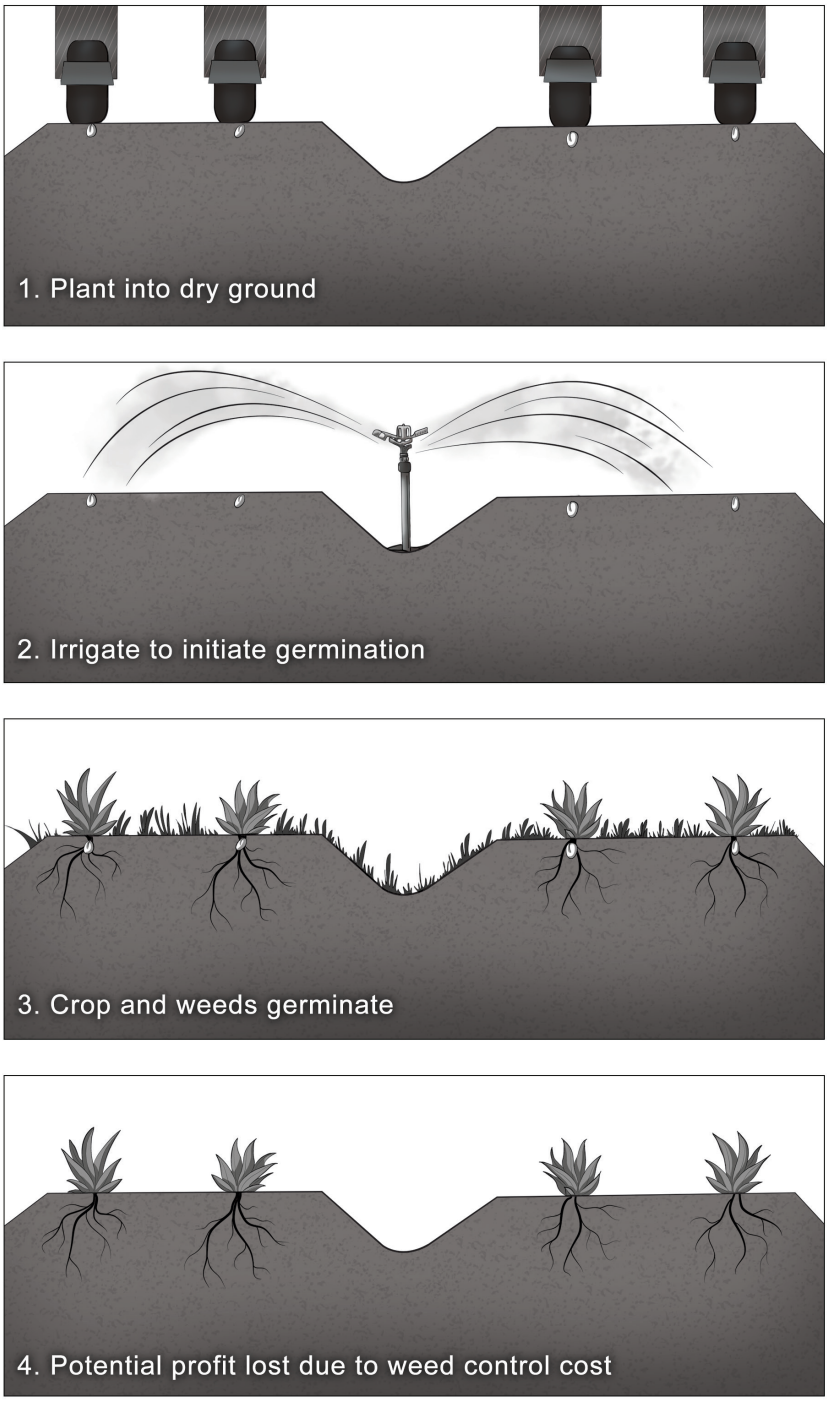


Illustration by José Miguel Mayo