1.11

Reading and Interpreting Soil Test Reports

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Introduction: Reading & 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.

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. Unit 2.2, Soil Chemistry and Fertility, is an especially useful complement to the material presented here. In addition, Unit 1.1, Managing Soil Health, should be presented prior to this unit.

MODES OF INSTRUCTION

> LECTURES (3 LECTURES, 2–2.5 HOURS TOTAL)

Lecture 1 covers the role of soil analysis in sustainable agriculture.

Lecture 2 addresses the soil properties measured in a comprehensive soil analysis.

Lecture 3 offers a short look at 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: NITROGEN BUDGETING (1 HOUR)

Demonstration 2 offers an example of how a simple nitrogen budget can be calculated for an organic farm or garden.

> DEMONSTRATION 3: FIELD OBSERVATIONS (1.5 HOURS)

Demonstration 3 provides an outline to use in visiting a farm or garden operation for which a soil report has been prepared. This outline directs 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.

> 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 develop an estimated nitrogen budget for your crop(s)
- How to relate observed crop problems to fertility programs

Lecture 1: Using a Soil Test to Assess Soil Quality

Pre-Assessment Questions

1. What is one of the drawbacks of relying on synthetic N-P-K fertilizers?
2. What negative consequences may result from excess nitrate nitrogen in the soil and in crops?
3. What role can a soil test play in developing a sound soil management plan?
4. 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
5. What are some of the key soil properties measured in a soil test?
6. Why is it important to ensure that soil pH is maintained in an optimal range?
7. How might one assure that adequate quantities of plant available nitrogen (N) are made accessible to crops without excessive fertilization?

A. 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
3. A fertilizer can also be a feedstock for soil microbes, thus improving soil's physical, biological, and chemical properties. Fertilizers such as gypsum/lime can improve soil structure; conversely, salt concentrates in fertilizers, e.g., sodium nitrate, can adversely affect soil structure. In addition, amendments such as composts or cover crops also supply nutrients to plants.

B. 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 (see also discussion in Unit 2.2, Soil Chemical Properties)
   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 1930–1980 domestic synthetic nitrogen fertilizer use increased from 9 to 47 million metric tons/year (see Gliessman 1998; U.S. Geological Survey 1998). Trends show steady increase in use of synthetic fertilizers (1960–2011) after a decline in the late 1980s (see *www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx*).

c) Coincident with the increased use of synthetic nitrogen fertilizers, the use of cover crops as fertilizers and soil amendments declined markedly on farm-scale operations

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. A 2006 study of field crops by the USDA's Economic Research Service found that only 35% of farmers employed all three recommended "best management practices" in applying nitrogen fertilizers (Ribaudo et al. 2011).

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 (see Supplement 4, Nitrate Contamination of Groundwater, in Unit 1.5, Irrigation–Principles and Practices). 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.

C. 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. This includes measures of % base saturation, which indicates the ratio of base ions held on the exchange sites; a quantitative measurement of the cation exchange capacity (CEC), a measurement of the soil's potential to hold and exchange cation nutrients; and parts per million (ppm) of nutrients such as 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.

How Does Parts Per Million (ppm) Relate to Pounds Per Acre?

One acre of soil to a 6-inch depth weighs approximately 2 million pounds. One ppm in 2 million pounds is 2 pounds. To convert ppm to pounds per acre, multiply by two. To convert pounds per acre to ppm, divide by 2.

D. 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; also known as % base saturation): The CSR approach states that there are optimal ratios and amounts 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. The % base saturation reflects the % of exchange sites on soil particles that are "held" by the basic cations (Ca^{++}, Mg^{++}, K^{+}, and Na^{+}); the remainder of sites are held by acidic cations (H^{+}, Al^{+++}).
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 import 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. Specify the crop or crops being grown, and let the lab know that you are using organic techniques. Request "recommendations" when submitting a soil sample for analysis.
5. If possible, use a regional soil testing lab, which will be familiar with your local soil conditions

   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, Lab Recommendations, & Interpretations

See also Unit 2.2, Soil Chemistry and Fertility

A. Review of the Soil Properties Measured in a Comprehensive Soil Analysis

(see Appendix 1, Sample Soil Analysis Reports)

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 soil organic matter higher than 2%, and ideally 3–5% organic matter content in cool temperate climates is desireable.
   c) Measuring changes in SOM over time is useful in monitoring impacts of a soil management program
2. Estimated Nitrogen Release (ENR)
   a) ENR defined: The amount of plant available nitrogen in lbs/acre estimated to be released through the mineralization (by microbial action) 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 soil temperature and other climatic conditions; soil pH; the chemical composition of the organic matter (e.g., soils amended with materials high in carbon will release nitrogen slowly, vs. cover crops that can release N quickly following incorporation); 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 Appendix 2, Example of a Nitrogen Budget and Appendix 3, Nitrogen Budgeting Worksheet.)
      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 acidic soils (pH below 6.2)
      i. Optimal levels of more readily available phosphorus (P1): 30–40 ppm
   b) Olsen sodium bicarbonate extraction for basic soils (pH above 7.5); this is the appropriate test for most California agricultural soils
      i. Optimal levels of phosphorus: 40–60 ppm at pH of 6.0 or higher for cool season vegetable crops, or 15–25 ppm for warm season vegetable crops
   c) Note that cool season crops may require P supplementation, as cold soil temperatures reduce biological activity and thus the availability of P to plants

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 base saturation
      ii. Total amount (in ppm) to achieve this is based on the CEC of the soil
      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
      ii. Optimal range of Mg: 100–250 ppm
      iii. The optimal level of Mg in a given soil is 10–20% of the base saturation. Soils with Mg levels over 23% of base saturation often exhibit drainage problems and require attention.
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 base saturation
   ii. The total amount (in ppm) to achieve this is based on the CEC of the soil
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 base saturation. The total amount (in ppm) to achieve this is based on the CEC of the soil, but in general should be below 100 ppm. Sodium levels exceeding 5% of base saturation can cause serious soil structure issues that will affect water movement, aggregation, and tilth.
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)
   c) Typically the most important soil lab recommendations are related to soil pH adjustment and the addition of liming materials, as proper soil pH is critical to plant nutrient availability. It is important to follow the soil lab recommendations for adjusting pH; there are many factors to be taken into account, including soil type, CEC, the buffering capacity of the soil, and macro and micro nutrient levels. It is often worth a call to the lab for clarification on amendment material composition and particle size, as the types of organically allowed materials are often limited. Materials applied to adjust pH include:
      i. $CaCO_3$ – calcium carbonate – calcitic limestone: added to acidic soils to increase pH
      ii. $CaMg(CO_3)^2$ – calcium/magnesium carbonate – dolomitic lime: added to acidic soils to increase pH when Mg is deficient
      iii. $CaS0_4$+$2H_20$ – calcium sulfate – gypsum: added to alkaline soils to decrease pH when Ca is deficient
      iv. S – elemental sulfur: added to alkaline soils to decrease pH when Ca is adequate

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 (CEC): 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 for more on CEC).
12. Base 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 (NO_3-): The amount of water-soluble nitrogen (nitrate) in ppm found in a given soil sample. Nitrate (along with ammonium, NH_4) is a plant-available form of nitrogen resulting from nitrogen fixation and mineralization actions of soil microbes.
    a) Note that the test for NO_3- is not reliable for determining the need for nitrogen inputs in organic farming systems because it doesn't reflect "non-mineralized" N available from SOM. Although the test provides a "snapshot" of NO_3- level at the time of sampling, it can't measure future availability of NO_3-.
14. Sulfate (SO_4-) sulfur (S): The total amount of sulfur in ppm found in a given soil sample
    a) Optimal levels of available S: 25–35 ppm
    b) A shortage of either S or N will limit the availability of the other
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 (ECE). 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 or <100 ppm

18. Chloride
    a) Present in small amount in practically all soils. In farming systems, chloride may be supplied by irrigation water and organic sources such as manure and compost. Soil testing for chloride is not a common practice.

B. Additional Lab Tests

1. Qualitative tests: Critical for assessing sustainable soil management practices over time; see more at: *soilquality.org/indicators.html*
    a) Aggregate stability: Indicator of soil organic matter and biological activity
    b) Available water capacity: Maximum amount of plant available water a soil can provide; indicates a soil's ability to hold water and make it available for plant use
    c) Field penetration resistance: A measure of soil compaction, measured in pounds per square inch (psi) using a tool that measures a soil's resistance to penetration
    d) Active carbon: A measure of soil organic matter that is readily available as a carbon and energy source for the soil microbial community, and a leading indicator of soil health response to changes in crop and soil management (see *Cornell Soil Health Assessment Training Manual* in Resources)
    e) Bulk density: Indicator of soil compaction, typically expressed as g/cm^3
2. Other plant, soil, and water tests
    a) Plant tissue analysis: Often used in conventional systems to provide guidelines for "quick fixes" of nutrient imbalances
    b) Soil texture/physical properties: The relative proportions (percentage) of sand, silt, and clay particles measured in the soil analysis
    c) Water analysis: Can be used to determine potential source of excess salt, boron, or sodium showing up on soil analysis
    d) Soil microbial community assessment (fungal/bacterial ratio): No current consensus about the utility of these types of tests
    e) Organic fertilizer/compost: Useful information for determining fertility management strategies that ensure proper nutrient balance
    f) Pathology: Most soil and airborne plant pathogens can only be accurately diagnosed through lab analysis

Lecture 3: Applying Soil Amendments & Fertilizers

A. Applying Soil Amendments and Fertilizers (see *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. Note, however, that soluble nitrogen is easily leached during winter rains.
   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. Leachable nutrients should be applied at and above the effective feeding root zone of crops being grown. Amendments such as P, which do not readily move downward in the soil profile, should be banded at the root depth of the crop.
   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. Ordering information: *www.allabs.com/publications/agronomy_handbook2.aspx*
- Magdoff, Fred and Harold Van Es. 2010. *Building Soils for Better Crops, Third Edition*. Handbook Series Book 4, Sustainable Agriculture Network. Ch. 21: Getting The Most from Routine Soil Tests. Free download available at: *www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*

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 prepatory reading: *A & L Reference Guide—"Sampling Soil"*

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/troubleshooting
   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. Ordering information: *www.allabs.com/publications/agronomy_handbook2.aspx*
- Illustrated soil sampling techniques: *www.al-labs-west.com/sections/anservice/sampling*
- Magdoff, Fred, and Harold Van Es. 2010. Building Soils for Better Crops, Third Edition. Chapter 21, Getting the Most from Routine Soil Tests. Free download available at: *www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*

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) Problems 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: 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 2 (Nitrogen Budgeting Exercise) includes an example of the steps involved in calculating a basic nitrogen budget.

PREPARATION AND MATERIALS

- Appendix 2, Example of a Nitrogen Budget
- Appendix 6, Approximate Pounds/Acre of Nutrients Removed by Common Crops
- Sample soil test report

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 6 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 (Appendix 3)

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/* 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 3: 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, Soil Chemistry and Fertility. (For crop deficiency symptoms see Lecture 2, Plant Nutrient Requirements and Nutrient Cycles; for websites 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 of 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 micronutrient 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?

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?

6. Explain the concepts of Cation Exchange Capacity (CEC) and Cation Saturation Ratios (CSR).

7. What are several advantages of optimum soil cation balance?

8. What are the three primary sources of nitrogen factored into a nitrogen budget for an organic farming system?

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 (CEC) 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 & L soil analysis report. Available from 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. *anrcatalog.ucdavis.edu/pdf/7249.pdf*

> *An 8-page overview of soil fertility for organic production systems.*

PRINT

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. Order from A& L Western Laboratories; see www.al-labs-west.com/files/order.pdf*

Albrecht, William A., and C. Walters (eds). 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, 9th Edition*. Long Grove, IL: Waveland Press, Inc.

> *This handbook presents fertilization, nutrient management, and related topics based on the fundamentals of biological and physical sciences.*

Cantisano, Amigo. 2012. *Know Your Soil: A Handbook for Understanding and Utilizing a Soil Analysis for Organic Growing, Third Edition*. Organic Ag Advisors.

Gugino, B. K., O. J. Idowu, R. R. Schindelbeck et al. 2009. *Cornell Soil Health Assessment Training Manual, 2nd Edition*. Ithaca, NY: College of Agriculture and Life Sciences, Cornell University. *soilhealth.cals.cornell.edu/extension/manual.htm*

> *Comprehensive information on assessing soil health, including definitions, testing, and management strategies.*

Hoskins, Bruce R. 1997. S*oil 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/soillab_files/faq/handbook.pdf*

> *Extensive information on all aspects of soil testing and soil amendments. Many sections of this online publication have been updated since the 1997 publication date.*

Magdoff, Fred, and Harold Van Es. 2010. B*uilding Soils for Better Crops, 3rd Edition*. Handbook Series Book 10, Sustainable Agriculture Research and Education (SARE) Program. *www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*

> *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 SARE as hard copy or free download.*

Ribaudo, Marc, et al. 2011. *Nitrogen in Agricultural Systems: Implications for Policy.* ERS Report Summary. U.S. Department of Agriculture, Economic Research Service. *http://www.ers.usda.gov/media/117600/err127_reportsummary.pdf*

A brief report summarizing research on nitrogen use in agricultural systems. Discusses policies and incentives to encourage the use of best management practices that match nitrogen applications to crop needs.

University of Maine Soil Testing Service and Analytic Lab (N.D.). *Interpreting Soil Test Results for Commercial Crops. anlab.umesci.maine.edu/soillab_files/under/commpam.pdf*

This 12-page publication from the University of Maine's Cooperative Extension service offers a clear explanation of soil test interpretation and use of soil testing recommendations, including information on choosing a fertilizer blend and calculating manure application rates.

Van Horn, Mark. (N.D.) *Organic Soil and Fertility Management: Principles and Practices.* UC Davis: The Student Farm, Agricultural Sustainability Institute. *www.sarep.ucdavis.edu/sf/files/Organic%20Soil%20and%20Fertility%20Managent.pdf/view*

An excellent 8-page summary of soil fertility management practices in organic systems: Addresses soil fertility needs, organic matter, determining crops' nutritional needs, soil testing, and the use of inputs such as cover crops, manures, compost, and mineral products in an easy-to-read, non-technical style.

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-BASED RESOURCES

Alternative Farming Systems Information Center, USDA

afsic.nal.usda.gov/

Part of USDA's National Agricultural Library, the AFSIC site offers access to technical information on organic farming, sustainable agriculture, soil and water management, and other topics of interest to organic producers. See the soil and water management link, afsic.nal.usda.gov/soil-and-water-management, *for information on soil testing, amendments, and nutrient management.*

Analytical Lab and Maine Soil Testing Service

anlab.umesci.maine.edu/soillab_files/under/index.html

This University of Maine resource includes a number of web-based guidelines on understanding soil test recommendations, along with information on organic nutrient sources, soil management, and more.

Appropriate Technology Transfer for Rural Areas: Soils & Compost

attra.ncat.org/soils.html

ATTRA is a national center for sustainable farming information. The soils and compost page of the ATTRA website lists numerous publications on soil management and soil amendments.

Determining Nutrient Needs for Organic Vegetables: Basic Calculations, Penn State Extension

extension.psu.edu/business/start-farming/soils-and-soil-management/determining-nutrient-applications-for-organic-vegetables-basic-calculations-introduction-to-soils-fact-3

Fundamentals of Soil Cation Exchange Capacity

www.extension.purdue.edu/extmedia/ay/ay-238.html

Clear explanation of CEC, by Purdue agronomist David B. Mengel

Interpreting Missouri Soil Test Reports

muextension.missouri.edu/xplor/agguides/soils/g09112.htm

University of Missouri website explains how to interpret soil test results and recommendations, and includes a useful FAQ section.

Interpreting Soil Tests for Efficient Plant Growth and Water Use, New Mexico State University

aces.nmsu.edu/pubs/_a/A141/welcome.html

Nutrient Cycling and Maintaining Soil Fertility in Fruit and Vegetable Crop Systems

www.extension.umn.edu/garden/fruit-vegetable/nutrient-cycling-and-fertility/#nutp

Ohio Agronomy Guide, Bulletin 472: Soil Fertility

agcrops.osu.edu/specialists/fertility/fertility-fact-sheets-and-bulletins/agron_guide.pdf

Includes a useful section on soil fertility.

Organic Materials Review Institute

www.omri.org

Lists materials, including fertilizers and other soil inputs, compatible with U.S. National Organic Program (NOP) standards. Includes brand name reviews, manufacturer contacts, and technical information.

Peaceful Valley Farm Supply

www.groworganic.com

A catalogue of tools and supplies and technical support for organic farmers and gardeners, including soil testing service and soil test kits.

Selecting an Analytical Laboratory, Colorado State University

www.ext.colostate.edu/pubs/crops/00520.html

Soil Cation Ratios for Crop Production

www.extension.umn.edu/agriculture/nutrient-management/soil-and-plant-sampling/soil-cation-ratios/

Addresses the history of the "basic cation saturation ratio" concept and examines its importance and relevancy for crop production.

Soil Test Explanation, Colorado State University

www.ext.colostate.edu/pubs/crops/00502.html

Soil Testing, Clemson University Cooperative Extension Home & Garden Information Center

www.clemson.edu/extension/hgic/plants/other/soils/hgic1652.html

UC Sustainable Agriculture Research and Education Program (UC SAREP)

www.sarep.ucdavis.edu/sarep

Sustainable agriculture news, technical information, grant programs, and other information from the University of California.

UC SAREP Solution Center for Nutrient Management

www.sarep.ucdavis.edu/sarep/sarep-solution-centers

An online information resource on nutrient management; provides opportunities to engage with researchers and farmers on pressing nutrient management needs. Includes forums, database, and decision-making tools.

Understanding the Numbers on Your Soil Test Report, University of Arkansas

www.uaex.edu/publications/PDF/FSA-2118.pdf

USDA National Organic Program.

www.ams.usda.gov/AMSv1.0/nop

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

SUPPLEMENT 1

Soil Contamination & Urban Agriculture

Urban agriculture promises to be an increasingly important part of the movement towards a sustainable and equitable food system. Urban farms and garden provide a local source of fresh vegetables in areas that often lack physical or economic access, reduce transportation, storage, and other environmental costs or industrial production, concentrate and support investment in the local economy, and provide communities with access to open spaces.

Contaminated soils present a significant challenge to the viability of urban food growing as many undeveloped areas in cities contain high levels of heavy metals hazardous to human health. Moreover, there is evidence to show that contamination is worse in poorer, communities of color where access to fresh food is often least available. Addressing soil contamination in urban areas is necessary to alleviate not only the health safety concern it raises, but also the food security and environmental justice implications from disproportionately high contamination levels in poorer communities. The sources of contaminated urban soils are introduced, contaminants of concern are mentioned, and resources for remediating soils are listed in this case study.

Urban soils in close proximity to large human populations are exposed to a variety of harmful substances. Past and current land uses and adjacent activities contribute to the level of contamination in the soil. Contaminating substances like pesticides and herbicides are intentionally applied to urban soils while industrial chemicals enter soils most often through accidental spills or leaks. Air and waterways can also deposit dust and other contaminants from farther distances. While soil on former industrial sites may contain a wider range of contaminants, the most common, and therefore most concerning, substances in urban settings are lead, cadmium, arsenic, zinc, and hydrocarbons. Because poverty limits housing choices, low-income families are generally located in communities nearest commercial and industrial parts of a city, with the oldest housing, and the most deferred maintenance; all of these are factors that increase their exposure to hazardous contaminants. In addition to a higher exposure risk, higher soil contamination levels prevent communities most in need of a real source of fresh, healthy, affordable food from starting farms and gardens where they live.

Sources of Contamination

- **Lead**: By far the most prevalent toxic substance in urban areas, was historically used in paint formulations, as a gasoline additive, and in pesticides
- **Cadmium**: Byproduct of sewage sludge and coal and garbage burning
- **Arsenic**: Commonly used as a wood preservative and, along with Zinc, is an ingredient in pesticides, herbicides, and fertilizers
- **Hydrocarbons**: Found in car emissions and other combustion activities.

While legal recourse may be available to some individuals and communities who attempt an urban agricultural project on land contaminated from previous uses, in reality, this relief is often unavailable. Litigation is prohibitively expensive for most communities and, even if expense is of no concern, proving who is responsible for the contamination and, hence, the cleanup costs is exceedingly difficult. As a result, people interested in growing food in urban areas are left to take precautionary and remediating measures on their own. Assessments, remediation, and non-remediation solutions can be expensive, yet necessary measures to ensure the safety of a particular site before food can be grown there.

A soil test is the first step towards understanding the extent of contamination on a given plot. Urban soil tests require testing for specific metals, often not included in the generally affordable soil fertility tests described in the lecture outline. Testing for metals of concern in urban areas can cost anywhere from $20-100 per metal, making them more expensive than what many individuals or groups can afford when starting a farm or garden. To cut down on costs, urban gardeners should consult with local libraries for historical land use information about their site to determine which of the several contaminants potentially present are most important to test for. For example, if a plot was previously a gasoline station, hydrocarbons and benzene should be tested. Additionally, some cities, such as Minneapolis, provide free testing for individual and have funds available for groups starting community gardens. The EPA offers grants for assessing contamination at designated brownfields through the EPA Brownfields Assessment Grant program, and some states have initiated similar grant programs. People interested in growing food in contaminated urban areas who are not responsible for the contamination should not be burdened with the cost of assessment and remediation, and ought to advocate for access to state and local funds for such purposes.

Once contamination is found, the next step is to determine what remediation measures, if any, can be successfully implemented. There are physical and biological remediation techniques commonly used in urban gardens. Most of the physical measures are high-cost and high-input, including excavation and replacement of all the soil or soil washing, which requires off-site treatment. Biological remediation measures use living organisms (microbes, plants, or fungi) to degrade or extract contaminants from the soil. The effectiveness of each technique depends to a great degree on the specific contaminant(s) targeted. Biological remediation is low-cost and low-impact, but is also a slower process. Remediation can take several years depending on the level of contamination, and with phytoremediation in particular, the plants that accumulate contaminants in their tissue must be disposed of off-site. As urban farming and gardening continue to develop as a significant source of food for urban communities, research into biological remediation must also increase so its practice can be scaled up to the future land needs of urban populations.

The slow process, limited effectiveness, and even cost of biological remediation, however, may be unsuitable for highly contaminated areas in poor urban communities. In cases where remediation is not possible, there are other non-remediation measures available to urban farmers and gardeners. The most common solution is to build raised beds and grow in clean, imported soil above the contaminated soil. Laying landscape fabric, biochar, or other barriers between the contaminated and clean soil will also help prevent plant roots from taking up contaminants. Again, public funds are available in some places for these mitigation measures, and with continued advocacy, more funds will be dedicated to this purpose.

Choosing fruiting crops over root or leafy green crops is another precautionary measure that limits the risk of plants absorbing contaminants, as they have less contact with the compromised soil. Finally, metals are more bioavailable—available for plant uptake—in acidic soils, so maintaining a non-acidic neutral pH (6.5-7) is another cultural technique that can minimize contamination of plant material.

Resources on Urban Agriculture

Guide to Implementing the Urban Agriculture Incentive Zones Act

ucanr.edu/sites/UrbanAg/files/190763.pdf

This easy-to-read 4-page guide describes California's AB 551 act and how it can be used to create new Urban Agriculture Zones.

Lead Hazard Risk Assessment and Management of Urban Gardens and Farms

www.sfdph.org/DPH/files/EHSdocs/ehsCEHPdocs/Lead/LeadHazardUrbanGardening.pdf

Developed by San Francisco's Department of Public Health, this guide includes protocols for conducting Lead Hazard Risk Assessment (LHRA) for urban gardens or farms and for managing and mitigating identified hazards.

Urban Agriculture – San Francisco

www.sfenvironment.org/buildings-environments/urban-agriculture

Example of a city-run website that offers "one stop shopping" for key information on urban agriculture and contacts for appropriate city officials.

Urban Agriculture – University of California, Division of Agriculture and Natural Resources

ucanr/sites/UrbanAg

Information on a wide variety of topics related to urban agriculture, including zoning laws and regulations, soil considerations, community and school gardens, and business management.

Appendix 1: Sample Soil Analysis Reports

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 13-284-063 **CLIENT NO:** 99999

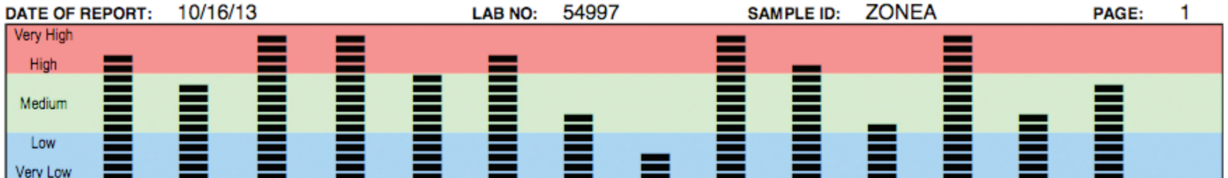
SEND TO: CONSERVATION CORPS NORTH BAY
11 PIMENTEL COURT
NOVATO, CA 94949-

GROWER:

SUBMITTED BY:

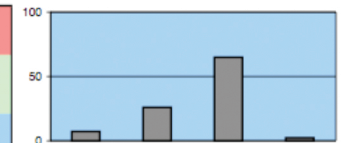
Graphical Soil Analysis Report

DATE OF REPORT: 10/16/13 **LAB NO:** 54997 **SAMPLE ID:** ZONEA **PAGE:** 1



Analyte	Organic Matter %	Nitrogen NO_3-N ppm	Phosphorus Weak Bray ppm	Phosphorus $NaHCO_3$-P ppm	Potassium K ppm	Magnesium Mg ppm	Calcium Ca ppm	Sodium Na ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Chloride Cl ppm
Results	7.5	27	185	73	471	534	2203	90	192	5.7	5	71	1.0	1.2	

Percent Cation Saturation (computed)



Potassium K %	Magnesium Mg %	Calcium Ca %	Sodium Na %
7.1	25.9	64.7	2.3

1.6 — ECe dS/m — LOW / AVERAGE / HIGH — INCREASING SALINITY →

17.0 — CEC meq/100g

L — Ex. Lime

7.1 — pH — ACIDIC / BASIC — ← INCREASING NEED FOR LIME

Buffer pH:

Soil Fertility Guidelines

CROP: MIXED VEG **RATE:** lb/1000 sq ft **NOTES:**

Dolomite (70 score)	Lime (70 score)	Gypsum	Elemental Sulfur	Nitrogen N	Phosphate P_2O_5	Potash K_2O	Magnesium Mg	Sulfur SO_4-S	Zinc Zn	Manganese Mn	Iron Fe	Copper Cu	Boron B	
				1.8										

Appendix 1: (cont.) Sample Soil Analysis Reports

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 00-336-047

CLIENT NO: 9999-D

SEND TO: A & L WESTERN AGRICULTURAL LABS
1311 WOODLAND AVE.
MODESTO, CA 95351-

SUBMITTED BY:

GROWER: EXAMPLE REPORT

DATE OF REPORT: 04/30/04

SOIL ANALYSIS REPORT

PAGE 1

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	$NaHCO_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
130-1	55931	4.0H	110	23M	14**	110L	460M	992VL	104L	4.7	6.2	9.7	19.1	1.5	19.8	25.9	50.5	2.4
130-2	55932	1.5L	60	27H	6**	41VL	569M	1154VL	185M	4.6	5.9	13.3	24.7	0.4	19.0	23.3	54.0	3.3
12-1	55933	3.5M	100	12L	11**	64L	471VH	841VL	87L	5.2	6.5	4.5	13.1	1.2	29.5	31.9	34.5	2.9
12-2	55934	2.8M	86	8VL	9**	29L	553VH	665VL	89M	5.3	6.6	3.7	12.1	0.6	37.7	27.5	31.0	3.2

** NaHCO3-P unreliable at this soil pH

SAMPLE NUMBER	Nitrogen NO_3-N ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS: SAND %	SILT %	CLAY %	SOIL TEXTURE
130-1	5L	5L	0.3VL	3M	53VH	0.2VL	0.1VL	L	0.3L			44	25	31	CLAY LOAM
130-2	3VL	41VH	0.1VL	1VL	14M	0.2VL	0.1VL	L	0.6L			60	16	25	SANDY CLAY LOAM
12-1	2VL	5L	0.1VL	2L	50VH	0.1VL	0.3VL	L	0.2VL			42	36	23	LOAM
12-2	2VL	4L	0.1VL	1VL	53VH	0.1VL	0.2VL	L	0.1VL			40	35	25	LOAM

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
** ENR - ESTIMATED NITROGEN RELEASE
*** MULTIPLY THE RESULTS IN ppm BY 2 TO CONVERT TO LBS. PER ACRE OF THE ELEMENTAL FORM
**** MULTIPLY THE RESULTS IN ppm BY 4.6 TO CONVERT TO LBS. PER ACRE P_2O_5
***** MULTIPLY THE RESULTS IN ppm BY 2.4 TO CONVERT TO LBS. PER ACRE K_2O
MOST SOILS WEIGH TWO (2) MILLION POUNDS (DRY WEIGHT) FOR AN ACRE OF SOIL 6-2/3 INCHES DEEP

This report applies only to the sample(s) tested. Samples are retained a maximum of thirty days after testing.

Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

Appendix 1: (cont.) Sample Soil Analysis Reports

Your Logo Here

A&L Analytical Laboratories, Inc.

2790 Whitten Rd. Memphis, TN 38133 (901) 213-2400 Fax (901) 213-2440

http://www.allabs.com

The One Source.

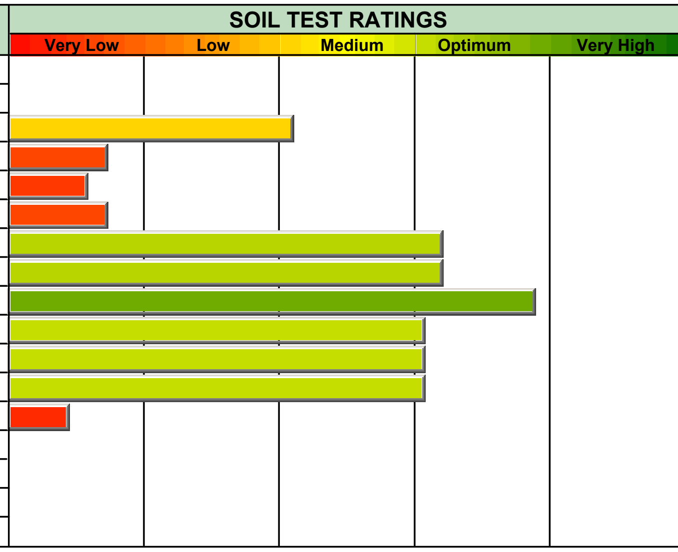
SOIL ANALYSIS

Client :	Grower :		
JOHN DOE	SUE DOE	Report No:	03-600-0500
1311 SOME STREET		Cust No:	99999
ANYWHERE TN 38105		Date Printed:	01/07/2003
		Page :	1 of 1
		A&L Agronomist	
	Date Received : 01/07/2003	Richard Large	

Lab Number : 60000 **Sample Id :** 1 **Signature :**

Test	Results	
Soil pH	4.9	
Buffer pH	6.83	
Phosphorus (P)	34	LB/ACRE
Potassium (K)	84	LB/ACRE
Calcium (Ca)	628	LB/ACRE
Magnesium (Mg)	50	LB/ACRE
Sulfur (S)	50	LB/ACRE
Boron (B)	1.6	LB/ACRE
Copper (Cu)	8.0	LB/ACRE
Iron (Fe)	204	LB/ACRE
Manganese (Mn)	310	LB/ACRE
Zinc (Zn)	7.0	LB/ACRE
Sodium (Na)	60	LB/ACRE
Soluble Salts		
Organic Matter	1.5 %	ENR 74
NO3-N		

SOIL TEST RATINGS



Calculated Cation Exchange Capacity

11.4

meq/100g

Calculated Cation Saturation

%K	0.9
%Ca	13.8
%Mg	1.8
%H	82.1
%Na	1.1

K : Mg Ratio

0.52

SOIL FERTILITY GUIDELINES

Crop : CHRISTMAS TREE-LEYLAND CYPRESS **Yield Goal :** 1 **Rec Units:** LB/ACRE

LIME	N	P_2O_5	K_2O	Mg	S	B	Cu	Mn	Zn
7500	60	50	100	25	0	0	0	0	0

Crop : **Yield Goal :** **Rec Units:**

Comments :

CHRISTMAS TREE-LEYLAND CYPRESS

APPLY 2/3 OF THE FERTILIZER IN THE SPRING AND 1/3 IN MID SUMMER
Limestone application is targeted to bring soil pH to 6.0.

Appendix 1: (cont.) Sample Soil Analysis Reports with Recommendations

Soil Report

Job Name **Sample Job** *Date* 1/1/2007

Submitted By Logan Labs *Sales Person*

Sample Location			Field	Field	Field	Field	Field
Sample ID			# 1	# 2	# 3	# 4	# 5
Lab Number			46	47	48	49	50
Sample Depth in inches			6	6	6	6	6
Total Exchange Capacity (M. E.)			11.85	13.93	12.39	12.77	13.87
pH of Soil Sample			6.60	7.00	6.90	6.80	6.80
Organic Matter, Percent			2.16	1.94	2.23	2.27	2.25
ANIONS	**SULFUR:**	p.p.m.	12	13	8	8	12
ANIONS	**Mehlich III Phosphorous:**	as (P_2O_5) lbs / acre	74	95	55	67	69
EXCHANGEABLE CATIONS	**CALCIUM:** lbs / acre	Desired Value	3223	3787	3369	3472	3773
		Value Found	3170	3858	3392	3398	3842
		Deficit	-53			-74	
	MAGNESIUM: lbs / acre	Desired Value	341	401	356	367	399
		Value Found	547	796	688	716	685
		Deficit					
	POTASSIUM: lbs / acre	Desired Value	369	434	386	398	432
		Value Found	180	185	145	153	178
		Deficit	-189	-249	-241	-245	-254
	SODIUM:	lbs / acre	63	52	51	56	61
BASE SATURATION %	Calcium (60 to 70%)		66.88	69.26	68.45	66.54	69.24
	Magnesium (10 to 20%)		19.23	23.82	23.14	23.37	20.58
	Potassium (2 to 5%)		1.95	1.70	1.50	1.54	1.65
	Sodium (.5 to 3%)		1.16	0.81	0.90	0.96	0.95
	Other Bases (Variable)		4.80	4.40	4.50	4.60	4.60
	Exchangable Hydrogen (10 to 15%)		6.00	0.00	1.50	3.00	3.00
TRACE ELEMENTS	Boron (p.p.m.)		0.69	0.69	0.65	0.72	0.73
	Iron (p.p.m.)		131	152	135	147	166
	Manganese (p.p.m.)		122	141	156	142	127
	Copper (p.p.m.)		1.46	1.89	1.67	2.41	2.03
	Zinc (p.p.m.)		1.06	1.41	1.06	2.69	1.97
	Aluminum (p.p.m.)		713	665	667	650	685
OTHER							

Logan Labs, LLC

Appendix 2: Example of a Nitrogen Budget

NITROGEN REMOVAL NITROGEN CONTRIBUTIONS		1) 150 lbs N/acre (spinach) (Estimated total N lost to crop removal)
Soil Organic Matter Estimated Nitrogen Release (ENR) Example ENR: 10 lbs/ac	• Use 60–80% of Estimated Nitrogen Release (ENR) on Soil Test for annual and perennial crops, respectively. • 110 lbs/acre (110 x .60) = 66 lbs/acre of actual N	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)	• Average application rate: 5–7 tons/acre/year of compost • ~1 % nitrogen content • 10,000–14,000* lbs x .01 = 65–91 lbs actual N • with ~50% available in the first year = 32.5–45 lbs N	3) 32.5–45 lbs N/acre (Estimated nitrogen released N released in the first year from compost)
Legume Cover Crops	• Estimated N fixation by Bell Beans = 100 lbs/ acre • Estimated % N Available in first season after incorporation = 50% • 100 lbs X .50 = 50 lbs estimated lbs of actual N available in first season after incorporation	4) 50 lbs. N/acre (Estimated N contribution of fabaceous cover crops)
Total Available Nitrogen	• 66 lbs + 45 lbs + 50 lbs = 161 total lbs of actual N/acre	5) 161 lbs N/acre (Estimated total available nitrogen/acre)
Calculating Additional Nitrogen Needs	• Line 1 (Total N lost to crop removal) – Line 5 (Total Available Nitrogen) • 150 lbs – 161 lbs = 11 lbs N/acre surplus. No supplemental N needed 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.	

Appendix 3: Nitrogen Budgeting Worksheet

NITROGEN REMOVAL *(See Appendix 6, Nutrients Removed by Common Crops* NITROGEN CONTRIBUTIONS		1) ______ lbs.N/acre (Estimated average total N lost to crop removal)
Soil Organic Matter Estimated Nitrogen Release (ENR) *(See soil analysis report for ENR figures)*	• Estimated Nitrogen Release (ENR) on Soil Test ______ x 60–80% (for annual and perennial crops, respectively)	2) ______ 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)	• Application rate: ______ tons/acre/year of compost • Average N content of compost = ______% • ______ lbs. compost* x %N of compost = ______ lbs. actual N applied • Average N available in the first year = 50% • ______ lbs. actual N applied x .050 = ENR of compost	3) ______ lbs N/acre (Estimated nitrogen released N released in the first year from compost)
Legume Cover Crops *(See Unit 1.6 for estimating N contribution of cover crops)*	• Estimated N fixation by cover crop = ______ lbs/ acre • Estimated % N Available in first season after incorporation = 50% • ______ lbs. X .50 = ______ lbs. estimated lbs of actual N available in first season after incorporation	4) ______ lbs. N/acre (Estimated N contribution of fabaceous cover crops)
Total Available Nitrogen	• ______ lbs. + ______ lbs. + ______ lbs. = ______ total lbs of actual N/acre	5) ______ lbs. N/acre (Estimated total available nitrogen/acre)
Calculating Additional Nitrogen Needs	• Line 1 ______ (Total N lost to crop removal) – Line 5 ______ (Total Available Nitrogen)	6) ______ lbs. N/acre (Total needed supplemental nitrogen in lbs./acre)

* 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 orginic matter, soil biological activity, soil moisture, and the placement of the organic matter amendments in the soil profile are all influencial 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 4: 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	ppm Ca (optimum)		ppm Ca (tested)		ppm needed
11	1430 –1650	-	950	=	480 – 700
CEC	ppm Mg (optimum)		ppm Mg (tested)		ppm needed
11	134 – 201	-	287	=	0

44 = 200 pounds/1000 sq feet.

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

Appendix 5: Nutrient Content of Common Fertilizers & 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
SYNTHETIC MINERALS							
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
MINED MINERALS							
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
CALCIUM AMENDMENTS							
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
ORGANIC MATTER FERTILIZERS & AMENDMENTS							
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 6: Approximate Pounds/Acre of Nutrients Removed by Common Crops

CROP	YIELD	NITROGEN	PHOSPHATE	POTASH	CALCIUM	MAGNESIUM	SULFUR
GRAINS							
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
HAY - LEGUMES							
Alfalfa	10 tons	600	140	500	280	50	50
Vetch	5 tons	275	75	225	120	25	25
HAY - GRASSES							
Coastal Bermuda	10 tons	500	120	350	75	45	60
Timothy	5 tons	180	68	220	40	24	14
FRUITS AND VEGETABLES							
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.