

# Garden and Field Tillage and Cultivation

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# Introduction: Soil Tillage & Cultivation

## UNIT OVERVIEW

*Cultivation is a purposefully broader concept than simply digging or tilling the soil—cultivation involves an array of tools, materials and methods that, when properly combined, promote and maintain optimum soil health and good tilth, a composite term for the overall physical characteristics of a soil (texture, structure, permeability, consistency, drainage, and water-holding capacity). In short, tilth equals the workability of a soil in relationship to its ability to grow plants.*

*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 tillage, students will learn about the aims of cultivation, and the appropriate applications of primary and secondary tillage techniques.*

Through demonstrations and a hands-on exercise, students will begin to develop the technical skills needed to cultivate French-intensive raised beds using both primary and secondary tillage tools and techniques, and will become familiar with the various tillage tools and processes used in mechanical cultivation and bed formation. Unit supplements detail cultivation goals, particularly at the garden scale; discuss tillage and bed formation sequences, and the importance of row spacings at the field scale; as well as the origins of the French intensive method.

## MODES OF INSTRUCTION

### > LECTURES (3 LECTURES, 1–1.5 HOURS EACH)

Lecture 1 covers the definition of cultivation and tillage, the general aims of soil cultivation, the factors influencing cultivation approaches, and the potential impacts of excessive or ill-timed tillage.

Lecture 2 includes a brief history of the French-intensive method of cultivation and the tillage tools and techniques used to prepare garden beds with this method.

Lecture 3 addresses tillage tools, techniques, and sequences used in field-scale mechanized production systems.

### > DEMONSTRATION 1: PREPARING THE GARDEN SITE FOR FRENCH-INTENSIVE CULTIVATION (1.5 HOURS)

Demonstration 1 outlines the steps for preparing a site for French-intensive permanent raised beds.

### > DEMONSTRATION 2: FRENCH-INTENSIVE CULTIVATION (1.5 HOURS)

Demonstration 2 outlines the steps for demonstrating the cultivation and maintenance of French-intensive permanent raised beds using primary and secondary cultivation.

### > HANDS-ON EXERCISE: GARDEN BED CULTIVATION (2 HOURS)

In this exercise, students practice cultivating permanent raised beds using traditional French-intensive cultivation techniques.

### > DEMONSTRATION 3: MECHANICAL TILLAGE AND CULTIVATION (1.5 HOURS)

The Demonstration 3 outline details the steps for demonstrating tractor-mounted tillage and cultivation equipment.

### > ASSESSMENT QUESTIONS (1 HOUR)

Assessment questions reinforce key unit concepts and skills.

### > POWERPOINT

See [casfs.ucsc.edu/about/publications](http://casfs.ucsc.edu/about/publications) and click on Teaching Organic Farming & Gardening.

## 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 1: Overview of Soil Tillage & Cultivation

## Pre-Assessment Questions

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

## A. 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

## B. Aims of Soil Cultivation (see also Supplement 1, Goals of Soil Cultivation)

1. To promote and maintain good soil structure and tilth, a composite term for the overall physical characteristics of a soil (such as texture, structure, permeability, consistence, drainage, and water-holding capacity)  
Primary cultivation loosens and opens untilled or compacted soils, allowing greater ease of root penetration and more desirable air/gas and water relations. Cultivation promotes soil particle aggregation by vertically distributing organic matter (e.g., cover crops, compost) and 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 hard pans  
Deep cultivation can physically fracture compacted and otherwise impervious soil layers or "hard pans," allowing more thorough aeration, the incorporation of soil amendments, and greater ease of root development. There are both naturally occurring and human created soil 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 foot traffic or animal grazing, especially when soils are moist (also known as "cow pan")
3. To aerate the soil
  - a) Cultivation increases soil air/gas exchange with the atmosphere. Cultivation timed to take place when beds are appropriately moist (50%–75% of field capacity) immediately increases soil pore space and aeration, allowing for the rapid diffusion of atmospheric gases into the soil. These gases, which include nitrogen, oxygen, and carbon dioxide, are vital components of soil air that are critical for plant growth. Proper cultivation techniques and the addition of organic matter and soil amendments encourage 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, ease of penetration by plant roots, and water infiltration, percolation, and drainage.
    - 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 ( $NO_3^-$ ) and ammonium

- ii. Oxygen (O<sub>2</sub>): When combined with organic matter inputs, elevated soil oxygen levels may increase soil biological diversity, stimulate soil biological activity, and increase the rate of microbial decomposition of organic matter in the soil. Soil aeration replenishes the soil oxygen reservoir that is continually being taken up through plant roots for use in respiration.
    - iii. Carbon dioxide (CO<sub>2</sub>): Cultivation allows for the movement of CO<sub>2</sub> out of the soil, to be replaced with oxygen and nitrogen
  - b) Increase water infiltration, percolation, retention, and drainage characteristics. A soil made more permeable through proper tillage allows water to infiltrate the soil and percolate slowly downward, draining into the subsoil at rates optimal for both crop plants and soil microbes.
  - c) Soil aeration increases the rate of mineralization and the release of plant-available nutrients into the soil solution for uptake by plant roots
4. To increase the temperature of cold soils in the spring
- Soil air warms more quickly than soil water and soil solids. Soils with well-developed aggregations and adequate pore space maintain more desirable drainage characteristics and therefore dry and increase in temperature more rapidly than soils having fewer pore spaces. Biological activity and biogeochemical reactions increase at higher soil temperatures, with soil temperatures of 50–55°F being a threshold below which soil microbial activity rates and plant growth slow dramatically.
5. To incorporate soil amendments
- Cultivation is a practical means of incorporating compost and other soil amendments, including mineral and non-mineral fertilizers, 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, biological, 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 and other soil amendments (e.g., bone meal, fish meal, etc.): 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 (see also Unit 1.6, Selecting and Using Cover Crops)
- a) Crop residues: Tillage is used both in hand-worked gardens and 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 (see also Unit 1.10, Managing 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 as well as throughout the crop cycle may be needed to reduce the soil weed seed bank and thereby reduce weed competition with cultivated crops.

8. To create particulate seedbeds

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, arugula) and transplants with small root systems (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 residue can be an effective means of controlling (or minimizing) certain insect pests 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. See Supplement 3, Overview of Dry Farming, in Unit 1.5, Irrigation—Principles and Practices, for information on dry farming practices and applications.

**C. Types of Soil Tillage** (see Appendices 2 and 5, Garden-Scale Tillage and Planting Implements, and Appendix 3, French Intensive/Double-Digging Sequence for a garden-scale example)

1. Primary tillage

a) Defined: Course and deep tillage that fractures, sifts, or mixes the top six inches to two feet of soil. Primary tillage is applied to soils in order to eliminate soil pans, incorporate organic matter and other soil amendments, incorporate cover crops and crop residues, and aerate soils. Tools used for primary tillage include:

- i. Hand scale: Spade and fork or U-bar
- ii. Small scale: Walk-behind tractor implements such as rotary plow or rototiller
- iii. Field scale: Often accomplished with a tractor implement such as plow, spader, chisels, offset discs, rotary tiller, or lister plow

2. Secondary tillage

a) Defined: Shallow and fine tillage. Secondary tillage produces a fine seed or transplant 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 6 inches of soil and used to form fine, level, firm planting beds following primary cultivation. Tools used for secondary tillage include:

- i. Hand scale: Tilthing forks and rakes
- ii. Field scale: Disc harrows, spring- and spike-toothed harrows, landplanes

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. Tools used for surface cultivation or cultivation tillage include:

- i. Hand scale: Various hoes—co-linear, hula, etc., along with hand weeding
- ii. Field scale: power incorporators and large rototillers, cutting knives and sweeps, spring-toothed harrows

## D. Factors Influencing Timing and Type of Tillage

### 1. Soil moisture

Soil tillage at both the garden and field scale should take place only within the soil moisture range of 50–75% of field capacity (see Appendix 1, Estimating Soil Moisture by Feel, and Unit 1.5). Whether using a spade and fork, or tractor-drawn tillage tools, tillage executed at soil moisture levels higher than 75% of field capacity can increase soil compaction, degrade soil structure, increase surface crusting, and increase erosion potential. 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 due to wind.

### 2. Soil texture classification (see also Unit 2.1, Soil Physical Properties)

- 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; note that the material in this manual refers mainly to annual row crop systems
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 (structure and bulk density) 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.

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

Frequent and intensive soil cultivation (along with excessive tractor and foot traffic)—especially if done when the soil is too wet—can lead to a number of negative impacts on soil structure. Possible impacts include:

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, particularly aggregation and overall granular/crumb structure.
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 (indicated by increased bulk density readings on a soil test) 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**

## **F. Indicators of Poor or Excessive Cultivation**

There are several quantitative and qualitative indicators of poorly timed and executed or excessive cultivation

1. **Bulk density, a measure of the weight or volume of soil (solids and pore space).** A low bulk density reading indicates good aggregation/soil structure. Increased bulk density readings indicate a deterioration of soil structure and reduced pore space as the soil becomes more compacted.
2. **Decrease in organic matter content, as measured by a soil test**
3. **Deterioration of soil structure/aggregates, especially aggregate stability, which can be measured with a simple DIY test and comparative visual observation.** To test for aggregation, drop a handful of soil in a glass of water: if it stays together, there is good aggregate stability. Pulverized soil will fall apart.
4. **Surface crusting, as aggregates break down**
5. **Reduction of estimated nitrogen release (ENR) as measured by a soil test.** ENR is proportional to the % organic matter of the soil and is a measurement of the anticipated annual release of N from soil organic matter by microbial action. It is usually given in #/acre (see also Unit 1.11, Reading and Interpreting Soil Test Reports).

# Lecture 2: French-Intensive Method of Soil Cultivation

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

1. Development of the French-intensive system
  - a) Defined as a method of gardening that features handworked, deeply dug beds amended with compost and other organic inputs, carefully managed and planted at an “intensive” spacing to maximize production and minimize weed pressure
  - b) Based on a system of intensive gardening started in the 1500s and popularized by Parisian market gardeners in the 1800s into the early 1900s, which featured practices that date back centuries (see Supplement 2, Origins of the French-Intensive Method)
  - c) Popularized in the U.S. by English gardener Alan Chadwick at UC Santa Cruz, Covello, Green Gulch, and other gardens that he started
  - d) Renamed “biointensive gardening” by former Stanford Research Institute scientist John Jeavons and popularized via his *How to Grow More Vegetables* books
  - e) See also *French Intensive Gardening: A Retrospective* in Resources
2. 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 particulate 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 in the beds
3. Implements used in French-intensive soil cultivation (see Appendix 2, Garden-Scale Tillage and Planting Implements)
  - a) Primary cultivation tools: Spade, fork, U-bar
  - b) Applications and effects
    - i. Spade: Used in single and 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
  - c) Secondary cultivation tool: Bow rake
  - d) Applications and effects
    - i. Rake: Used to shape garden beds after primary cultivation and reduce, when necessary, the surface soil particle size in preparation for planting seeds and seedlings

4. Common tillage sequences used in French-intensive soil cultivation (see Appendix 3, French Intensive/Double-Digging Sequence)
  - a) Primary cultivation or “double digging” (for unimproved soil)
    - i. Spread compost over surface of bed at a rate of ~1 pound/square foot
    - ii. If soil is extremely compacted or on undeveloped clay soils, 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 put in wheelbarrow; move wheelbarrow to end of bed where the soil will be used to fill the last trench
    - 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) Secondary cultivation
 

This step occurs following primary cultivation (deep digging or double digging) of unimproved soil

    - i. Incorporate additional mineral and organic matter soil amendment into top 4–6 inches of surface soil with a garden fork
    - ii. Use a garden fork to reduce the surface soil particle size, when necessary (tilthing)
    - iii. Use a bow rake to shape garden beds after primary cultivation in preparation for transplanting or direct sowing of crops
  - c) Primary cultivation or “side forking,” a form of tilthing (for improved soil; see Appendix 4, Side Forking or Deep Forking Sequence)
 

Once soil has been improved through deep or double digging, raised beds can often be maintained in subsequent crop cycles through single digging or “side forking” prior to planting. If beds become compacted over time, they may require another round of deep or double digging, but over-cultivation should be avoided (see Lecture 1, E. Possible Impacts of Frequent and Intensive Soil Cultivation). To side fork a bed:

    - i. Spread mineral and organic matter soil amendments evenly onto the surface of the garden bed
    - ii. Articulate edge of bed and pathways with garden fork or spade
    - iii. Incorporate soil amendments into top 4–6 inches of surface soil with garden fork using “side forking” technique
5. Potential benefits of the French-intensive system
  - a) Rapid improvements in soil health: Improves soil physical properties, which in turn improves chemical and biological properties. French-intensive cultivation methods may rapidly increase the rate of topsoil development.
  - 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) Close spacing of cultivated plants creates a living mulch microclimate that reduces rates of surface evaporation 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
6. Potential disadvantages of the French-intensive system
  - a) Requires large volume of organic matter inputs. Traditional French-intensive garden systems use, on average, up to 40 tons per acre of compost during the initial stages of soil development and 10–20 tons per acre of compost for maintenance. 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.

# Lecture 3: Mechanical/Field-Scale Tillage Systems & Implements

## A. Mechanical/Field-Scale Tillage Systems

1. Conventional tillage
  - a) Defined: Combined primary and secondary tillage operations normally performed in preparing beds for a given crop or area
  - b) Mechanical tillage implements and operations (see Appendix 5, Field-Scale Tillage implements and Appendix 6, Tractors and Implements for Mixed Vegetable Farming Operations Based on Acreage)
    - i. Off-set disc: Primary tillage implement used to incorporate 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 in organic systems.
    - 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. See more about ring rollers in Supplement 3, Tillage and Bed Formation Sequences for the Small Farm.
    - 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. reduced, conservation, or strip 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. In the West, used primarily in large-scale conventional systems (e.g., cereal crops, processing tomatoes).
  - b) Types of minimum 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. Used successfully by some organic growers, but usually in rotation with conventional tillage due to weed and soil fertility concerns.
    - 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
  - iv. Requires expensive, specific implements (drills, chisels, seeders, transplanters, cultivators) that may be prohibitively expensive or not available for smaller-scale systems
- 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); see Supplement 3 for additional details
  - a) Primary tillage: Incorporation of cover crop residue in spring
    - i. Mow cover crop (flail or rotary)
    - ii. Apply compost with manure spreader prior to residue incorporation, if necessary
    - iii. Incorporate cover crop residue and compost with mechanical spader or offset wheel disc
    - iv. Rototill or disc field to improve surface uniformity following residue breakdown
  - b) Bed configuration/in-row spacings (see Supplement 4, Field-Scale Row Spacing)
    - i. Width of bed(s) often dictated by spacing of tractor tires
    - ii. Once bed width is determined, set lister bar and furrowing shovels to appropriate spacing
  - c) Secondary tillage: Seedbed establishment
    - i. Form beds with lister bar and shovels or rolling cultivator
    - ii. Shape bed with bed shaper
  - d) Bed planting
    - i. Plant beds with seeder, transplanter, or by hand
  - e) Cultivate planted beds with sweeps, knives, or rolling cultivator at timely intervals to minimize weed pressure (see Unit 1.10, Managing Weeds)
  - f) Incorporation of crop residue for cover cropping or fall crop planting (see also Unit 1.6, Selecting and Using Cover Crops)
    - i. Mow crop residue
    - ii. Incorporate crop residue
    - iii. Chisel or subsoil, if necessary
    - iv. Plant cover crops
    - v. Disc and roll
    - vi. Reshape and plant beds for fall cropping

# Demonstration 1: Preparing the Garden Site for French-Intensive Soil Cultivation

## *for the instructor*

### **INTRODUCTION**

*The following demonstration takes students through the steps required to assess soil moisture and prepare a site prior to creating garden beds using the French-intensive method of soil cultivation. Once the site is prepared, move on to Demonstration 2 and the accompanying Hands-on Exercise.*

### **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. 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 show students how to gauge soil moisture and to illustrate the importance of tillage operations within the range of optimal soil moisture. Print out and use the USDA-NRCS publication *Estimating Soil Moisture by Feel and Appearance* as a guide for this step (see Resources).
3. 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.
4. 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 Site Preparation with Students

1. Assess soil moisture
  - 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 and the USDA-NRCS publication *Estimating Soil Moisture by Feel and Appearance*)
    - 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. List 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. Demonstrate how to adjust soil moisture when too moist or too dry
  - b) The stage of soil development
    - i. Review the influence of soil development on tillage strategies
    - ii. Discuss with 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 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. Tell students how and why tillage approaches may differ on: sand, silt and clay soils. Provide examples of each.
    - iii. Talk about 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. Talk about 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 fertility amendments to apply (compost and OMRI-approved granular concentrated organic fertilizers; OMRI = materials approved by the Organic Materials Review Institute for use in certified organic systems, [www.omri.org](http://www.omri.org))
    - 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 OMRI-approved granular organic fertilizers 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.



# Demonstration 1: Preparing the Garden Site for 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 site assessment and preparation steps to take prior to French-intensive tillage operations or “double digging.” In Demonstration 2 you will prepare the French-intensive raised beds.*

### **PREPARATION AND MATERIALS**

- Soil moisture chart (Appendix 1 and the USDA-NRCS publication *Estimating Soil Moisture by Feel and Appearance*)
- Tools: Garden spade and fork, U-bar/broad fork, stakes and string, wheelbarrow or buckets, tape measure, digging board, bow rake
- Any needed amendments (mineral amendments, soy meal, fish meal, etc.)
- Stabilized, mature compost

Collect and organize the materials listed above.

## DEMONSTRATION OUTLINE

### 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 in Demonstration 2.
  - 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. Select mineral amendments and application rates as needed based on lab recommendations.
  - 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)
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. 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.

The site is now ready for cultivation, as described in Demonstration 2 and the Hands-on Exercise



# Demonstration 2: French-Intensive Soil Cultivation

## *for the instructor*

### **OVERVIEW**

*The following demonstration introduces the 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. Following Demonstration 1, you should have garden beds staked and marked out with string, at proper soil moisture, and ready for cultivation.
2. In advance of the demonstration, divide the pre-existing garden bed into four\* 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. 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.
3. On the day of the demonstration, gather tools, materials, and handouts: spade, garden fork, u-bar/broad fork, digging board, granular soil amendments, finished compost/aged manure, the soil moisture chart (Appendix 1), and the USDA-NRCS publication *Estimating Soil Moisture by Feel and Appearance* (see Resources)

### **PREPARATION TIME**

1 hours

### **DEMONSTRATION TIME**

1.5 hours

## **DEMONSTRATION OUTLINE**

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

1. Discuss tools used and why
2. Demonstrate proper use of each tool
3. Discuss importance of proper digging technique to prevent injury

### **B. Demonstrate and Discuss Primary Cultivation Steps**

1. Double digging (primary cultivation for unimproved soils)
  - 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: If the soil is compacted or high in clay, 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 as a fulcrum 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/Side Forking” steps (see below)
  - k) Discuss/ask students 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 or side forking (primary cultivation for improved soils)
  - 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 or Deep Forking Sequence)
  - e) Discuss/ask student under which circumstances the above technique is used

### **C. 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



#### **D. 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 2: 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 execution, and evaluation of French-intensive tillage operations. Follow the steps outlined below when developing and maintaining French-intensive raised beds. Note that the site preparation for this exercise is done in Demonstration 1.*

### **PREPARATION AND MATERIALS**

- Soil moisture chart (Appendix 1) and USDA publication *Estimating Soil Moisture by Feel and Appearance*
- 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. 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

## **B. Primary Cultivation Steps**

1. Double digging (primary cultivation for unimproved soils; see Appendix 3, French Intensive/Double-Digging Sequence)
  - 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 wheelbarrow or buckets and set aside.
  - e) Step 5: Spread additional compost on the bottom of the trench
  - f) Step 6: Standing on the path or on a digging board 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 you reach the end of the bed
  - 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 or side forking (primary cultivation for improved soils; see Appendix 4, Side Forking or Deep Forking Sequence)
  - 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) Rototiller
  - c) Others

### **C. 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 bow rake to remove large soil clusters resistant to fracturing
5. Under which circumstances is the above technique used?

### **D. 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. 57–59, Demonstration 2)
- 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 3: Field Demonstration of Mechanical Tillage & 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 Bed Forming and Shaping Implements**

1. Examine furrowing shovels and rolling cultivator
  - a) Explain the use of furrowing shovels and rolling cultivators for bed formation
  - b) Demonstrate methods for forming straight beds (following wheel tracks / using guidance)
  - c) Demonstrate the use of a rolling cultivator for bed forming
  - d) Demonstrate the use of a bed shaper

### **D. Demonstration of cultivators**

1. 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
2. Do a field demonstration of row crop cultivator set up with sweeps and knives
  - a) Run cultivator down crop row
  - b) Discuss the various components of cultivator operation and set up



# Assessment Questions Key

- 1) List four objectives of soil tillage.
  - *Increase soil aeration*
  - *Increase soil temperature*
  - *Increase gas exchange*
  - *Stimulate soil biological activity/ increase rate of mineralization*
  - *Improve drainage characteristics: Infiltration and percolation*
  - *Incorporate soil amendments*
  - *Control of pests and diseases*
  - *Break up hard pans*
  - *Incorporate crop residue and/or cover crops*
  - *Create planting bed for transplants and seeds*
  - *Soil moisture conservation*
- 2) What are two possible problems associated with tilling soil when it is too wet or too dry?
  - *Soil compaction (the compression of pore space)*
  - *Soil pulverization (the degradation of soil aggregates)*
  - *Difficult to work*
- 3) What is the optimal range of soil moisture (in % field capacity) for tillage operations?
  - *Between 50% and 75% of field capacity*
- 4) What are you attempting to achieve through the double-digging process? In what situations is this technique best applied?
  - *Stimulation of biological activity and diversity through organic matter inputs*
  - *The rapid improvement of soil physical properties through soil aeration and the alleviation of compacted soil*
  - *The rapid improvement of soil chemical properties through deep incorporation of generous amounts of organic matter and mineral amendments*
  - *Used during the initial stages of soil development*
- 5) What are the common tillage sequences used in preparing ground in the spring? Please give steps for both French-intensive (double digging) and mechanical cultivation.
  - *Double digging*
    - a) *Step 1: Spread needed organic matter and mineral amendments evenly over soil surface*
    - b) *Step 2: Using string line as guide, articulate edges of bed with a garden fork*
    - c) *Step 3: Fracture and loosen surface soil with garden fork to the depth of the tines*
    - d) *Step 4: Using a spade, create a trench 1 foot deep by 1 foot wide across the width of the bed. Place this soil in wheelbarrow 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*



# Resources

## PRINT RESOURCES

Fortier, Jean-Martin. 2014. *The Market Gardener: A Successful Grower's Handbook for Small-Scale Organic Farming*. Gabriola Island, British Columbia: New Society Publishers.

*Includes a section on permanent raised beds, tillage equipment for small-scale production, and minimum tillage.*

Grubinger, Vernon. 1999. *Sustainable Vegetable Growing from Start-Up to Market*. Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.

*Includes a section on tillage equipment and field preparation.*

Jeavons, John. 2012. *How To Grow More Vegetables, Fruits, Nuts, Berries, Grains, and Other Crops Than You Ever Thought Possible on Less Land Than You Can Imagine, Eighth Edition*. Berkeley, CA: Ten Speed Press.

*An overview of the French-intensive, biodynamic method of horticulture, with information on cultivation and bed preparation.*

Martin, Orin. 2007. French-Intensive Gardening: A Retrospective. *News & Notes of the UCSC Farm & Garden*, Winter 2007. Center for Agroecology & Sustainable Food Systems.

*Summarizes the history and practice of French-intensive organic gardening, as introduced by Alan Chadwick at UC Santa Cruz and in use today at UCSC's Alan Chadwick Garden. Available for free download from [casfs.ucsc.edu/about/publications/for\\_the\\_gardener.html](http://casfs.ucsc.edu/about/publications/for_the_gardener.html)*

Plaster, Edward. 2014. *Soil Science and Management, 6th Edition*. Delmar Publications.

*Contains a chapter on tillage and cropping systems.*

Pressman, Andy. 2011. *Equipment and Tools for Small-Scale Intensive Crop Production*. NCAT Publication #IP417.

*Focuses on equipment and tools for intensive crop production on small-scale commercial farms. Includes information on field-scale and hand tools used for soil preparation, planting*

*and weed management, and an extensive list of tool suppliers. Available for online purchase at: [attra.ncat.org/attra-pub/summaries/summary.php?pub=373](http://attra.ncat.org/attra-pub/summaries/summary.php?pub=373)*

## WEB-BASED RESOURCES

ATTRA, National Sustainable Agriculture Service  
[attra.ncat.org](http://attra.ncat.org)

*ATTRA provides a wide range of free and low-cost resources, including publications on organic farming, field crops, horticultural crops, and resources for beginning farmers.*

Agricultural Network Information Collaborative  
[www.agnic.org/](http://www.agnic.org/)

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

Estimating Soil Moisture by Feel and Appearance, USDA NRCS Program Aid Number 1619

[www.nrcs.usda.gov/wps/portal/nrcs/detail/mt/newsroom/?cid=nrcs144p2\\_056492](http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mt/newsroom/?cid=nrcs144p2_056492)

[www.ext.colostate.edu/sam/moisture.pdf](http://www.ext.colostate.edu/sam/moisture.pdf)

*This user-friendly guide describes how to use the “feel and appearance” method to estimate soil moisture. Includes photos of a range of soils at various moisture levels and provides useful guidelines for estimating soil moisture conditions, e.g., by using the “squeeze test.”*

Good Fruit Grower

[www.goodfruit.com/buyersguide/](http://www.goodfruit.com/buyersguide/)

*Includes a listing of national equipment retailers.*

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

[cropwatch.unl.edu/tillage](http://cropwatch.unl.edu/tillage)

*Tillage system descriptions and comparisons.*

Rodale Institute—Organic No-Till

[rodaleinstitute.org/our-work/organic-no-till/](http://rodaleinstitute.org/our-work/organic-no-till/)

*Describes the Rodale Institute's work on organic no-till cropping systems.*

## SUPPLEMENT 1

# Goals of Soil Cultivation

*Cultivation is a purposefully broader concept than simply digging or tilling the soil—it is a process toward optimum fertility. It encompasses a broad array of tools, materials, and methods. In the French-intensive approach to gardening it usually involves single and/or double digging. This supplement reviews the goals of cultivation.*

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By definition, cultivation is derived from *cultivate* (verb) from the Latin, *colo, cult* = to till, worship.

To cultivate means to –

- improve or prepare the soil for raising of crops
- grow or tend a plant or crop (hoeing, weeding)
- form or refine as by education
- cherish, or seek the acquaintance or goodwill of
- nourish

All of the above definitions apply in regards to soil cultivation, appreciation, and stewardship.

Regardless of the scale or style of working the soil you choose, there are some fundamental concepts and goals of which to be cognizant.

### Promoting Good Tilth and Structure

The main objective of cultivation is to promote and maintain good tilth. Tilth is a composite term for the overall physical characteristics of a soil (texture, structure, permeability, consistence, drainage, and water-holding capacity). In short, tilth equals the workability of a soil in relationship to its ability to grow plants, as in “this soil has good tilth!” The fork used in breaking up soil clods is a tilthing fork; the act of shattering clods is tilthing.

Regardless of soil textural class (sand, silt, or clay), one of the aims of cultivation is to develop good soil structure, with stable soil aggregates. Primary cultivation (rough digging or plowing) can aid in beginning the process of cementing soil separates together into aggregates. Limited and timely primary cultivation promotes aggregate formation.

Almost any action that shifts soil particles back and forth and forces contact will foster aggregation. Other natural forces that aid aggregation include but are not limited to –

■ Plant roots, which compress soil particles into small aggregates and break apart large clods. Organic slimy exudates from the fine root hairs cement soil particles together.

■ The alternating effects of both wetting and drying and freezing and thawing assist in aggregation.

■ Natural cultivators such as gophers, earthworms, sow bugs, millipedes, and centipedes have a mixing and cementing effect on soil separates.

In contrast, secondary cultivation—breaking up a soil to create a particulate seed bed—can have a destructive effect on soil aggregates and should be done carefully.

### Preventing or Breaking Up Hard Pans

Deep cultivation, such as double digging, can physically fracture or break up impervious soil layers or “pans.” This allows better and deeper aeration, improved drainage, and deeper root penetration. The penetrating, fracturing action of both wild and cultivated crops’ roots can also be a partial antidote to pans.

Pans, be they hard, cow, or plough induced, can occur for various reasons:

■ Physical compaction created by animal, foot, or machine traffic (plough pan) can compact both surface and subsoil layers of soil. This is more pronounced on clay and if a soil is worked when wet (>50–75% of field capacity). The weight of a tractor, the number of passes and the speed and type of tines pulled behind play a hand in the compaction imparted to a soil.

Probably the most destructive yet alluring cultivation tool is the rototiller. On the plus side, it renders up a perfect, particulate seed bed. On the negative side, the high number of tines and the rapid speed of rotation, coupled with a constant scraping action at 6–8” deep, damage or destroy soil structure and rapidly create a hard pan. Rototillers also tend to kill earthworms. The spade and fork, skillfully manipulated, offer minimum compaction but obviously limit the scale of cultivation possible.

■ As a result of rainfall and irrigation, the fine particles of clay in a soil leach downward over time (and along with them nutrients, especially nitrogen and potassium). At some point they accumulate, forming an impervious natural clay pan. Soils with high clay content in areas with high annual precipitation are subject to clay pans.

■ Clay pans also occur in areas where soil is formed and deposited in layers over time, such as alluvial flood plains and valley bottoms.

It is important to dig a soil profile (3–5 feet deep) and examine and evaluate a soil before embarking on a cultivation and fertility plan.

## Promoting and Maintaining Good Aeration

Cultivation increases pore space, especially macropores. Macropores drain quickly after a rain or irrigation, allowing air to re-enter a soil. In fact the raising of a bed via digging is primarily accomplished by adding air to the soil volume (keep in mind that this “loft” is temporary). Aeration is necessary to allow diffusion (a passive process) of atmospheric air into the soil and to allow excess  $\text{CO}_2$  to exit the soil. Because of the aerobic respiration of soil microbes and plant roots, soil oxygen is significantly lower and the  $\text{CO}_2$  is higher than that of atmospheric air: soil air can contain up to 100 times the .035%  $\text{CO}_2$  in the atmosphere. Adequate pore space and a continuous system of pores (from the surface to the subsoil) allow a soil to “breathe.”

Constant and excess moisture also limits the re-entry of air into the soil. Keep in mind that all components of soil air are important for plant and microbial growth:

**Nitrogen (N)** – Soil and root bacteria in association with legumes (peas, beans, clovers, vetches, etc.) can use atmospheric nitrogen gas to produce a combined form of nitrogen (nitrate or ammonia) that roots can assimilate.

**Carbon dioxide ( $\text{CO}_2$ )** – Water dissolves small amounts of  $\text{CO}_2$  given off by roots and microbial respiration to form a weak carbonic acid. This carbonic acid slowly dissolves minerals so they are more available to plants in solution over a period of years.

**Oxygen ( $\text{O}_2$ )** –  $\text{O}_2$  is often the most overlooked, yet most important constituent of soil air. Adequate oxygen is essential in a soil, as all parts of plants respire/breathe: fruit, seed, stem, leaf and roots. Soil microbes also require oxygen in order to flourish: 80–90% of the beneficial microbes exist in the top 6–8 inches of the soil, where aeration and warmth

are optimal. If you use cultivation practices to extend downward the conditions of the top 6–8 inches, you exponentially increase the area where microbes grow.

Respiration is a process by which carbohydrates made by photosynthesis are converted into energy for work. Just as humans need energy for bodily functions, so do plants and microbes. The better and deeper the soil aeration, the less energy is expended by plant roots to push through the soil to get air, water, and nutrients, which translates to quicker and more vigorous subsequent growth and maturation.

Plants’ needs for air, water, and nutrients are best met when the soil has a continuous system of large- and intermediate-size pores from the surface to the subsoil through which water can enter, infiltrate, percolate, and drain while soil air is constantly being replenished from the atmosphere. This set of circumstances is optimized when proper cultivation practices are coupled with the addition of organic matter to create a granular or crumb structure. Keep in mind that roots don’t grow in soil but in the interstitial spaces between soil solids—the pore spaces.

## Warming and Drying Soil

A dry soil warms more quickly than a wet one, principally because the amount of energy required to raise the temperature of water is much greater than that required to warm soil solids and soil air.

Additionally, on poorly aerated soils, if water can’t drain freely it takes a large amount of energy to evaporate the moisture via solar radiation. On average, temperate zone soils are 3–6° warmer in the spring if well drained. Cultivation—along with building and maintaining good structure—warms a soil quickly.

Reactions (biological and chemical) happen faster at higher temperatures. Thus the decomposition of organic matter by microbes, as well as water and nutrient uptake by plants, happen more quickly as soil warms: 50–55°F is a threshold figure above which there is noticeable growth, and below which growth is negligible.

## Incorporating Organic Matter

Cultivation is a practical means to incorporate organic matter and fertilizers into a soil at various depths.

While all organic matter is originally derived from plant tissues, animals (micro- and macro-organisms in the soil), and animal manures



(composted alone or with plant material) are a secondary and valuable source of organic matter. The decomposed remains of microorganisms can contribute up to 20% of the total organic matter content of biologically active soils. Green manures, crop residues (roots as well as tops) and weeds, as well as intentional grass/legume cover crops incorporated into soils on a regular basis serve as fundamental building blocks of organic matter and plant nutrition (fertilizer).

Organic matter is a major force in the formation and stabilization of granular or crumb structure of soil aggregates (think of a cross section of a loaf of freshly baked whole wheat bread as a visual analogy). When organic matter is added to a soil via cultivation, the plant residues cement or bind soil particles together as a result of gels, gums, and glues that are byproducts of decomposition. Mycelial strands or webs of fungi also bind soil particles together.

### Controlling Weeds

Cultivation (digging) is a practical means to knock down annual weeds and to weaken the crowns, rhizomes, etc. of pernicious perennial weed species. Note: This is a bit of a vicious cycle in that stirring the soil via cultivation also stimulates the germination of weed seeds in the soil bank.

### Creating an Appropriately Well-tilthed Particulate Seed Bed

Surface tilth (particle size) should be appropriate to that which is being grown: fine seeds (carrots, poppies, etc.) need a fine seed bed. Bigger seeds (beans, peas, corn, etc.) require moderate tilth. Similarly there are smaller (lettuce, brassicas) and larger (tomatoes, squashes, peppers) transplants with their requisite surface tilth needs. Creating the appropriate surface tilth is achieved by secondary cultivation tools (fork and rake) and techniques (tilthing and raking). Use restraint when creating the seedbed; if done too often and to an extreme degree such actions destroys soil aggregates.

### *A Word Regarding Texture and Structure—Soil's Two Most Fundamental Physical Properties*

Soil texture is a given. A clay is a clay, a sand a sand. Only on a small scale, such as with propagation and potting mixes, can you create a soil with the textural qualities required by mixing proportions of sand, soil, compost, peat, etc.; otherwise it is almost volumetrically impossible to add enough clay to a sandy soil (or vice versa) to alter texture.

An undesirable result of adding clay to sand or sand to clay is that the particles of clay and sand tend to separate and the clay surrounds and seals off the sand. This arrangement of segregated soil particles wreaks havoc with air and water movement and will turn your plant roots bipolar—they penetrate easily through the sandy pockets and slow down considerably in the clay zones.

Unlike texture, soil structure can be managed—either improved or degraded. Unfortunately the hard work and results of good practices that take years, even decades, to “come a cropper” can be lost in a few short seasons with poor practices. Things that improve structure (the opposite actions degrade structure) –

- Digging at the proper time intervals and soil moisture (50–75% of field capacity).

- Minimizing compaction (foot, animal, and machine traffic). Sandy soils are more forgiving than clay as per these first two points

- Adding organic matter frequently. Immature green manures serve more as a fertilizer, while mature cover crops (with a higher percent of carbon) improve both the organic matter content and structure of a soil.

- Proper irrigation practices. Basically, smaller droplets and lower amounts applied per time are less destructive of structure. A heavy application of water (irrigation or rain) tends to break down aggregates. The individual particles of clay disperse and seal off the surface, resulting in crusting, puddling, runoff, erosion, and the creation of massive structure, i.e., clods.

- The binding, cementing effects of plant roots and microbial exudates.

- No bare soil—either a living or dead mulch to protect surface structure. For every time water doubles its velocity it squares its erosive potential. Mulching softens and slows the speed of water.

## SUPPLEMENT 2

# Origins of the French-Intensive Method

*The term “French-intensive method” taught in this unit is named after the market gardens on the outskirts of Paris that reached their peaks in the 19th and early 20th centuries. The cultivation, soil amendment, and water conservation practices of this method date centuries earlier; they represent techniques developed by a number of cultures and continue to be used in diverse small-scale agricultural settings worldwide.*

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The Parisian market gardens for which the practice was originally named were small plots of land that were deeply and attentively cultivated by French gardeners, or “maraîchers.” The “marais” system, as it is known in French, was formed in part as a response to the increasing urbanization of Paris, the attendant increase in the cost of urban land, and the ready availability of horse manure as a fertility source. English master gardener Alan Chadwick popularized both the term and the gardening method in the U.S. when he introduced them at UC Santa Cruz’s Student Garden Project (now the Alan Chadwick Garden) in 1967, and they have served as the theoretical foundation supporting the cultivation methods used at the UCSC Farm & Garden ever since.

But as Chadwick was quick to point out, other societies were using similar practices far earlier than the Parisian market gardeners. He acknowledged the influence of early Chinese, Greek, and Roman agriculture specifically, on the development of the French-intensive method. The concept of small farms dedicated to intensive cultivation of the land, improved soil fertility, water conservation, and closed-loop systems was a feature common to many early civilizations and, in fact, characterizes the majority of agriculture today in developing countries where these techniques have been passed down to successive generations.

Of the world’s 525 million farms, approximately 85% are fewer than 4 acres in size, tended to mostly by poor farmers in China, India, and Africa,<sup>1</sup> where methods often reflect the same philosophies of stewardship and cultivation that inform the French-intensive method we use today. In fact, small-scale agriculture represents the global history of agriculture up until the Industrial Revolution in the 18th

century. And in much of the developing world, locally adapted traditions continue to shape the way agriculture is practiced. This supplement examines some of the methods used by farmers around the world, past and present, reflecting the principles on which the French-intensive method is based.

## Soil Fertility Management

As part of one of the oldest agriculture-based societies in the world, Chinese farmers have succeeded in maintaining fertile soils for thousands of years. Prior to the availability and use of synthetic fertilizers, one method Chinese farmers commonly used to maintain their soil’s fertility was to apply human waste to their fields, thereby returning large quantities of potassium, phosphorous, and nitrogen lost through harvest back to the soil. Applying this source of fertilizer, also called “night soil,” achieved many of the goals we aspire to in a French-intensive system. Recycling waste minimized external inputs and helped “close the system” by relying on a renewable, readily available source of fertilizer. High in organic matter, night soil also provided the necessary nutrients for growing successive crops on the same land without depleting the soil. Waste, both human and animal, served as the major source of fertility amendments that helped to build soil ecology and microbial activity.

## Compost Production and Use

In Japan, compost production has been tied to small-scale farming for centuries. Farmers harvested herbaceous growth from nearby hillsides as a source of compost material. Compost houses were built and filled with this herbage, manure, and soil daily until piles reached five feet high. Water was constantly added to ensure saturation. Once the designated height was reached farmers let the piles sit five

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<sup>1</sup> [www.globalagriculture.org/report-topics/industrial-agriculture-and-small-scale-farming.html](http://www.globalagriculture.org/report-topics/industrial-agriculture-and-small-scale-farming.html)

weeks in summer and seven weeks in winter before turning them to the other side of the house. The compost was then applied to dryland cereal crops in spring. A study conducted in the early 20th century found that nitrogen, phosphorus, and potassium were replenished by this composting system nearly at the level lost through harvest.<sup>2</sup>

## Intercropping

Intercropping, another feature of French Intensive gardening,<sup>3</sup> is a system of growing multiple crops together in the same bed or field. Intercropping is a common feature of indigenous agriculture around the world, including the famous “three sisters” planting of corn, beans, and squash originating from Mesoamerica. Extending the growing season while maximizing land use was, and still is, essential for subsistence communities to maintain their food and economic security. In the Shantung Province in China, cotton is broadcast into nearly-mature stands of wheat, adding almost a month to the cotton growing season. Maize and pigeon pea intercropping is common in East Africa, a practice that fixes nitrogen while providing farmers with both food and fiber crops necessary for subsistence.

These are just a few examples of the locally-adapted, sustainable techniques based on the same philosophies that influenced the French-intensive method. In developing countries, especially, global development threatens the survival of this land-based knowledge as industrial agriculture encroaches on smallholder farms. Our responsibility, then, is to protect and preserve this knowledge for future generations. As Liberty Hyde Bailey, one of America’s foremost horticulturists, said, speaking of indigenous practices in East Asia, “We may never adopt particular methods, but we can profit vastly by their experience.”

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2 King, F. H. 2004. Chapter IX. Utilization of Waste in *Farmers of Forty Centuries: Organic Farming in China, Korea and Japan*. Mineola, New York: Dover Publications, Inc. (Note: originally published in 1911 as *Farmers of Forty Centuries, Or Permanent Agriculture in China, Korea, and Japan*, reprinted by Rodale Press in 1973.)

3 Martin, O. 2007. *French-Intensive Gardening: A Retrospective*. For the Gardner series. Center for Agroecology & Sustainable Food Systems. Available online at: [casfs.ucsc.edu/about/publications/for\\_the\\_gardener.html](http://casfs.ucsc.edu/about/publications/for_the_gardener.html)

## SUPPLEMENT 3

# Tillage & Bed Formation Sequences for the Small Farm

*Understanding tillage sequences is critical for good soil and bed preparation prior to spring planting. Ill-timed or poorly executed tillage will lead to frustration and soil cloddiness. This is especially true for more challenging soils higher in clay content. The specific sequences you use will depend entirely on soil type and implement selection.*

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Here are two examples of common tillage and bed formation sequences (see Appendices 5 and 6 for more information on implements). One uses a mechanical spader to incorporate cover crop residue, the second an offset disc.

### Spring Incorporation of Cover Crop Residue and Bed Formation

**Tools:** Flail mower, mechanical spader, rolling cultivator

- Flail mow cover crop at appropriate soil moisture to minimize compaction
- Immediately after flail mowing cover crop, use a spader to incorporate residue
- Immediately after spader incorporation of cover crop, form beds with rolling cultivator
- Allow adequate time for breakdown of cover crop residue. If rainfall is not adequate after bed forming then pre-irrigate to maintain enough moisture to facilitate residue breakdown.
- Shortly after weed emergence re-work the beds with rolling cultivator

Beds are now ready for shaping and planting.

**Tools:** Flail mower, heavy offset disc, chisel, rolling cultivator, rototiller

- Flail mow cover crop at appropriate soil moisture to minimize compaction
- Disc and cross disc cover crop until residue is adequately cut and mixed into the top 6 inches of soil (see below for details on discing patterns)
- Chisel and cross chisel to break up compaction from disc and open up ground. It may be necessary to disc again after chiseling.
- Form beds with rolling cultivator\*
- Shortly after weed emergence re-work the beds with rolling cultivator

Beds are now ready for shaping and planting.

\* Note: It may be necessary to rototill to break up clods prior to bed formation. Moisture from either rain or sprinkler irrigation will facilitate rototilling. Once clods are mitigated then beds can be formed with the rolling cultivator.

### Bed Shaping

Once beds are raised with either listing shovels or a rolling cultivator, and assuming optimum tilth has been achieved through well-timed tillage, a “bed shaper” can be used to shape a bed suitable for precision seeding and follow-up weed management.

Bed shapers are three-point implements that run behind the tractor and flatten out the bed top, providing a smooth, uniform, and well-defined bed for planting. Vegetable seeders can be attached directly to the shaper so that beds can be shaped and planted in one pass. Markers can also be attached to the shaper to provide distinct lines for transplanting. For information on direct seeding and transplanting following bed formation, refer to Unit 1.4. Transplanting and Direct Seeding.

### Discing and Discing Patterns

Vegetable growers on California’s Central Coast rely on drawbar-pulled offset wheel discs, often with a ring roller run behind, as a primary means of tillage. The disc/ring roller combination quickly and efficiently mixes crop residue with the soil and effectively knocks down and incorporates weeds that have emerged in non-cropped open fields.

One advantage of discing is the speed at which ground can be covered. For example, an 8-foot wide offset disc running at the optimum 4 miles per hour can easily cover an acre in 20 minutes.

However, for small farms, discing with a drawbar-pulled offset wheel disc can be challenging, as it is difficult to disc small plots of ground (a half

acre or less) effectively. Discs don't corner well and require significant space to turn. They move soil around in a field (especially in small plots), necessitating either the use of a land plane or wheel scraper to cut high spots and fill low spots left by the disc. Field corners are most notable for soil deposition or removal.

In small plot situations (half acre or less) where cover crop residue is not excessive, flail-mowed cover crop residue can be effectively incorporated with a three-point rototiller behind a small tractor. Multiple passes with a three point off-set or tandem disc will also work to incorporate moderate amounts of cover crop residue, but these implements tend to be light and will require more passes compared to the heavier offset wheel discs. Notched blades on a three-point disc will greatly enhance its ability to work deeper and cut through heavy residue.

One of the most important considerations when pulling a draw bar-hitched offset wheel disc is the need to disc in a "pattern" (see Appendix 7). Drawbar-pulled offset discs can only be turned to the left. Turning the disc to the right when it is soil engaged will result in serious damage to the disc frame or the discs themselves. This is very important to understand.

While running through the field the front gang of discs throws soil to the right and the second gang throws the soil back to the left (as viewed from the back of the disc forward). The back gang leaves what is referred to as a "dead furrow." The second pass of the disc will cover this dead furrow and leave a new one on the right side of the disc. Follow the last pass on the right side to minimize the number of dead furrows in the field.

As an example, when discing a one-acre plot, it is important to disc in a pattern that allows you to make left turns only and follow your last pass on the right side. If done correctly the field would have a dead furrow down the middle and along each of the two sides.

It is always advantageous to cross disc either on a diagonal or perpendicular to your last pass. It is not uncommon to disc a field multiple times to get the desired mixing and tilth.

Optimum soil moisture for discing is just moist enough that you don't raise a huge dust cloud. On soils prone to compaction, discing when soil moisture is too high can be extremely detrimental to soil tilth—the soil should never be so wet that the soil sticks to the discs.

Note that there are many different configurations for offset discs but they all have two disc gangs that are diagonally opposed. Many of the small offset discs are set up on a three-point hitch, but their light weight limits their usefulness.

## Other Tillage Operations

### Deep tillage (ripping)

On most soil types, deeper tillage (i.e., ripping) is best done in the fall at the end of the cropping season when the soil is relatively dry prior to the onset of fall rains so that the compacted layers "fracture" effectively. Deep ripping is critical on some soils to improve water infiltration and break up compacted layers formed from prior shallower tillage.

Ripping is usually followed by discing to break up clods brought to the surface from the ripping. A ring roller running behind the disc should be used to break clods and push small clods into the soil so that they will more easily take in and hold moisture from irrigation or rainfall.

Ripping typically involves two passes, with the second pass done diagonally to the first pass. This second pass allows the ripper to penetrate deeper, allows for a more complete "shatter" of the sub soil, and is much easier on the tractor operator than a perpendicular pass since the tractor will rock from side to side rather than slam up and down as it goes over the soil indents left from the first pass. Ripping is a slow, energy intensive and tedious task and requires excellent traction.

## SUPPLEMENT 4

# Field-Scale Row Spacing

*Choosing the proper bed configuration/row spacing for your farm is one of the most important decisions you will make as a beginning farmer. This decision is often dictated by the wheel spacing on your tractor, depending on the tractor or tractors you use in your operation (see Figure 1, below).*

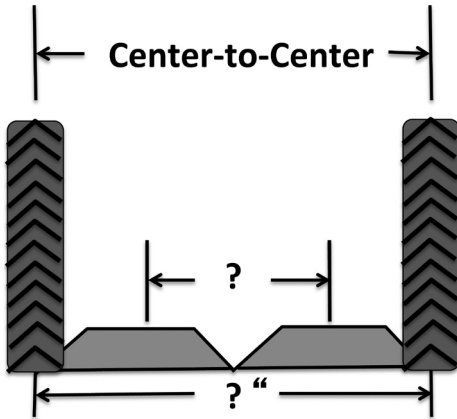


Figure 1

Row crop tractors are “adjustable” for a range of row spacings but are only designed for “in row” field operations such as planting and cultivation. The challenge many small farmers face is that they can only afford one tractor for both in row and tillage operations, and most tractors designed for pulling heavy tillage equipment (discs, chisels etc.) are not suitable for in row field operations.

As a compromise, many small farmers in California’s Central Coast region use small 4-wheel drive tractors for both tillage and in-row operations. This can work, but because the wheel spacing cannot be adjusted (or only minimally adjusted) on 4-wheel drive tractors, the distance between the tractor tires will dictate the row spacing.

The center-to-center spacing between the rear tires is the most important thing to measure since the rear tires are wider and they “lock” into the furrow. The front tires must fit within the footprint of the rear tires. Many small 25 to 35 HP tractors are set on rear wheel spacings ranging from 48 inches “on center” to 60 inches “on center.” Larger HP tractors (80 HP and up) typically used in larger scale row crop systems are almost all set at 80 inches “on center” (see Figure 2).

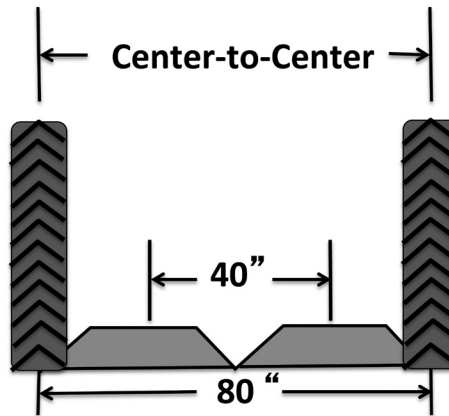


Figure 2

Once you know the center-to-center spacing of your rear tires then all bed forming implements (i.e., furrowing shovels, bed shapers) must be set to this spacing. All other “in-row” implements used following the initial bed shaping must also match this spacing (i.e., planting sleds, cultivators, mowers, bed recycling discs, rototillers etc.). Most small farms are thus either on a 48” or 60” bed spacing. These spacings dictate either a single 48”- or 60”-wide bed, or two 24”- or 30”-wide beds (see figures 3 and 4).

Another critical consideration when setting up bed spacings is tire width. If possible, tires should not be any wider than 12 inches for vegetable farming if you plan on getting into the field to perform in-row operations after beds have been formed. Wider rear tires will take up critical production space.

Also note that most lower-horsepower 4-wheel drive tractors have poor clearance for “in-row” work. The basic limitation with poor clearance is that final cultivations on taller crops (e.g., sweet corn, peppers, eggplant, tomatoes) must be done much earlier, since crop height will dictate timing. This limitation could impact weed management options.

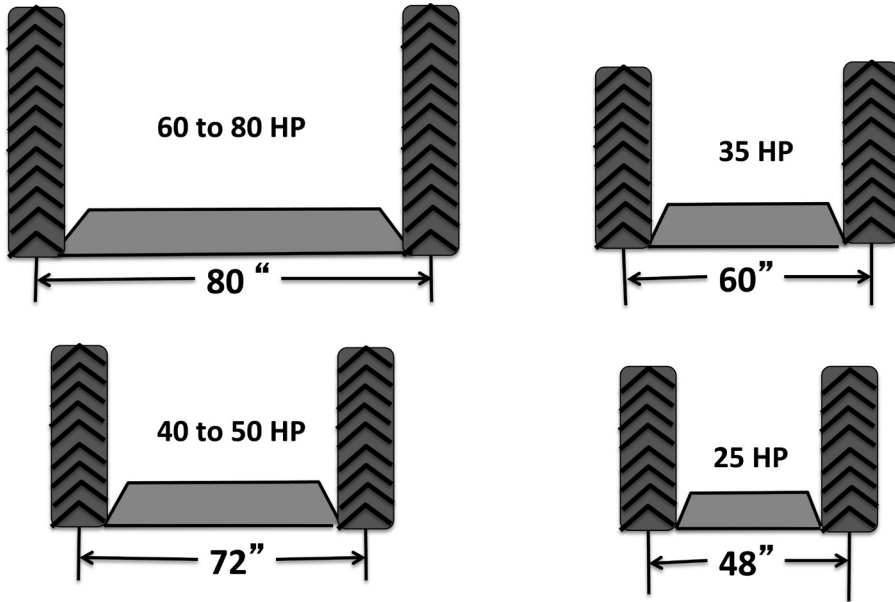


Figure 3

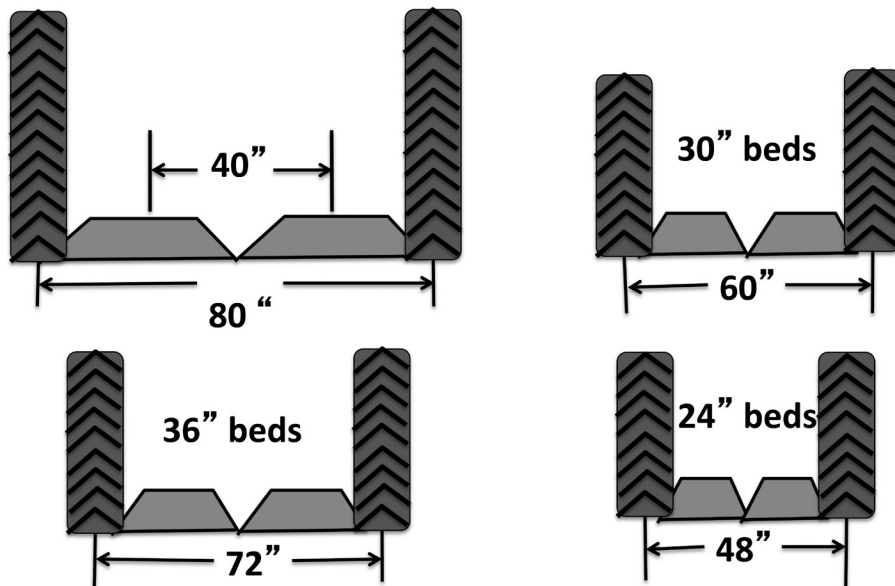


Figure 4

## **Basic tractor configurations:**

**Standard** – basic 2 wheel drive (2WD) tractor in the 25 to 40 HP range

**Row Crop** – 2WD high clearance, adjustable tire width, upright exhaust, 12-inch rear tires, 25 to 50 HP (occasionally with belly bar cultivators)

**Compact Utility** – 25 to 35 HP 4WD with front loader, 16-inch rear tires, non-aggressive tire tread, often hydrostatic transmission

**Mudder** – 80 HP 4WD “row crop,” front and rear tires same diameter

**Orchard** – very wide tires, fenders, low clearance, exhaust out the back

**Vineyard** – very narrow

**Industrial** – Front loader, 2 or 4 WD, painted yellow, non-aggressive tire tread

**Crawler** – “caterpillar” or “track layer” tractor used for high traction applications. Good stability on steep slopes, minimal compaction, very expensive to work on.

Many small-scale row crop operations (5–10 acres) use “Standard” and “Compact Utility” configurations. Many medium-scale row crop operations (10–25 acres) use “Row Crop” configurations and most larger row crop operations (25 acres and up) utilize “Mudder” configurations.



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

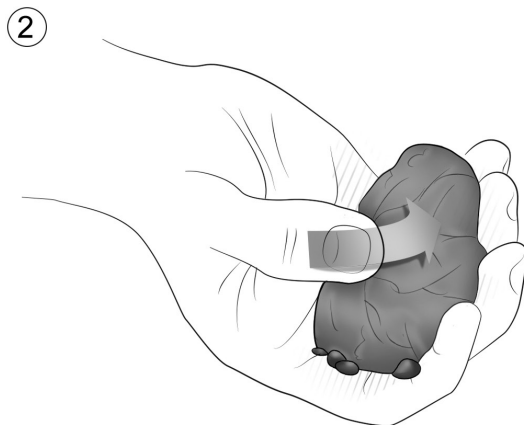
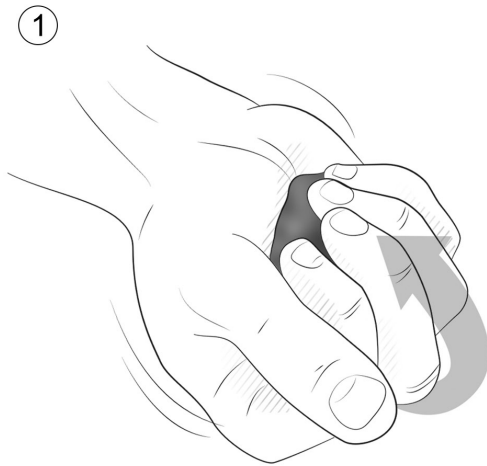
<sup>1</sup> Ribbon is formed by squeezing and working soil between thumb and forefinger

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

See also:

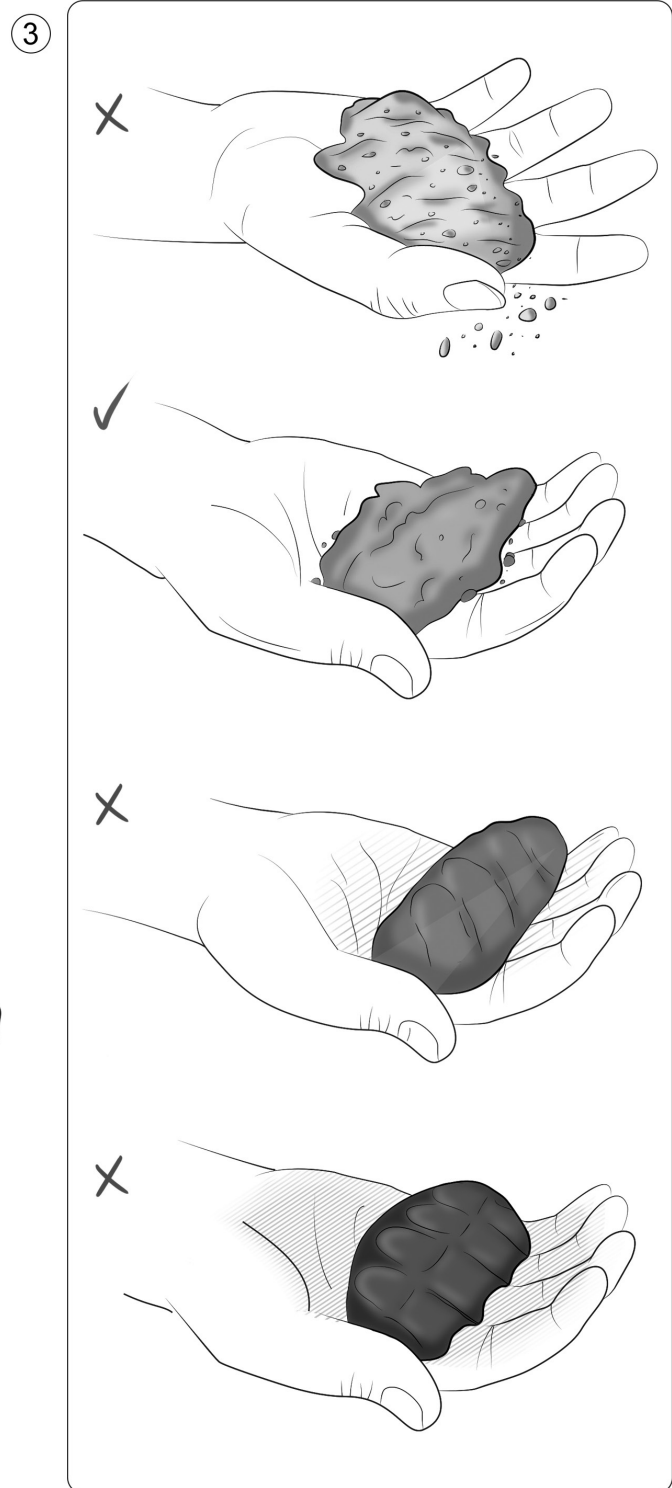
USDA, Natural Resources Conservation Service. 1998. Estimating Soil Moisture by Feel and Appearance. Program Aid Number 1619. [www.nrcs.usda.gov/wps/portal/nrcs/detail/mt/newsroom/?cid=nrcs144p2\\_056492](http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mt/newsroom/?cid=nrcs144p2_056492) and [www.ext.colostate.edu/sam/moisture.pdf](http://www.ext.colostate.edu/sam/moisture.pdf)

# Appendix 1 (cont.): Estimating Soil Moisture By Feel

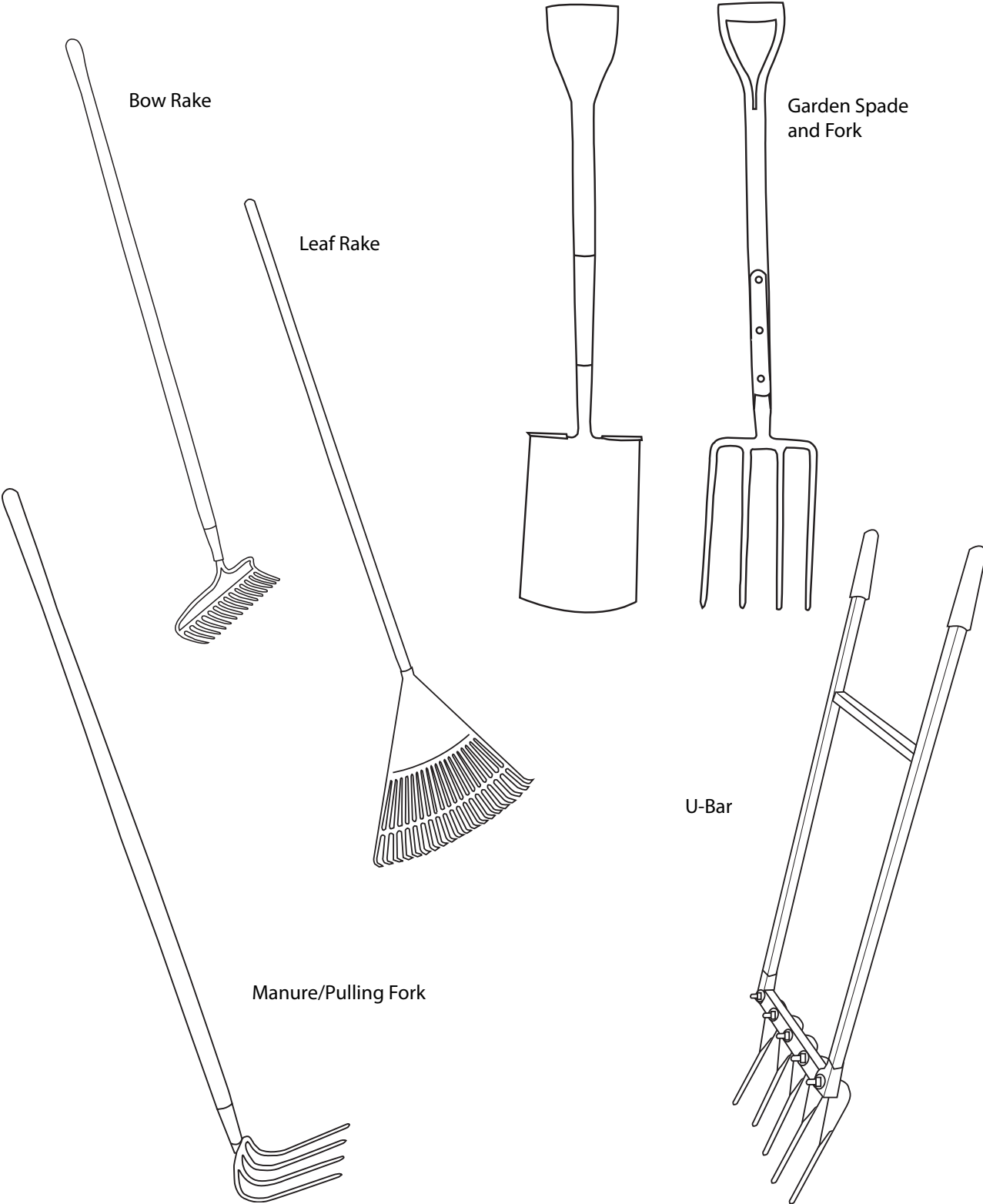


Using the “squeeze test” to estimate soil moisture. Soil at the correct moisture level will form a ball that will hold together, but can be readily broken apart (depending on soil type).

*Illustrations by José Miguel Mayo*

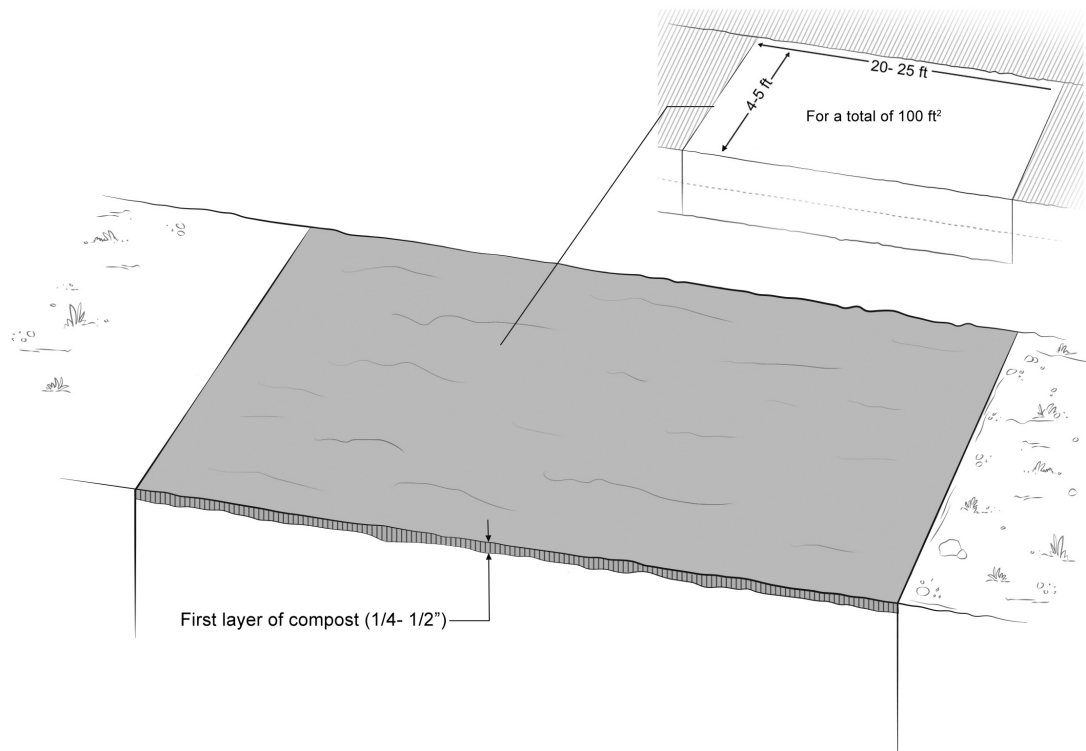


# Appendix 2: Garden-Scale Tillage & Planting Implements



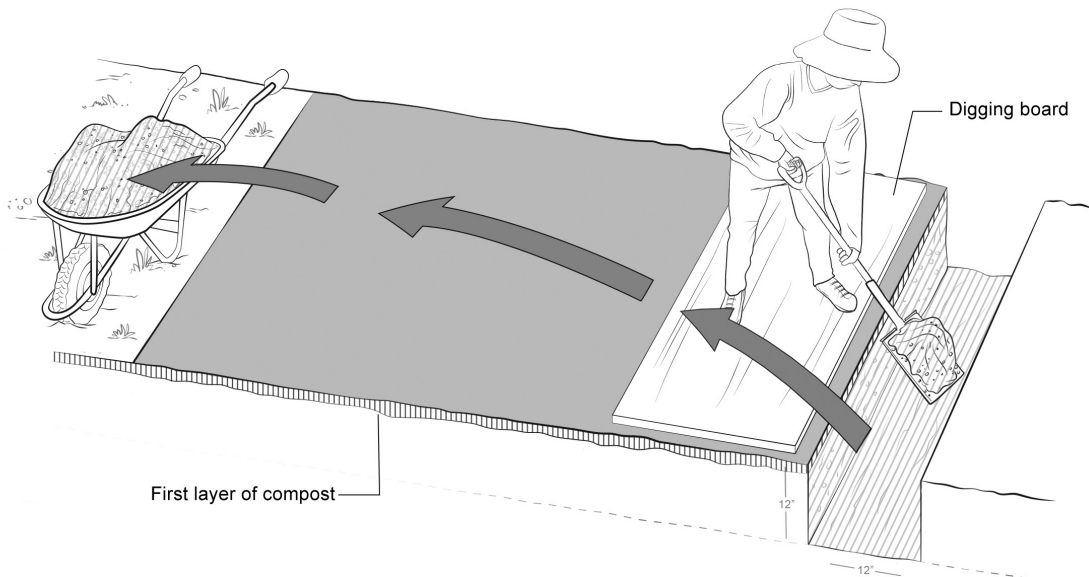
Illustrations by Cathy Genetti Reinhard

# Appendix 3: French Intensive/Double-Digging Sequence



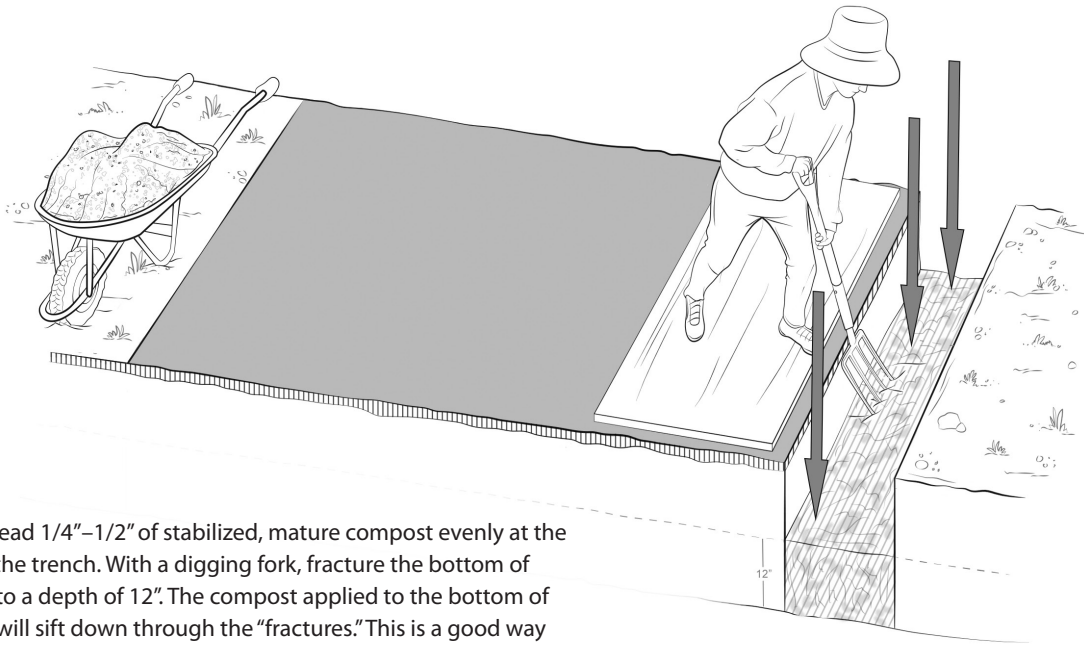
**Step 1.** Spread a 1/4"–1/2"-deep layer of compost on top of the bed.

**Step 2.** Create a trench, 12" x 12" across the width of the bed. Place soil from this trench into a wheelbarrow; it will later be used to fill the last trench in the bed.



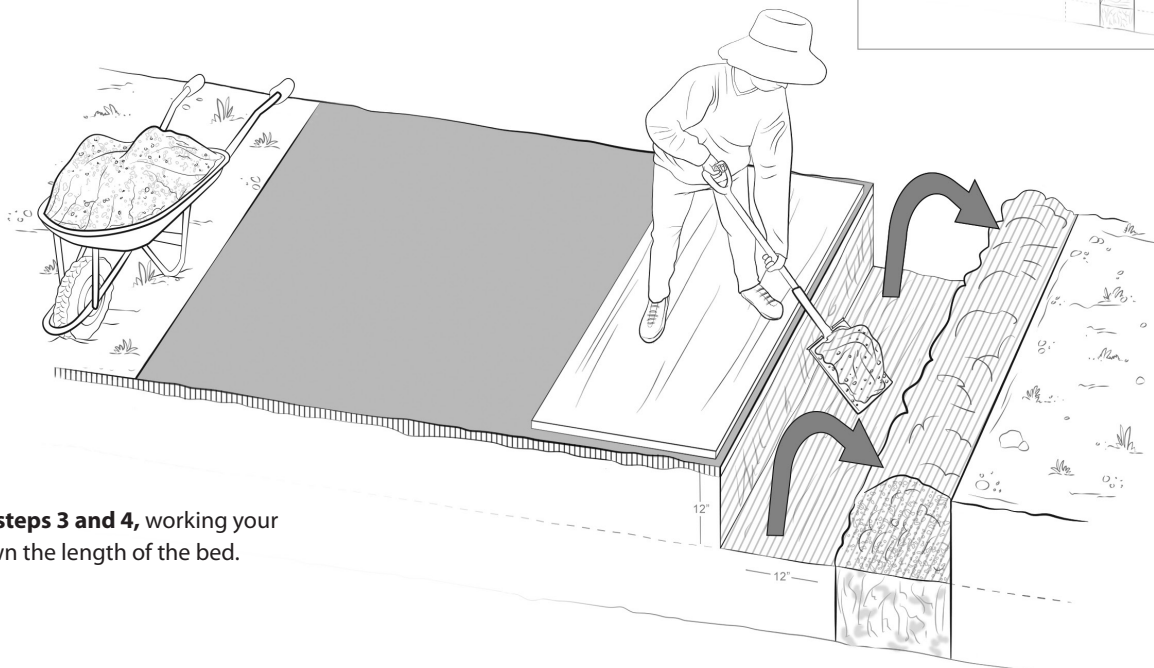
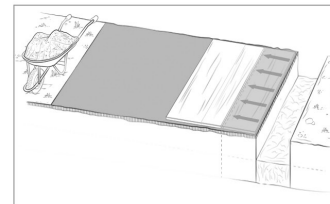
*Illustrations by José Miguel Mayo*

# Appendix 3 (cont.): French Intensive/Double-Digging Sequence



**Step 3.** Spread  $\frac{1}{4}$ "– $\frac{1}{2}$ " of stabilized, mature compost evenly at the bottom of the trench. With a digging fork, fracture the bottom of the trench to a depth of 12". The compost applied to the bottom of the trench will sift down through the "fractures." This is a good way to open up compacted subsoil with a high clay content.

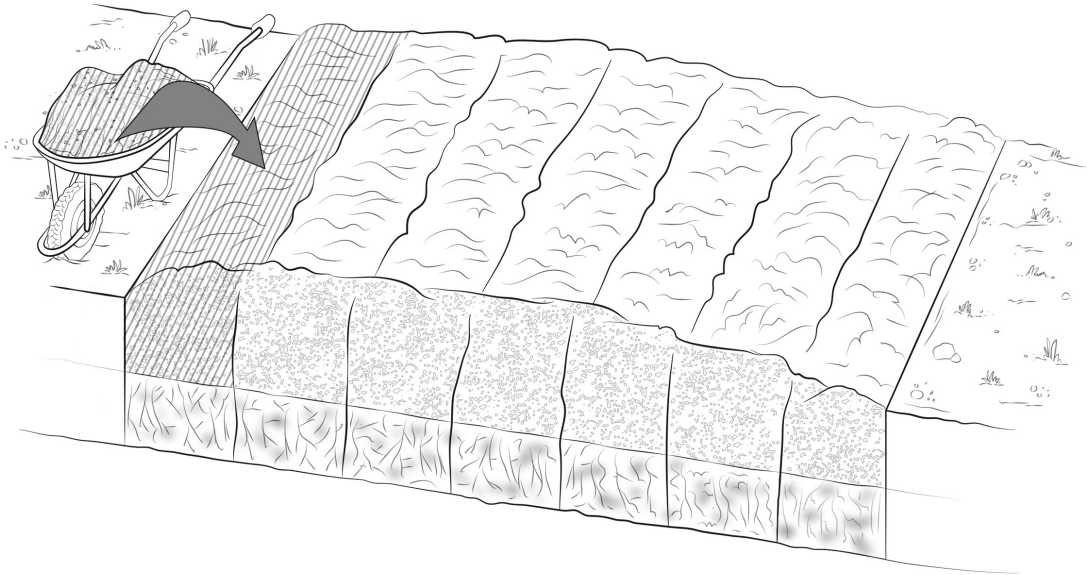
**Step 4.** Slide the digging board to the left. Use a spade to slice off a 3" x 12" vertical slice of soil. Lever it forward using the digging board as a brace to fill the open trench. Working from one side to the other, repeat this step until you have opened a new trench, 12" wide and 12" deep.



**Repeat steps 3 and 4,** working your way down the length of the bed.

*Illustrations by José Miguel Mayo*

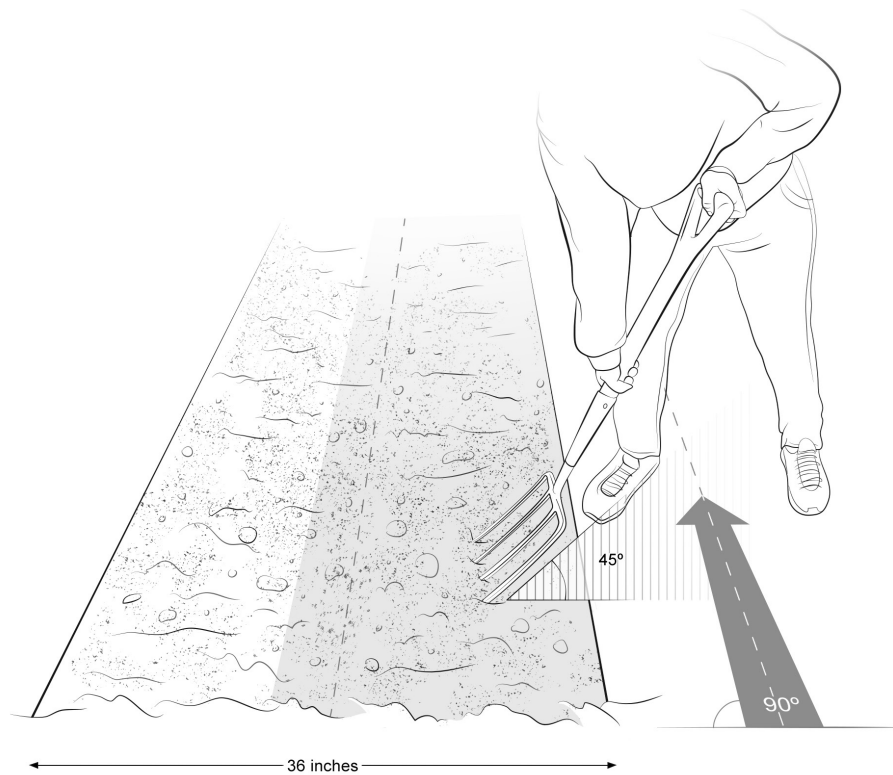
## Appendix 3 (cont.): French Intensive/Double-Digging Sequence



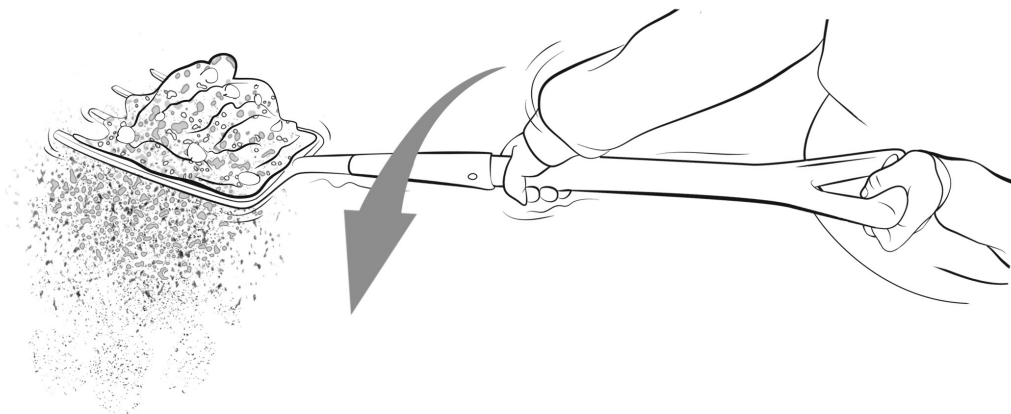
**Step 5.** After the final trench has been opened, compost applied, and the bottom of the trench fractured, fill the last trench with the soil from the wheelbarrow.

*Illustration by José Miguel Mayo*

# Appendix 4: Side Forking or Deep Forking Sequence



**Step 1.** Standing on the path perpendicular to the bed, plunge a tilting fork 6"–8" into the soil at a 45° angle. Lift and, with a shaking motion, sift the soil through the tines of the fork. The finer particle will fall through first, with the clods falling through last and remaining on the bed's surface.

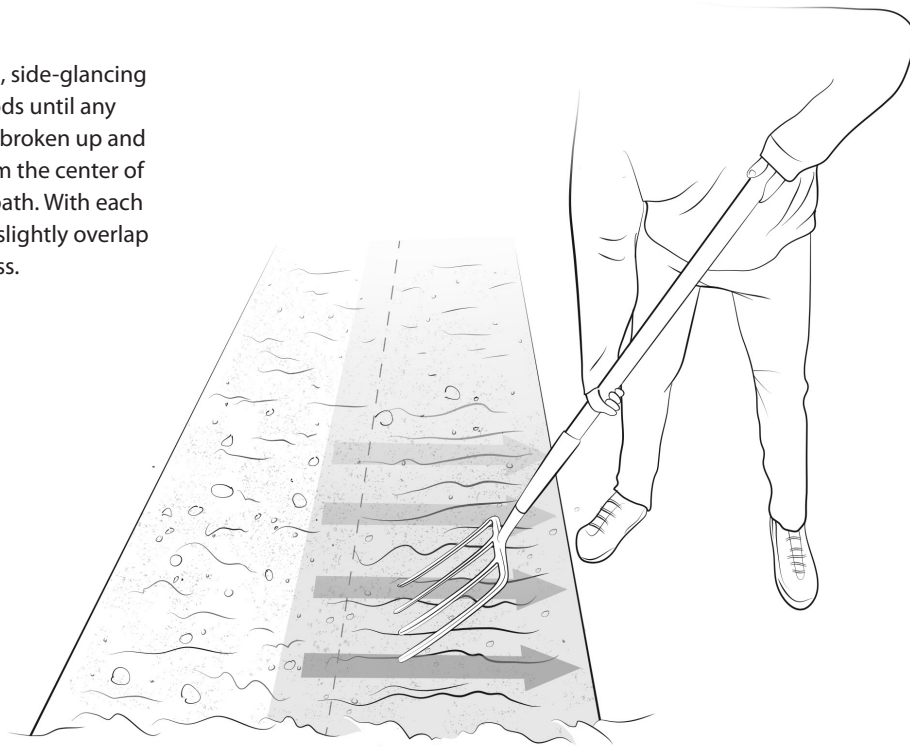


*Illustrations by José Miguel Mayo*

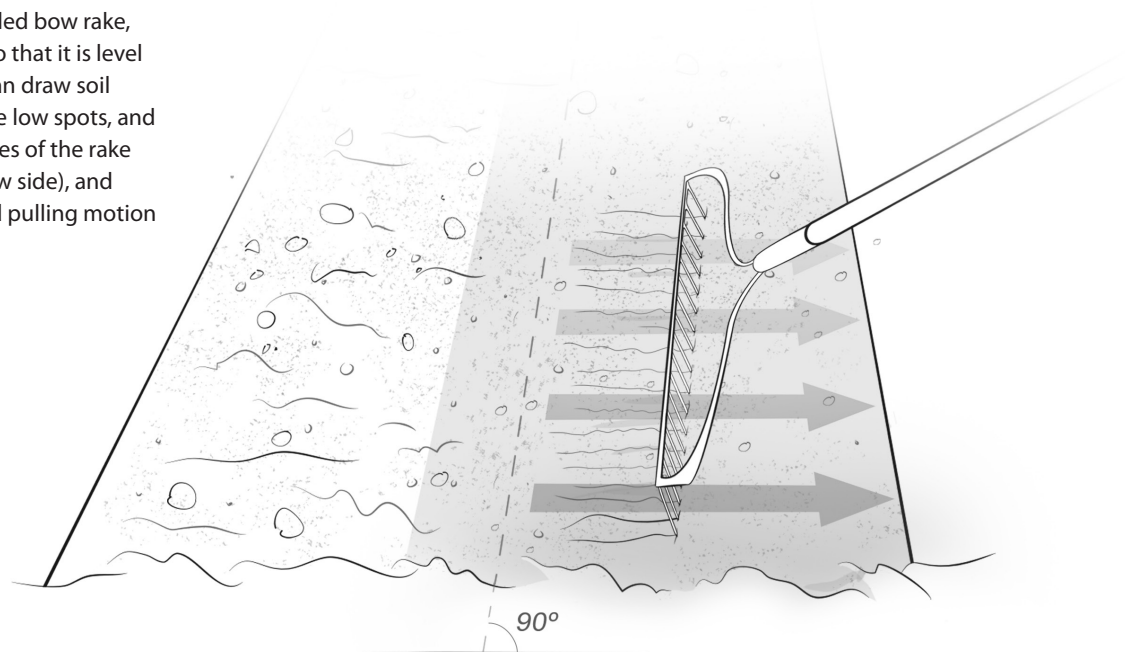


# Appendix 4 (cont.): Side Forking or Deep Forking Sequence

**Step 2.** With a gentle, side-glancing blow, “whack” the clods until any substantial clods are broken up and eliminated. Work from the center of the bed toward the path. With each pass, center to path, slightly overlap with the previous pass.



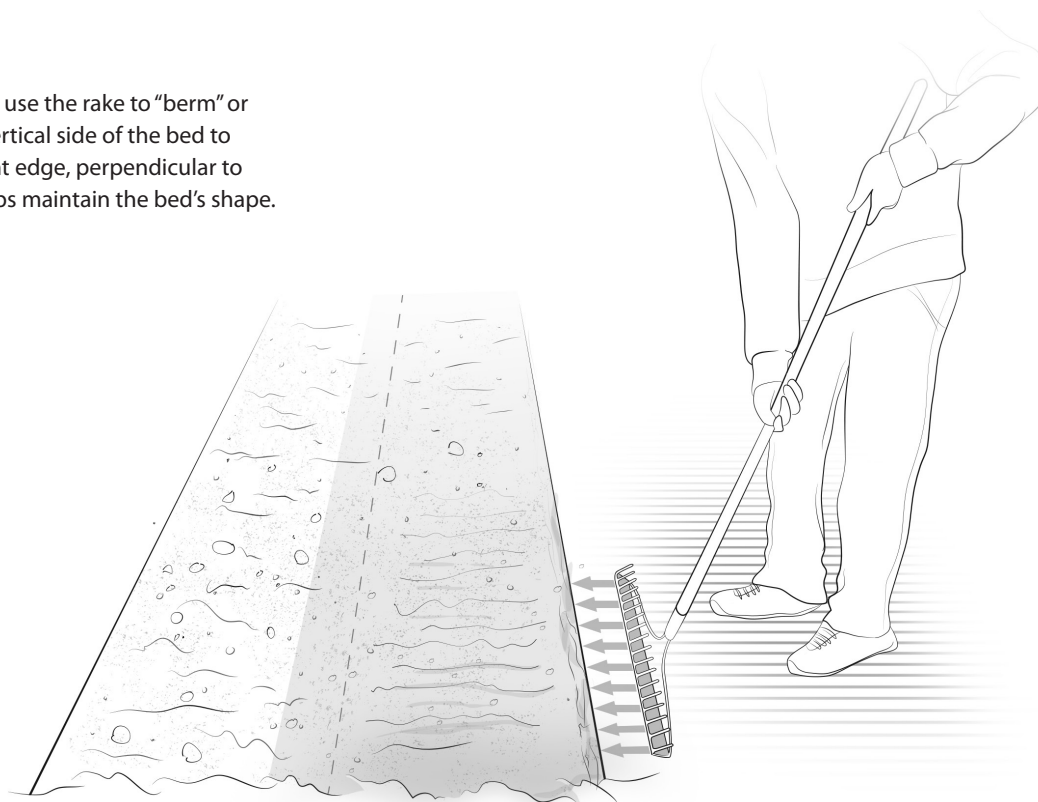
**Step 3.** With a long-handled bow rake, begin to shape the bed so that it is level and straight-sided. You can draw soil from the high spots to the low spots, and vice versa. Using both sides of the rake (the tines and the flat/bow side), and using both a pushing and pulling motion will facilitate this process.



*Illustrations by José Miguel Mayo*

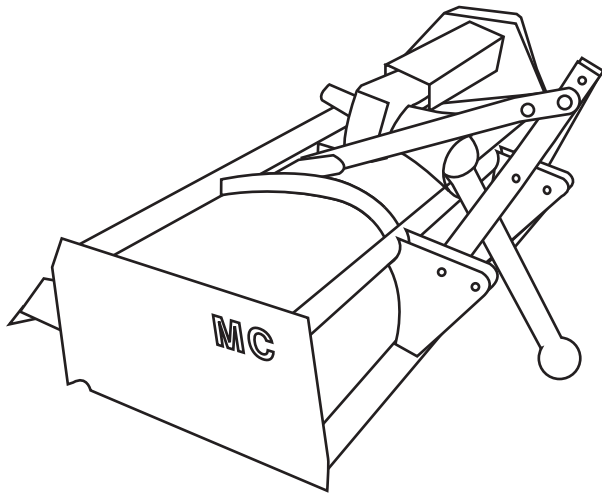
## Appendix 4 (cont.): Side Forking or Deep Forking Sequence

**Step 4.** You can also use the rake to “berm” or gently pound the vertical side of the bed to create a firm, straight edge, perpendicular to the flat top. This helps maintain the bed’s shape.

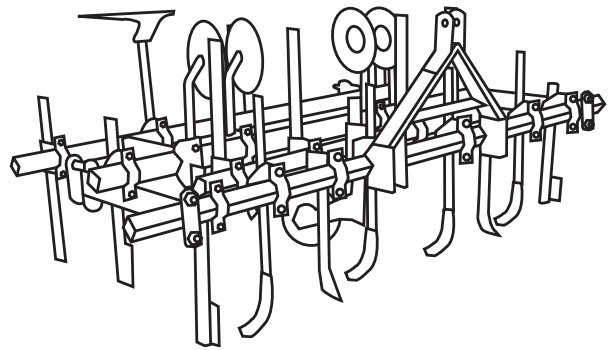


*Illustration by José Miguel Mayo*

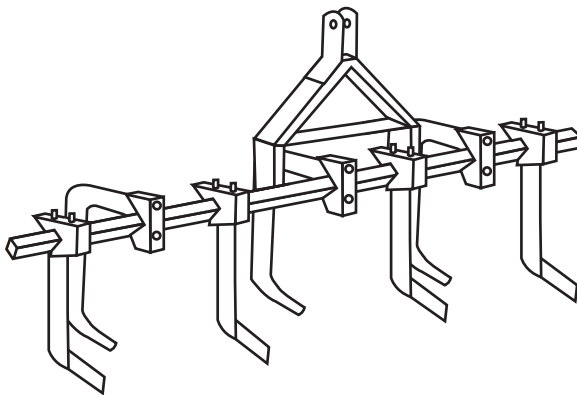
# Appendix 5: Field-Scale Tillage & Planting Implements



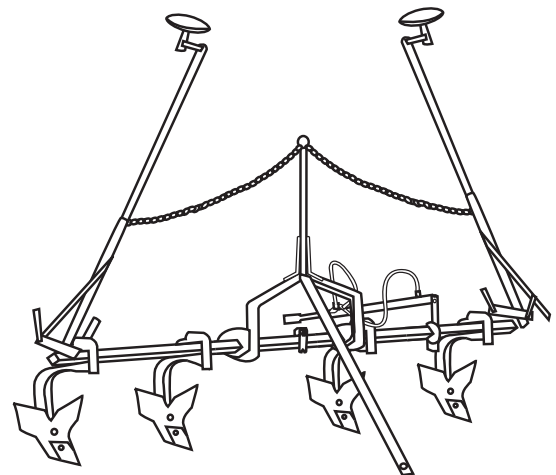
3-Point Flail Mower



3-Bar Cultivator



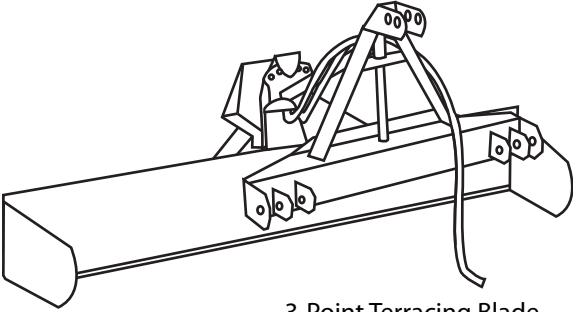
3-Point Chisel



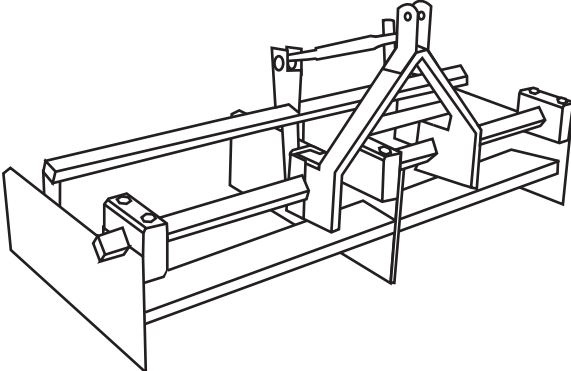
Lister Bar

*Illustrations by Cathy Genetti Reinhard*

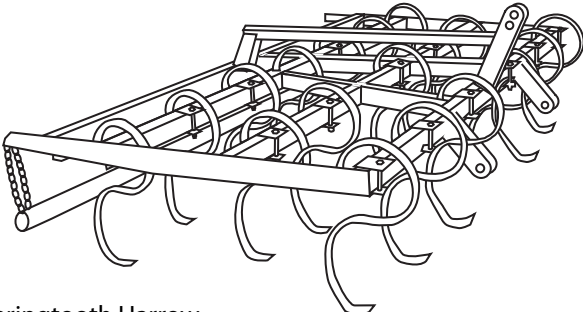
# Appendix 5 (cont.): Field-Scale Tillage & Planting Implements



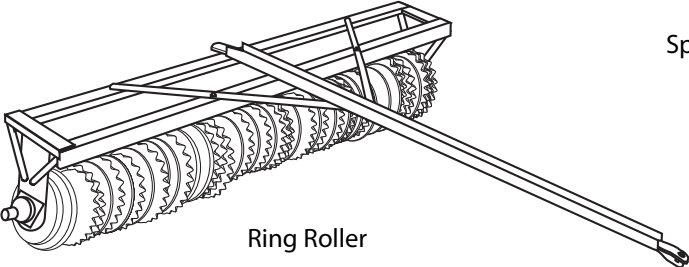
3-Point Terracing Blade



2-Row Bed Shaper



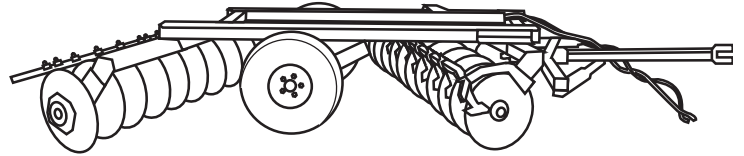
Springtooth Harrow



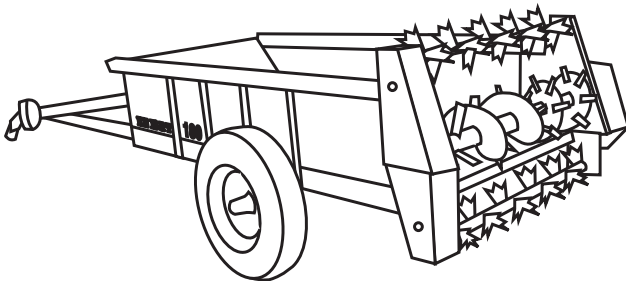
Ring Roller

*Illustrations by Cathy Genetti Reinhard*

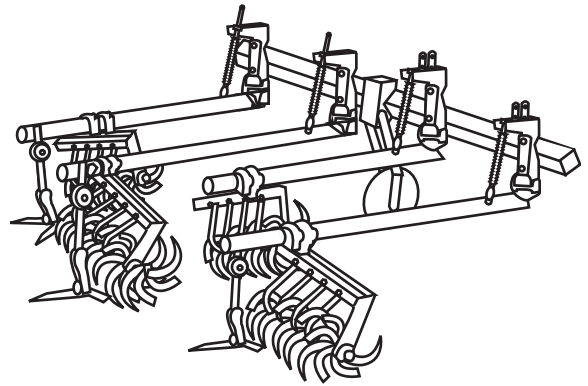
# Appendix 5 (cont.): Field-Scale Tillage & Planting Implements



Offset Wheel Disc



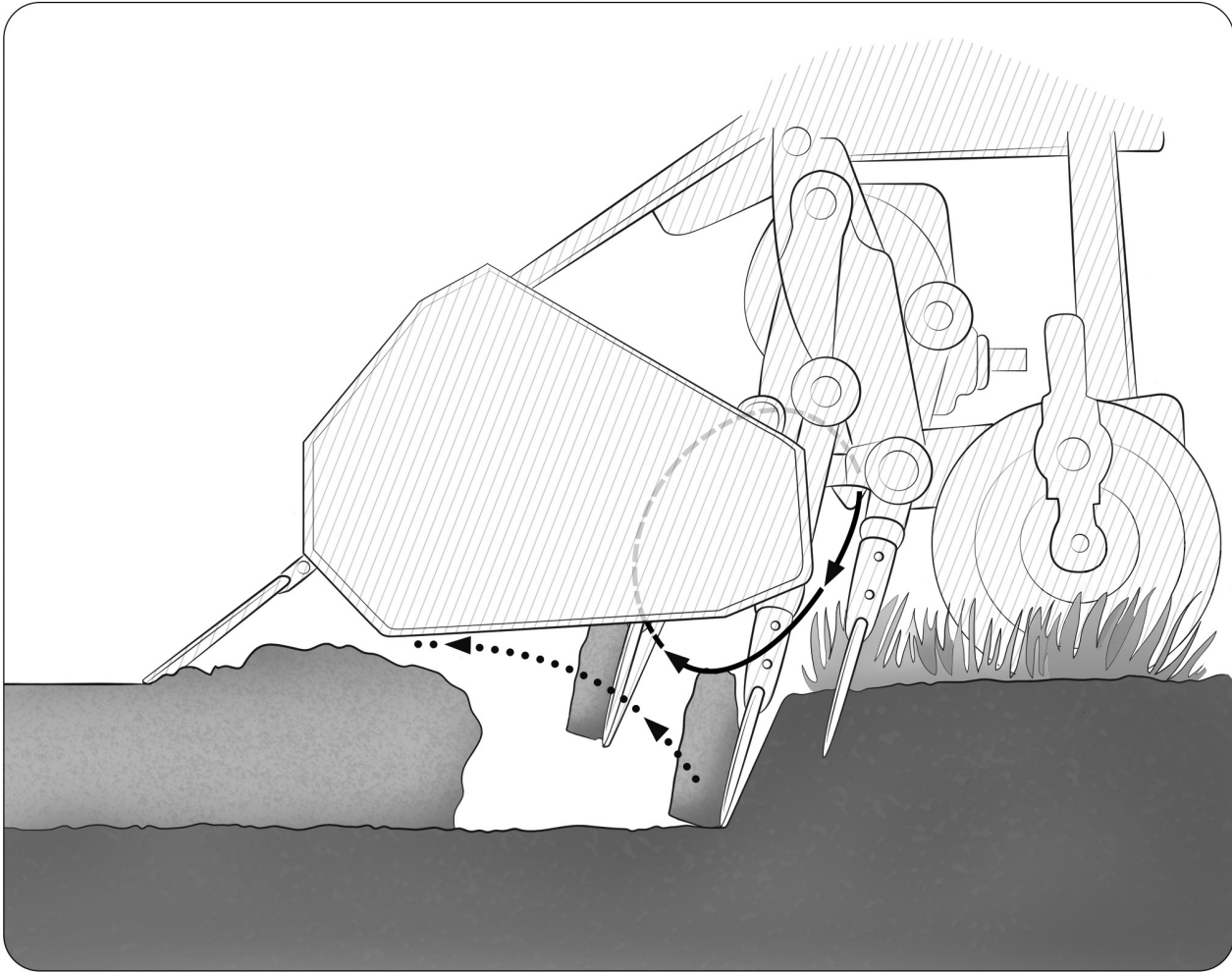
Manure Spreader



Lilliston Cultivator

*Illustrations by Cathy Genetti Reinhard*

## Appendix 5 (cont.): Field-Scale Tillage & Planting Implements



**Mechanical Spader:** A primary tillage implement used to incorporate cover crop and crop residue. Spaders operate at a very slow speed and perform deep tillage (14+ inches) without soil inversion to create a similar effect on soil as double digging.

*Illustration by José Miguel Mayo*

# Appendix 6: Tractors & Implements for Mixed Vegetable Farming Operations Based on Acreage



## 2 to 5 acres:

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- 30 HP diesel 4x4 tractor (compact utility configuration with decent clearance, “Ag” tires, three point hitch, PTO, low gearing, upright exhaust, power steering, auxiliary hydraulics etc.)
- 5 foot three point rototiller
- double tool bar and “A” frame (5.5 feet wide) with assortment of clamps, standards, shovels, sweeps, etc.
- push planter
- various hand and push cultivation tools
- single three point ripper shank capable of running 2 feet deep
- bed shaper/marker
- three point heavy tandem disc
- flail mower
- 6 foot spring-tooth cultivator
- box scraper
- under-cutter
- three point fork lift attachment for moving harvest bins etc.
- hand crank broadcaster for broadcasting cover crop seed
- backpack flamer



## 5 to 10 acres:

---

- 40 HP diesel 4x4 tractor (row crop configuration with good ground clearance, 12 inch wide tires, as well as all the amenities mentioned above)
- 6 foot three point rototiller
- double tool bar and “A” frame (6.6 feet wide) with assortment of clamps standards, shovels, sweeps
- rolling cultivator
- bed shaper with vegetable seeders
- three point ripper (two shank) capable of running 2 feet deep
- three point heavy tandem disc
- flail mower
- 6 foot spring-tooth cultivator
- box scraper
- under-cutter

- three point fork lift attachment for moving harvest bins etc.
- three point three bar cultivator with sweeps, knives, disc hillers etc. for cultivation of furrow bottoms and bed sides
- three point seed broadcaster for cover crop seeding
- backpack flamer

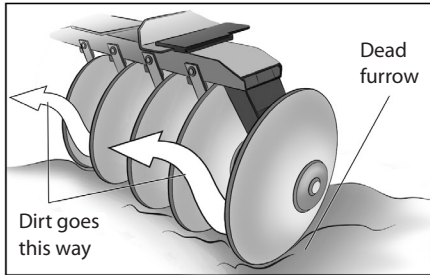


## 10 to 20 acres:

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- 60 HP diesel 4x4 tractor with wide tires and weights for pulling discs, rippers etc.
- 25 to 30 HP 2 WD tractor (row crop configuration/ high clearance, three point etc.)
- 6 foot three point rototiller
- rolling cultivator
- bed shaper with vegetable seeders
- three point ripper (three shank) capable of running 2 feet deep
- off set wheel disc 7 feet wide with ring roller
- flail mower
- 8 foot spring-tooth cultivator
- hydraulic wheel scraper (6 foot)
- under-cutter
- three point fork lift attachment for moving harvest bins etc.
- three point three bar cultivator with sweeps, knives, disc hillers etc. for cultivation of furrow bottoms and bed sides
- grain drill for cover crop seeding
- mechanical spading machine (6 feet wide)
- three point heavy tandem disc with tool bar and shovels for recycling beds
- terracing blade for making drain ditches, etc.

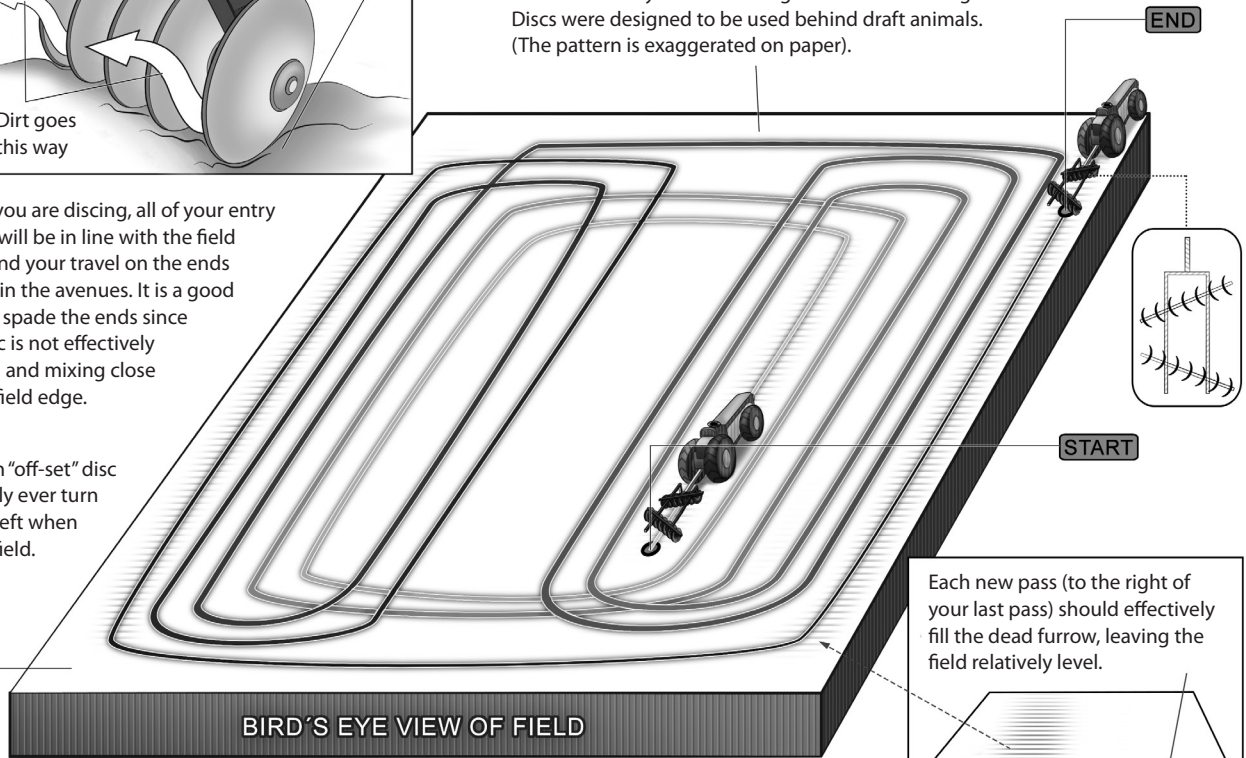
# Appendix 7: Tillage Pattern for Offset Wheel Disc



On your tight turns you can leave the disc lowered. On the broader turns you can lift the disc on the avenue so that you can avoid making a mess of the avenue. The disc will actually lift out of the ground when turning. Discs were designed to be used behind draft animals. (The pattern is exaggerated on paper).

When you are discing, all of your entry points will be in line with the field edge and your travel on the ends will be in the avenues. It is a good idea to spade the ends since the disc is not effectively cutting and mixing close to the field edge.

With an "off-set" disc you only ever turn to the left when in the field.



Each new pass (to the right of your last pass) should effectively fill the dead furrow, leaving the field relatively level.

Typical discing pattern for a half-acre field. If done properly you will have only one "dead" furrow in the middle of the field. Each edge will also have a "dead furrow."

Illustrations by José Miguel Mayo