

1.2 Garden and Field Tillage and Cultivation

Introduction	3
Instructor's Lecture Outline	5
Detailed Lecture Outline for Students	9
Demonstration 1: French-Intensive Soil Cultivation	19
Instructor's Demonstration Outline	21
Students' Step-by-Step Instructions	25
Hands-on Exercise	29
Demonstration 2: Mechanical Tillage and Cultivation	31
Assessment Questions and Key	33
Resources	36
Glossary	37
Appendices	
1. Estimating Soil Moisture By Feel	38
2. Tillage and Planting Implements	39
3. Double-Digging Sequence	43
4. Side Forking	44

Introduction: Soil Tillage and Cultivation

UNIT OVERVIEW

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

MODES OF INSTRUCTION

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

LEARNING OBJECTIVES

CONCEPTS

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

SKILLS

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

Lecture Outline: Soil Tillage and Cultivation

for the instructor

A. Pre-Assessment Questions

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

B. Defining Soil Cultivation and Soil Tillage

1. Cultivation
2. Tillage

C. Aims of Soil Cultivation

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

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

D. Types of Soil Cultivation

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

E. Factors Influencing Timing and Type of Cultivation

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

F. Possible Consequences of Frequent and Intensive Soil Cultivation

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

G. The French-Intensive System of Soil Cultivation

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

H. Mechanical/Field-Scale Tillage Systems

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

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

Detailed Lecture Outline: Soil Tillage and Cultivation

for students

A. Pre-Assessment Questions

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

B. Defining Soil Cultivation and Soil Tillage

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

C. Aims of Soil Cultivation

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

- ii. Oxygen (O₂): When combined with organic matter inputs, elevated soil oxygen levels may increase soil biological diversity, stimulate soil biological activity, and increase the rate of mineralization. Soil aeration replenishes the soil oxygen reservoir that is continually being taken up through plant roots for use in respiration.
 - iii. Carbon dioxide (CO₂): Cultivation allows for the movement of CO₂ out of the soil, to be replaced with oxygen and nitrogen
 - b) Increase water infiltration, percolation, retention and drainage characteristics. A soil made more permeable through proper tillage allows water to infiltrate the soil and percolate slowly downward, draining into the subsoil at rates optimal for both crop plants and soil microbes.
 - c) Soil aeration increases the rate of mineralization and the release of plant-available nutrients into the soil solution for uptake by plant roots
4. To increase the temperature of cold soils in the spring
- Soil air warms more quickly than soil water and soil solids. Soils with well-developed aggregations and adequate pore space maintain more desirable drainage characteristics and therefore dry and increase in temperature more rapidly than soils having fewer pore spaces. Biological activity and biogeochemical reactions increase at higher soil temperatures, with soil temperatures of 50–55°F being a threshold below which mineralization rates and plant growth dramatically slow.
5. To incorporate mineral and organic matter soil amendments
- Cultivation is a practical means of incorporating organic matter and mineral amendments, cover crops, and crop residues. Cultivation may be used to incorporate soil amendments to desired soil depths in order to increase the immediate or long-term availability of essential plant nutrients or to improve the physical and/or chemical properties of the soil.
- a) Composts, manures, and fertilizers: Tillage and cultivation techniques are needed to incorporate organic matter amendments beneath the soil surface in order to avoid the loss of carbon and volatile nitrogen compounds through surface oxidation. Tillage may also be used to evenly distribute organic matter amendments for general soil improvement or to place fertilizers in particular locations for specific short-term crop nutrient requirements (i.e., banding).
 - b) Incorporation of mineral amendments: Mineral soil amendments must be incorporated into the soil to allow for additional biological or chemical decomposition and to liberate and cycle essential plant nutrients
6. To manage crop residues and cover crops
- a) Crop residues: Tillage is used primarily in mechanized systems to incorporate crop residues. This process cycles the organic matter and nutrients held in the crop tissues back into the soil and prepares the site for subsequent cropping.
 - b) Cover crops: Tillage is also used to incorporate cover crops in order to cycle organic matter and nutrients held in the cover crop tissues back into the soil and to prepare the site for subsequent cropping. The nutrients liberated as cover crops decompose may be a significant source of essential plant nutrients for a given season's crop production.
7. To control weeds
- Cultivation is a practical means of destroying annual weeds and weakening crowns and rhizomes of perennial weeds. Because cultivation stimulates germination of annual weed seeds, multiple cultivations prior to transplanting or direct sowing may be used to reduce the soil weed seed bank and thereby reduce weed competition with cultivated crops.
8. To create particulate seed beds and root beds

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

9. To manage plant pathogens and insect pests

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

10. To retain soil moisture

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

D. Types of Soil Tillage

1. Primary tillage

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

2. Secondary tillage

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

3. Surface cultivation or cultivation tillage

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

E. Factors Influencing Timing and Type of Tillage

1. Soil moisture

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

2. Soil texture classification

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

3. Climate

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

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

4. Season (temperate climate)

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

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

F. Possible Impacts of Frequent and Intensive Soil Cultivation

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

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

G. The French-Intensive Method of Soil Cultivation

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

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

H. Mechanical/Field-Scale Tillage Systems

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

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

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

Demonstration 1: French-Intensive Soil Cultivation

for the instructor

OVERVIEW

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

SITE PREPARATION AND MATERIALS

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

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

PREPARATION TIME

1.5 hours

DEMONSTRATION TIME

1.5 hours

DEMONSTRATION OUTLINE

A. Plan the Cultivation with Students

1. Assess soil prior to cultivation

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

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

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

B. Demonstrate Site Preparations

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

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

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

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

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

3. Alternative cultivation tools: Advantages and disadvantages

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

E. Demonstrate and Discuss Secondary Cultivation Steps

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

F. Discuss Evaluation Process

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

Demonstration 1: French-Intensive Soil Cultivation

step-by-step instructions for students

INTRODUCTION

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

PREPARATION AND MATERIALS

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

Collect and organize the materials listed above.

A. Cultivation Planning

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

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

B. Soil Cultivation Preparations

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

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

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

D. Primary Cultivation Steps

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

E. Secondary Cultivation Steps

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

F. Evaluation

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

Hands-On Exercise: French-Intensive Soil Cultivation

for the student

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

PREPARATION AND MATERIALS

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

EXERCISE

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

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

Demonstration 2: Field Demonstration of Mechanical Tillage and Cultivation

for the instructor

OVERVIEW

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

PREPARATION AND MATERIALS

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

PREPARATION TIME

1 hour

DEMONSTRATION TIME

1.5 hours

DEMONSTRATION OUTLINE

A. Demonstration of Primary Tillage Implements

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

B. Demonstration of Secondary Tillage Implements

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

C. Demonstration of Row Crop Cultivation Implements

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

Assessment Questions

- 1) List four objectives of soil tillage.

- 2) What are two possible problems associated with tilling soil when it is too wet? What are two possible problems associated with tilling soil when it is too dry?

- 3) What is the optimal range of soil moisture (in % field capacity) for tillage operations?

- 4) What are you attempting to achieve through the double-digging process? In what situations is this technique best applied?

- 5) What are the common tillage sequences used in preparing ground in the spring? Please give steps for both French-intensive (double digging) and mechanical cultivation.

Assessment Questions Key

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

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

Resources

PRINT RESOURCES

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

An overview of the French-intensive method of horticulture.

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

Contains a chapter on tillage and cropping systems.

WEB RESOURCES

Agricultural Network Information Center

www.agnic.org/

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

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

www.ccagcans.com/cansdefault.html
(see "Course Curriculum")

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

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

zzyx.ucsc.edu/casfs/instruction/esa/index.html

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

Good Fruit Grower

www.goodfruit.com/buyers/equipment.html

Listing of national equipment retailers.

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

www.ianr.unl.edu/pubs/fieldcrops/g1046.htm

Tillage system descriptions and comparisons.

USDA—Agricultural Research Service

www.florence.ars.usda.gov/research/bauer.htm

Research on no-till cropping systems.

Glossary

Aerobic

Oxygen containing

Cultivation

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

Diffusion

The dispersal of gases through a medium

French intensive

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

Granular structure

A specific and desirable form of soil structure

Humus

Residual and decomposed organic matter held in the soil

Infiltration

The absorption of water into the soil

Organic matter

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

Pan

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

Percolation

The downward movement of water through soil horizons

Pore space

The air spaces between soil particles

Primary cultivation

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

Secondary cultivation

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

Soil horizon

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

Soil organic matter

Organic matter held in the soil

Soil separates

Individual soil particles of sand, silt, and clay

Soil structure

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

Soil texture

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

Soil tilth

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

Tillage

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

Appendix 1: Estimating Soil Moisture By Feel

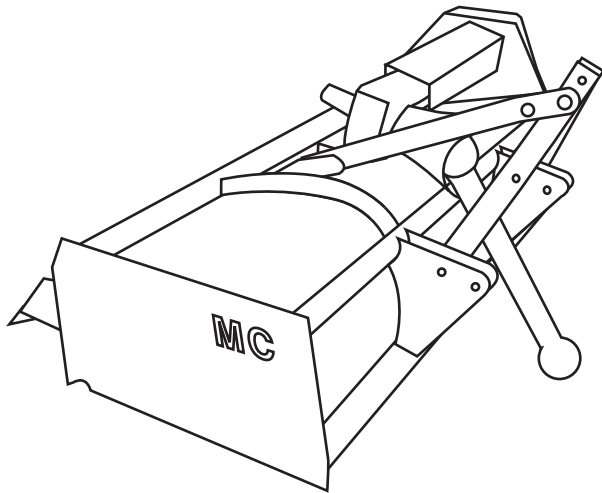
SOIL MOISTURE LEVEL (% OF FIELD CAPACITY)	COARSE (SAND)	LIGHT (LOAMY SAND, SANDY LOAM)	MEDIUM (FINE, SANDY LOAM, SILT LOAM)	HEAVY (CLAY LOAM, CLAY)
0 –25% No available soil moisture. Plants wilt. Irrigation required. (1 st range)	Dry, loose, single grained, flows through fingers. No stain or smear on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

¹Ribbon is formed by squeezing and working soil between thumb and forefinger.

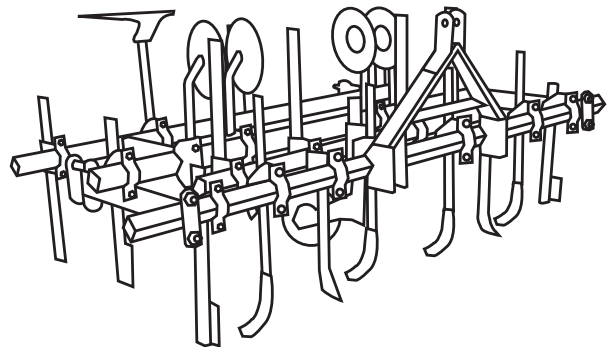
²Cast or ball is formed by squeezing soil in hand.

Appendix 2: Tillage and Planting Implements

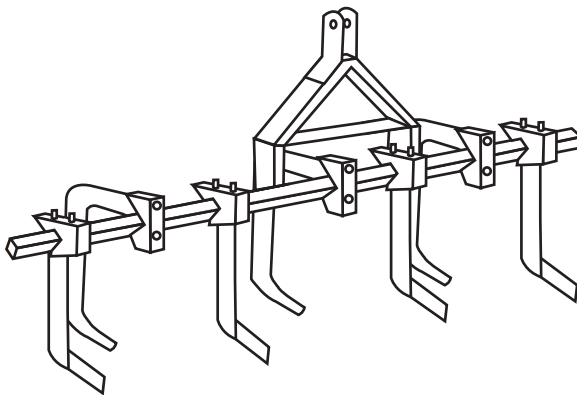
FIELD-SCALE IMPLEMENTS



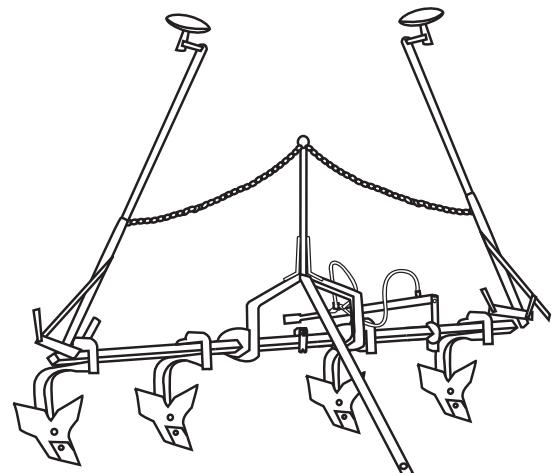
3-Point Flail Mower



3-Bar Cultivator



3-Point Chisel

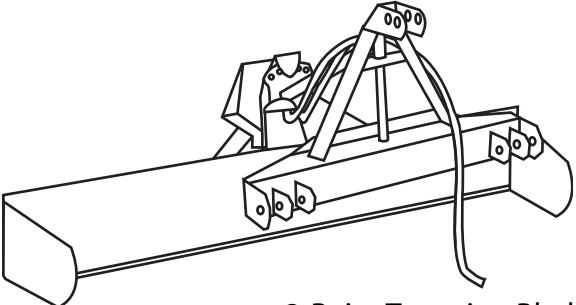


Lister Bar

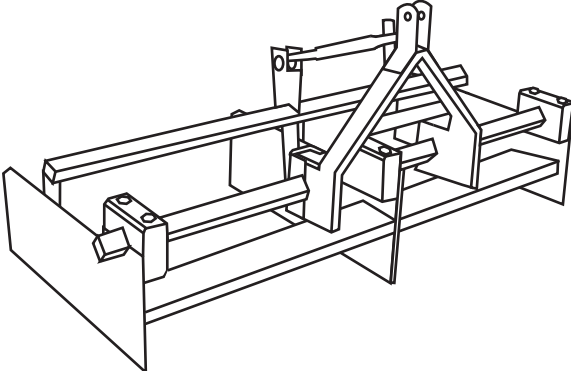
illustrations by Cathy Genetti Reinhard; not to scale

Appendix 2: Tillage and Planting Implements

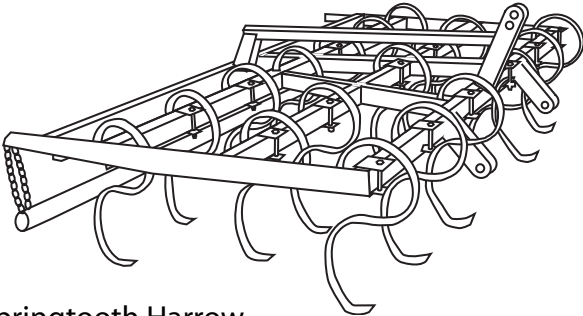
FIELD-SCALE IMPLEMENTS



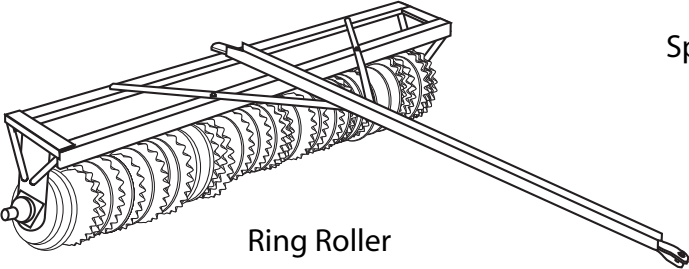
3-Point Terracing Blade



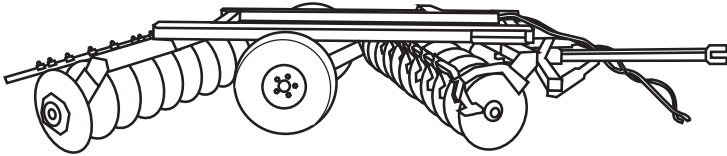
2-Row Bed Shaper



Springtooth Harrow



Ring Roller

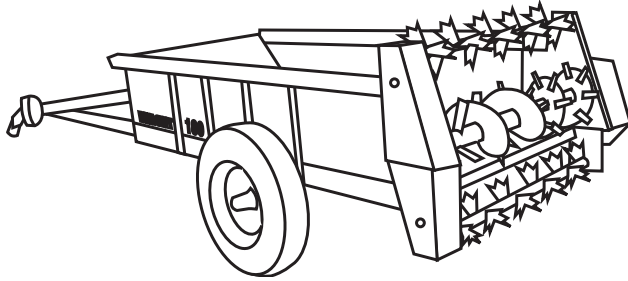


Offset Wheel Disc

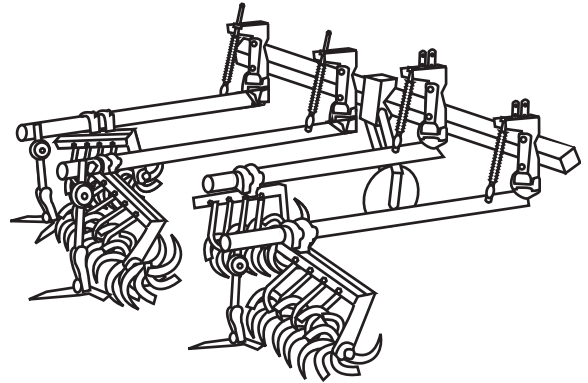
illustrations by Cathy Genetti Reinhard; not to scale

Appendix 2: Tillage and Planting Implements

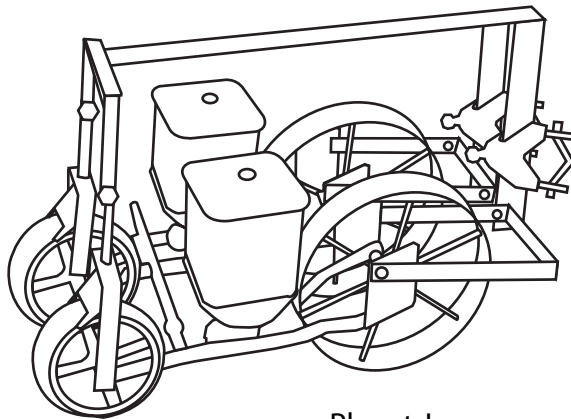
FIELD-SCALE IMPLEMENTS



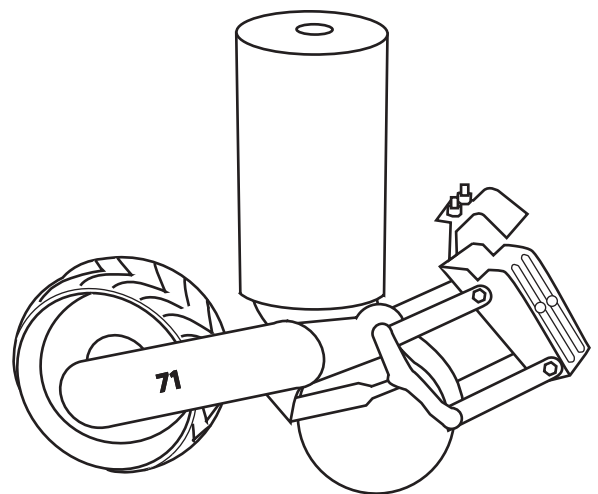
Manure Spreader



Lilliston Cultivator



Planet Jr.
Vegetable Planter

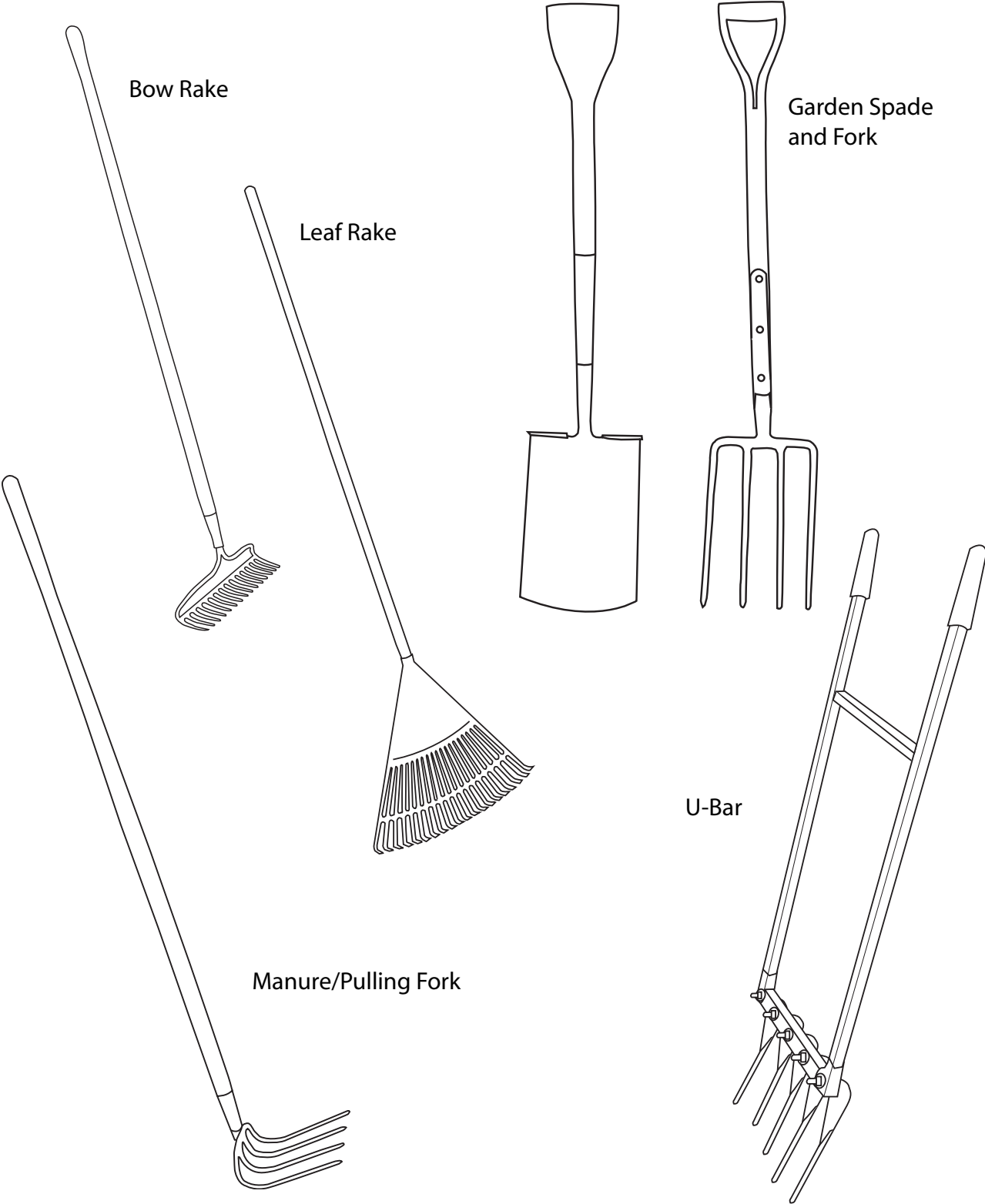


John Deere Model 71 Plate
Planter

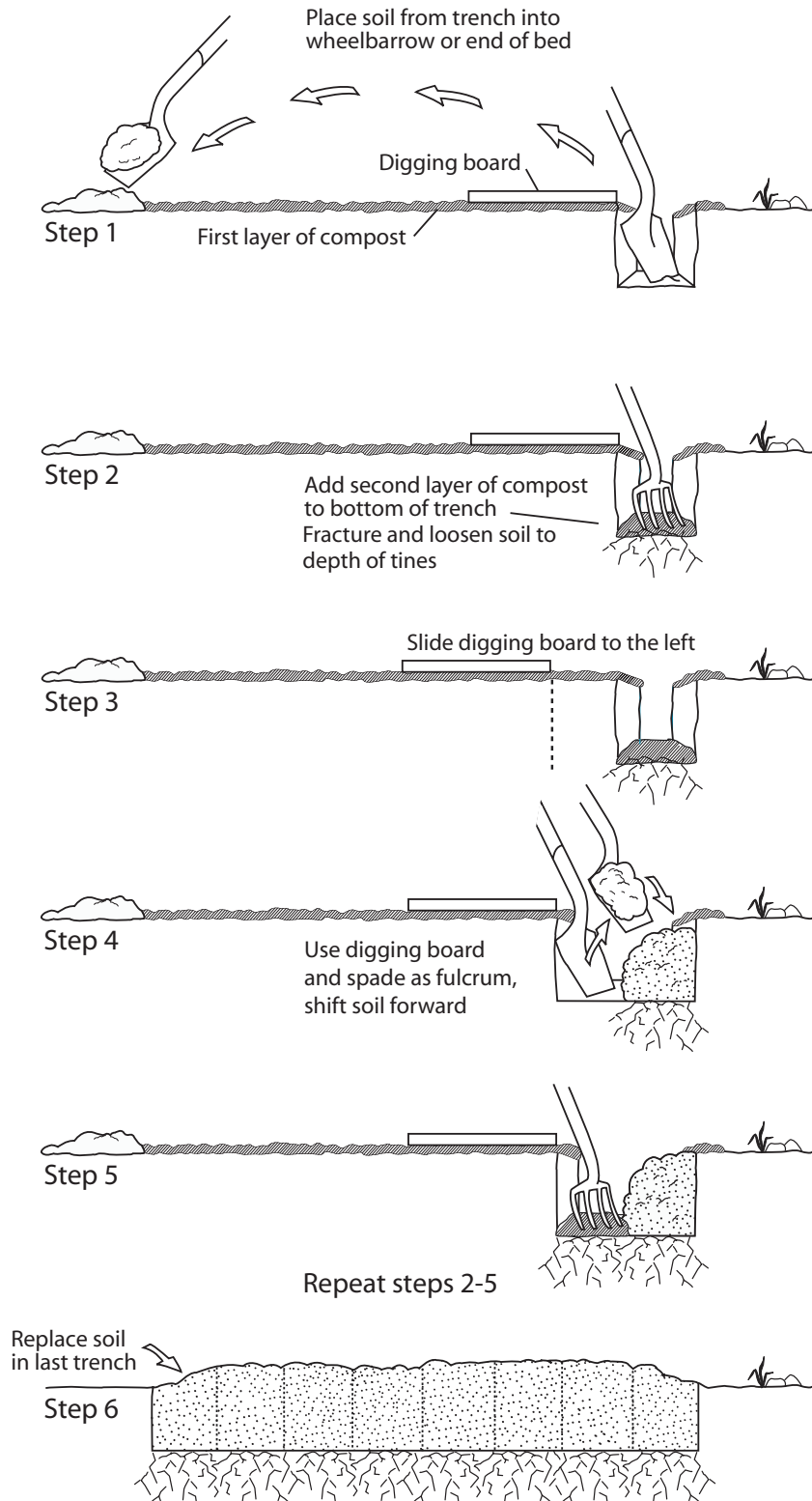
illustrations by Cathy Genetti Reinhard; not to scale

Appendix 2: Tillage and Planting Implements

GARDEN-SCALE IMPLEMENTS

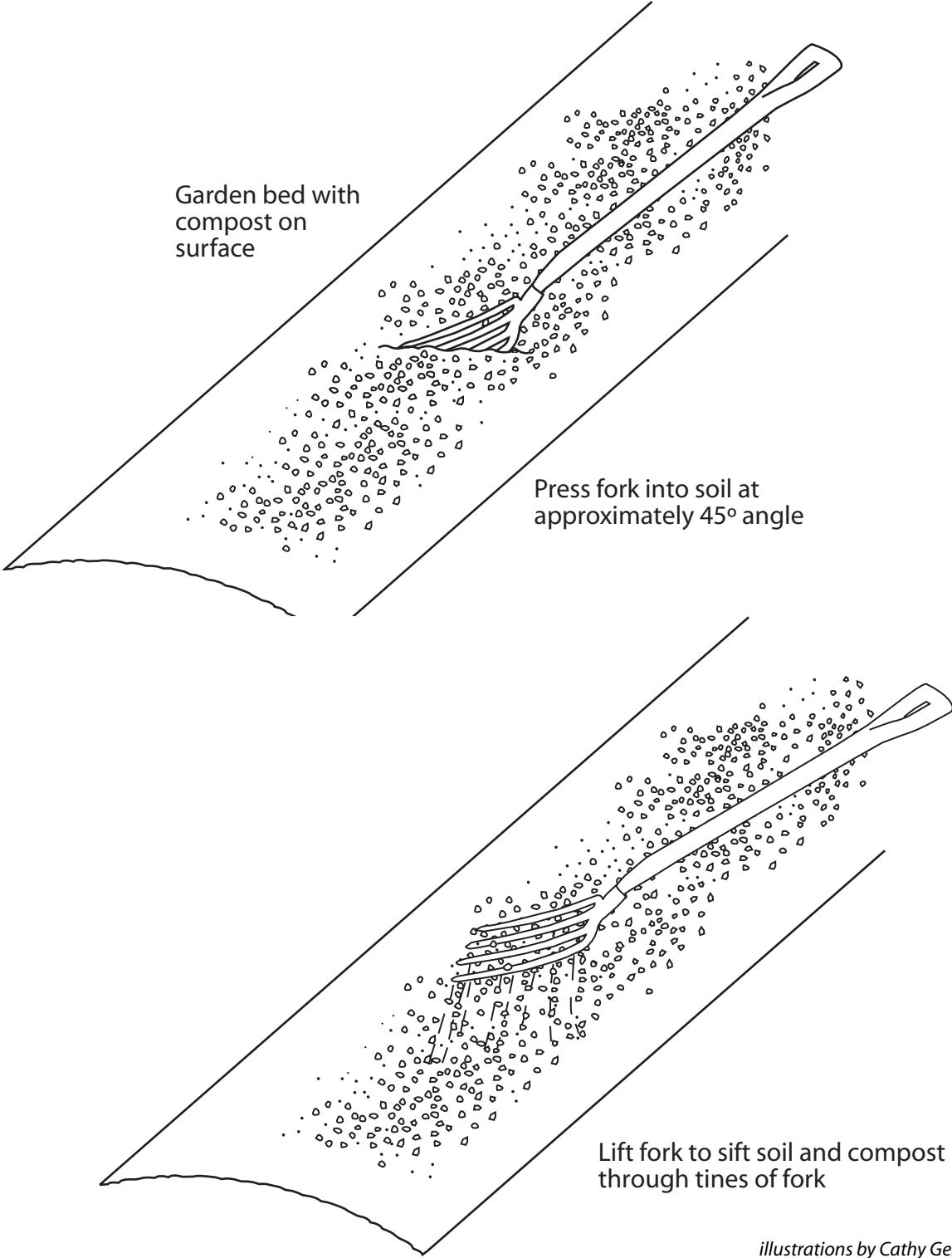


Appendix 3: Double Digging Sequence



illustrations by
Cathy Genetti Reinhard

Appendix 4: Side Forking Technique



illustrations by Cathy Genetti Reinhard