1.1 Managing Soil Fertility

Introduction 3

Instructor's Lecture 1 Outline: Soil Fertility Management—Concepts, Goals, and Components 5

Detailed Lecture 1 Outline for Students 9

Instructor's Lecture 2 Outline: Sustainable Agriculture Practices 15

Detailed Lecture 2 Outline for Students 19

Assessment Questions and Key 23

Resources 25

Introduction: Soil Fertility Management

UNIT OVERVIEW

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

MODES OF INSTRUCTION

> LECTURE (2 LECTURES, 3 HOURS TOTAL)

Lecture 1 presents the concepts, objectives, and components of sound soil fertility management programs for certified organic production systems. Lecture 2 describes the sustainable agriculture practices (e.g., tillage, cover crops, composts, soil amendments) that go into organic fertility management.

> ASSESSMENT QUESTIONS (0.5 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

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

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

for the instructor

A. Pre-Assessment Questions

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

B. Organic Agriculture

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

C. Soil Fertility and Soil Quality in Sustainable Farming Systems

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

c) Soil fertility: The capacity of a soil to provide nutrients required by plants for growth; one component of soil quality

2. Soil fertility, plant health, and the resistance and resilience of crop plants to pest and pathogens

D. Goals of a Sustainable Soil Fertility Management Program

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

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

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

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

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

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

for students

A. Pre-Assessment Questions

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

B. Organic Agriculture

1. "Certified Organic" agriculture as defined by The National Organic Program (NOP; www.ams.usda.gov/nop/)

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

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

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

v. Fifth, the organic system plan must describe the management practices and physical barriers established to prevent commingling of organic and non-organic products

vi. Finally, the organic system plan must contain the additional information deemed necessary by the certifying agent to evaluate site-specific conditions relevant to compliance with these or applicable State program regulations.

3. "Sustainable agriculture" defined (see www.sarep.ucdavis.edu)

Sustainable agriculture can be defined as an approach to agriculture where the aim is to create environmentally sound, economically viable, and socially just food and agricultural systems. Maximum reliance is placed on locally or farm-derived renewable resources and the management of self-regulating ecological and biological processes and interactions in order to provide acceptable levels of crop, livestock, and human nutrition, protection from pests and diseases, and an appropriate return to the human and other resources employed. Reliance on external inputs, whether chemical or organic, is reduced as far as possible. The objective of long-term sustainability lies at the heart of organic farming and is one of the major factors determining the acceptability of specific production practices.

Sustainable agriculture is not just the conservation of non-renewable resources (soil, energy, minerals) used to produce food and fiber. Sustainable agriculture also encompasses maintenance or restoration of the environmental quality of surrounding landscapes; the economic viability for all involved in agricultural production; and more equitable distribution of agricultural products to assure that basic human needs are met (see Unit 3.4, Sustainable Agriculture and Food Systems).

C. Soil Fertility and Soil Quality in Sustainable Farming Systems

1. Soil fertility and soil quality defined (see soils.usda.gov/sqi/)

a) Soil quality: The capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health

b) Soil quality indicators

i. Soil accepts, holds, releases, and mineralizes nutrients and other chemical constituents

ii. Soil accepts, holds, and releases water to plants, streams, and groundwater

iii. Soil promotes good root growth and maintains good biotic habitat for soil organisms

iv. Soil resists degradation (e.g., erosion, compaction)

v. Soil maintains good soil structure to provide adequate aeration

vi. Good soil structure allows for rapid water infiltration

vii. Soil has a moderate pH (~6.0–7.0) at which most essential soil nutrients are available

viii. Soil has low salinity levels

ix. Soil has low levels of potentially toxic elements (e.g., boron, manganese, and aluminum)

x. Balanced fertility that provides adequate levels of macro- and micronutrients that plants and soil microbes require

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

2. Soil fertility, plant health, and the resistance and resilience of crop plants to pest and pathogens

Soil fertility requires a balance of critical plant nutrients and either deficiency or excess of nutrients can adversely affect plant growth, susceptibility to pests, and post-harvest quality

D. Goals of a Sustainable Soil Fertility Management Program

1. To sustain high crop productivity and crop quality in food and fiber production (not maximum yields, which typically require excessive nutrient inputs to achieve)
   a) Crop productivity, crop quality, and the economic viability of a given farming operation
2. To minimize environmental quality and human health risks associated with agricultural production
   a) Important steps in minimizing human health risks and on- and off-farm impacts
      i. Avoid the use of all synthetically compounded materials (e.g., fertilizers and pest control agents, etc.) known to have an associated environmental quality or human health risk
      ii. Avoid creating non-point source pollution through surface runoff and leaching. Agricultural nutrients can degrade the quality of groundwater or the water in rivers, lakes, wetlands, and estuaries through eutrophication.
      iii. Prevent soil erosion and sedimentation of waterways. Soil loss reduces production capacity and soil entering waterways may degrade aquatic habitat.
      iv. Close nutrient cycles as much as possible within the field and farm to reduce energy used and environmental impact of food and fiber production
      v. Close nutrient cycles at multiple scales (e.g., watershed, regional, and national scales)

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

1. Improve and maintain physical and biological properties of soil
   a) Sustainable agricultural practices used to improve and sustain soil physical and biological properties
      i. Maintaining or building soil organic matter (SOM) levels through inputs of compost and cover cropping: SOM has a large capacity to hold and release inorganic (crop-available) nitrogen and other essential nutrients. Organic matter inputs enhance the stability of soil aggregates, increase the porosity and permeability to water and air, and improve the water-holding capacity of soils. Building or maintaining the level of soil carbon provides the energy and nutrients necessary to stimulate the soil biological activity responsible for decomposition, the formation of soil aggregates, and more desirable soil structure.
      ii. Properly timed tillage: Stimulates the decomposition of SOM by increasing aeration (O_2 supply to aerobic microbes), breaking up compacted areas and large soil clods, and exposing a greater surface area of SOM for microbial breakdown. Appropriate tillage also increases water infiltration and good drainage (see Unit 1.2, Garden and Field Tillage and Cultivation).
      iii. Irrigation: For irrigation-dependent crops, manage soil moisture between 50% and 100% of field capacity through soil moisture monitoring and moisture retention techniques such as mulching
      iv. Use of sound crop rotations, soil amending, and fertilizing techniques all serve to improve the quality of agricultural soils, which in turn affects soil quality and crop performance
2. Improve and maintain chemical properties of soil
   a) Benchmarks of optimal soil chemistry
      i. Balanced levels of available plant nutrients (see Unit1.11, Reading and Interpreting Soil Test Reports, for more on this subject)
      ii. Soil pH ~6.0–7.0: At this soil pH the greatest amount of soil nutrients are available to crops
      iii. Low salinity levels: The accumulation of salts in the soil may result in plant water and salt stress

b) Sustainable agricultural practices used to develop and maintain optimal soil chemical properties
   i. Provide a balanced nutrient supply for the crop. As plant growth is related to the availability of the most limiting nutrient, it is essential that we consider the balance (ratios) of soil nutrients available. Yield and quality may be limited if levels of some nutrients are too high while others are too low.
   ii. Conduct soil analysis with periodic monitoring. Soil analysis provides current quantitative information on the nutrient profile of a given soil. Soil analysis report data should be compared to established optimal benchmarks of soil fertility when developing soil amendment plans to assure adequate but not excessive nutrient applications. Comparing results from multiple years of sampling will show whether you are depleting or accumulating soil nutrients over time, and indicate whether changes in fertility management are needed.
   iii. Conduct plant tissue testing. In-season plant tissue testing provides current quantitative data on the nutrient profile of growing plants. Such data may be compared with recommended nutrient levels and may be used to determine the need for mid-season supplemental fertilizing (see Resources section). However, be aware that most tissue testing information has been developed for systems using synthetic chemical fertilizers, and sufficiency levels may well differ for organic systems.
   iv. Time seasonal nutrient release from organic amendments to correspond with crop requirements. Example: Along the central coast of California, crops are planted approximately 2–3 weeks after the incorporation of cover crops in late March–early April in order to synchronize the nitrogen demand of cash crops with the nitrogen liberated from cover crop decomposition. Important factors influencing the mineralization rate include:
      - The quality of the organic matter input: E.g., carbon:nitrogen ratio, lignins, tannins, polyphenols, etc.
      - Environmental factors such as soil temperature and moisture
      - Note: When nitrogen from cover crops is mineralized in excess of crop demand, nitrate will be vulnerable to leaching
   v. Avoid leaving fields bare to avoid wind and water erosion and nutrient leaching
   vi. Manage irrigation carefully to avoid runoff, erosion, and leaching of soluble nutrients
   vii. Supply major nutrients primarily through organic matter and mineral soil amendments (e.g., cover crops, composts, limestone, rock phosphate, etc.)
   viii. Allow sufficient time for fresh residue to break down before planting crops
   ix. Use in-season supplemental fertilizers (when suggested as necessary by soil test results, plant growth observations, or plant tissue testing) to prevent or address plant nutrient deficiencies

3. Minimize disease/pest susceptibility
   a) Sustainable agriculture practices used to minimize disease/pest susceptibility in organic farming systems
      i. Maintain soil nutrient levels and soil pH within optimal range to reduce possibility of plant nutrient deficiencies or excesses. Plant nutrient deficiencies or excesses often lead to increased susceptibility to pests and pathogens.
      ii. Build and maintain soil organic matter to promote desirable soil physical properties and supply essential plant nutrients. Soil physical properties are an essential component of soil fertility, influencing aeration (gas exchange and mineralizaton), drainage, root penetration and development, and habitat for beneficial soil microbes that may impart disease-suppressive qualities to agricultural soils.
      iii. Maintain soil moisture within optimal ranges for plant growth and the avoidance of compaction and erosion.

iv. Design appropriate rotations to break pest cycles, and include disease-suppressive crops or cover crops. Annually changing the place in the garden or field where crops are grown interrupts the host/pest cycle and thereby reduces or limits the development of populations of pest and pathogens.

v. Plant polycultures. Planting a diversity of crops in a garden or farm reduces the carrying capacity of the land for a given pest population.

vi. Use appropriate preventive (e.g., farmscaping) and active biocontrol practices to suppress the growth of pest populations (see Unit 1.8, Managing Arthropod Pests)

4. Summary

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

Lecture 2 Outline: Sustainable Agriculture Practices

for the instructor

A. Soil Tillage in Sustainable Agriculture

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

B. Cover Crops in Sustainable Agriculture

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

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

C. Composts and Animal Manures in Sustainable Agriculture

1. Composts
   a) How much compost to apply annually
   b) The nutrient contribution of a manure-based compost: ~1N-1P-1K, i.e., balanced contribution of N-P-K. As nutrient levels in compost vary, it is recommended that you check with supplier or have a compost nutrient assessment done to confirm nutrient levels and proportions.
   c) Application timing: Nutrient release should ideally coincide with crop demand
      i. Depending on compost quality, may be an inefficient source of N in short term
      ii. Release of N may last 6 weeks–several months following incorporation, depending on compost quality and environmental conditions
      iii. Need to incorporate into root zone if applying mid season as side dress
   d) Compost quality indicators
      i. C:N ratio
      ii. CO_2 levels
      iii. Ammonia levels
      iv. Smell

v. Color

vi. Texture/feel

vii. Temperature

e) Ease and economics of use

f) Labor and/or equipment requirements for on-farm production of compost (see Unit 1.7, Making and Using Compost)

g) National Organic Program standards for on-farm compost production

h) Transportation issues

i. Local/regional availability and costs

ii. Variability in quality

2. Manure

a) The use of fresh and undecomposed manure in agricultural systems

b) Restrictions on the use of manure under National Organic Standards of 2002

c) Variations in the nutrient profiles of animal manures

d) Handling and storage of animal manures to conserve nutrients

e) Food safety issue

D. Soil Amendments and Supplemental Fertilizers in Sustainable Agriculture

1. Organic amendments

a) OMRI/NOP-certified materials in certified organic farming systems

b) Nutrient budgeting

2. Supplemental fertilizers

a) When used

3. Soil fertility management and nutrient budgets: Balancing nutrient inputs with nutrient outputs each year

a) Inputs > outputs = accumulation. Potential risk of excess nutrients creating nonpoint source pollution through leaching and run off, and enhancing disease and pest incidence.

b) Inputs < outputs = soil depletion. Potential risk of plant nutrient deficiencies and stress, reduced yield, and increased susceptibility to pest and pathogens.

c) Goal: Balance inputs and outputs once you have achieved desired/optimal nutrient levels in the soil

Example of inputs factored into budget for nitrogen

i. Inputs = imported fertilizers and amendments + atmospheric deposition + N fixation through cover crops

ii. Outputs = N exported in crop harvest + N lost through leaching, erosion, and denitrification

iii. Calculating nutrient budgets: See Unit 1.11, Reading and Interpreting Soil Test Reports

4. Application of nutrient budgets in assessing the health of larger-scale units: Watersheds, regions. Example of accumulation and depletion, e.g., the impact of high densities of confinement animal production facilities.

E. Crop Rotation in Sustainable Agriculture

1. Crop rotation

2. Rotation considerations

a) Try to avoid rotation of crop species that share similar pests and diseases. Intersperse with different crops to break pest and disease cycles.

i. Example: Solanaceae rotation

b) Rotation of crops to maximize use of nutrient inputs and distribute nutrient demand placed on the soil
    i. Examples of multi-year crop rotations (see Coleman 1995)
c) Fallow periods and perennial cover crop rotations

Detailed Lecture 2 Outline: Sustainable Agriculture Practices

for students

A. Soil Tillage in Sustainable Agriculture

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

B. Cover Crops in Sustainable Agriculture

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

iii. As a source of labile carbon, cover crops can stimulate microbial activity and increase the breakdown of existing SOM

iv. Deep-rooted cover crops are able to recycle nutrients acquired from deeper in the soil profile (e.g., phosphorus)

v. Grass/cereal cover crops, when used alone or with nitrogen-fixing legume cover crops, may reduce nutrient losses by capturing mobile nutrients (e.g., N) that would otherwise be vulnerable to leaching, or loss through soil erosion

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

ii. Allelopathy: Many plants and certain cover crop species secrete allelopathic compounds from their root systems or other plant part. Such compounds inhibit the germination and retard the vegetative development of weedy plants.

d) Importance of gathering regional cover crop information: Which to use, which to avoid to address pests and diseases prevalent in your area

C. Composts and Animal Manures in Sustainable Agriculture

1. Composts (see Unit 1.7, Making and Using Compost, for additional information)
    a) Common annual application rates: ~4–5 tons/acre/year on field scale; 10–12 tons/acre/year on garden scale (cropping dependent)
    b) The nutrient contribution of compost: ~1-1-1 (N-P-K on a dry-weight basis); varies with source. Check with supplier or have a compost nutrient assessment done to confirm nutrient levels and proportions.
    c) Application timing: Nutrient release should ideally coincide with crop demand
        i. Depending on compost quality, may be an inefficient source of N in short term
        ii. Release of N may last 6 weeks–several months following incorporation, depending on compost quality and environmental conditions
        iii. Need to incorporate into root zone if applying mid season as side dress
    d) Compost quality indicators (see Unit 1.7, Making and Using Compost, for details)
        i. C:N ratio
        ii. CO_2 levels
        iii. Ammonia levels
        iv. Smell
        v. Color
        vi. Texture/feel
        vii. Temperature
    e) Ease and economics of use: E.g., costs associated with shipping, application equipment
    f) Labor and/or equipment requirements for on-farm compost production (see Unit 1.7, Making and Using Compost)
    g) National Organic Program standards for on-farm compost production
    h) Transportation issues
        i. Local/regional availability and costs
        ii. Variability in quality
2. Manure
    a) The use of fresh and undecomposed manure in agricultural systems: Cropping in soils with fresh and/or undecomposed manures may result in nitrogen "burns" (due to high ammonium levels) and nitrate depression/net immobilization, respectively
    b) Restrictions on the use of manure under National Organic Standards of 2002 (see Resources reference on National Organic Program)
    c) Variations in the nutrient profiles of animal manures: The nutrient profile of fresh manures range from approximately .75-.75-.75 (horse manure) to 2-2-2 (poultry manure). See the *Rodale Book of Composting* in the Resources section for more information.
    d) Handling and storage of animal manures for the conservation of nutrients: Fresh animal manures should be temporarily stored and protected from sun and rain by covering with tarps
    e) Food safety issue: NOP guidelines designed to prevent contamination by E. coli and other disease-causing organisms

D. Soil Amendments and Supplemental Fertilizers in Sustainable Agriculture

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

E. Crop Rotation in Sustainable Agriculture

1. Crop rotation: Crops vary in their specific nutrient requirements and their ability to access nutrients from different parts of the soil. A good rotation will take this into account. For example, follow a high nutrient-demanding, shallow-rooted vegetable crop such as lettuce or spinach with a deeper-rooted crop or cover crop that can utilize the available nutrients left in the soil. This is especially important if these residual nutrients are susceptible to leaching during high rainfall periods.
2. Rotation considerations
   a) Try to avoid rotation of crop species that share similar pests and diseases. Intersperse with different crops to break pest cycles.
      i. Example: Solanaceae rotation. It is common practice to change the location of Solanaceae family crops each year. Because these crops (tomatoes, eggplants, peppers, potatoes, etc.) share common pests and pathogens, repeated cropping in the same location can lead to the buildup of pest populations.
   b) Rotation of crops to maximize use of nutrient inputs and distribute nutrient demand placed on the soil
      i. Examples of multi-year crop rotations (see Coleman 1995)
   c) Fallow periods and perennial cover crop rotations. Fallow periods—areas intentionally left uncultivated and planted to perennial cover crops (e.g., perennial rye grass)—allow the soil to remain undisturbed and the aggregation processes to proceed uninterrupted. This can help restore the desired physical properties of agricultural soils.

Assessment Questions

1) What is certified organic agriculture?

2) Describe the goals of an organic and sustainable soil fertility management program.

3) Define soil fertility.

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

5) What are the major goals of a sound soil fertility management program? List two organic/sustainable agricultural practices that help to assure each.

Assessment Questions Key

1) What is certified organic agriculture?

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

2) Describe the goals of an organic and sustainable soil fertility management program.

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

3) Define soil fertility.

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

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

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

5) What are the major goals of a sound soil fertility management program? List two organic/sustainable agricultural practices that help to assure each.

   1. *Improve and maintain physical and biological properties of soil*

   - *Organic matter inputs: Compost and cover crops*
   - *Fallow periods*
   - *Properly timed irrigation and tillage*
   - *Soil testing and proper soil amending*

   2. *Improve and maintain chemical properties of soil*

   - *Organic matter inputs: Compost and cover crops*
   - *Soil testing and proper soil amending*
   - *Supplemental fertilizing when necessary*
   - *Avoid leaving soils exposed*
   - *Proper irrigation to avoid leaching of nutrients*

   3. *Minimize disease/pest susceptibility*

   - *Design appropriate crop rotations and fallow periods*
   - *Polycultures/non-monoculture production*
   - *Use appropriate preventive and active biocontrol practices*
   - *Provide optimal level and balance of nutrients for good plant health*

Resources

PRINT RESOURCES

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

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

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

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

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

An introductory overview of organic management of soil fertility covering the basics of soil organic matter, physical, and chemical properties of soil, ecological soil and crop management. Practical and accessible information. Available from www.sare.org.

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

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

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

Very useful information on the characteristics, costs, seeding rates, and management of different cover crop species. Available from www.sare.org.

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

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

WEB RESOURCES

Alternative Farming Systems Information Center, USDA

www.nal.usda.gov/afsic/

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

Appropriate Technology Transfer for Rural Areas (ATTRA)

www.attra.org/

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

Organic Materials Review Institute (OMRI)

www.omri.org

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

Soil Quality Institute—NRCS

soils.usda.gov/sqi/

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

UC Sustainable Agriculture Research and Education Program (SAREP)

www.sarep.ucdavis.edu/

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

USDA National Organic Program

www.ams.usda.gov/nop/

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