



for the Gardener

UCSC FARM & GARDEN
Center for Agroecology
& Sustainable Food Systems,
UC Santa Cruz

Soil Cultivation: Fundamental Concepts & Goals

*To cultivate (verb) — from the Latin colo,
cult = to till, worship*

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

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

In a “Chadwickian* sense” cultivation is a purposefully broader concept than simply digging or tilling the soil. Cultivation 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. 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!”. Tilth is also a verb (a very active verb I might add). 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; see discussion, page 3), 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, earth worms, 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 (see page 3).

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.

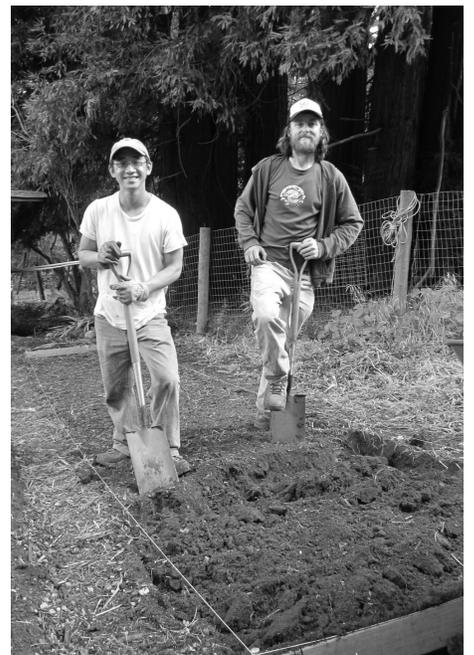
Pans, be they hard, cow, or plough induced, can occur for various reasons –

- 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, almost mesmerizing 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 slice and dice 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

Double digging beds in the Alan Chadwick Garden to break up hard pan and create a garden bed with good “tilth.”



Britt Retzlaff

*A reference to Alan Chadwick, founder of UCSC’s Student Garden Project (now the Alan Chadwick Garden)

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.

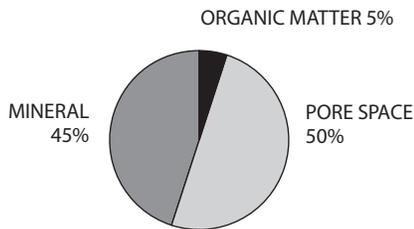
- Clay pans also occur in areas where soil is formed and deposited in layers over time, such as alluvial flood plains and valley bottoms.

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 CO₂ to exit the soil. Because of the aerobic respiration of soil microbes and plant roots, soil oxygen is significantly lower and the CO₂ content is higher than that of atmospheric air: soil air can contain up to 100 times the .035% CO₂ and 5–10 times less than the 20% O₂ 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 –

SOIL COMPOSITION:
AN IDEALIZED SOIL



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 (NO₃—Nitrate, or NH₄—Ammonium) that plant roots can assimilate (“free” nitrogen).

Carbon Dioxide (CO₂) — Water dissolves small amounts of CO₂ given off by roots and microbial respiration to form a weak carbonic acid (CO₂ and H₂O). This carbonic acid slowly dissolves minerals so they are more available to plants in solution over time (years).

Oxygen (O₂) — O₂ 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 can (and you can) extend

downward (through cultivation practices) 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, astonishing as it may seem, 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 1°C is much greater than that required to warm soil solids and soil air 1°C. 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°C 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.

“Organic matter influences physical, biological and chemical properties of soil far out of proportion to the small quantities present (3–5%). It commonly accounts for at least half the cation exchange capacity of soils and is responsible perhaps more than any other single factor for the stability of soil aggregates. Furthermore it supplies energy and body-building constituents for the microorganisms.”

Nyle C. Brady, *The Nature and Properties of Soil*

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

Using a tilthing fork to incorporate compost into the top few inches of the soil and create a seed bed.



Britt Rezlaff

RELEASING NUTRIENTS (IN BALANCE)

Cultivation adds air to the soil. The infusion of oxygen in soil air has a warming effect and promotes a microbial “bloom.” The increased microbial population breaks down or oxidizes organic matter. In this process nutrients are released for plant uptake and growth. To a limited degree this is a good thing. In excess, it can degrade structure (excessive pulverization), destroy aggregates, reduce pore space, create surface crusting and erosion, and result in poor water-holding capacity and decreased biological life.

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).

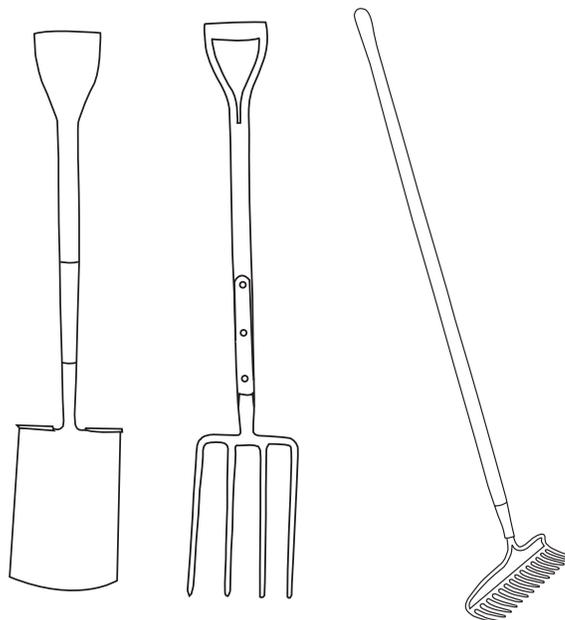
Organic matter is a major force in the formation and stabilization of granular or crumb structure of soil aggregates (think of a cross section of a loaf of freshly baked whole wheat bread as a visual analogy). When organic matter is added to a soil via cultivation, the plant residues cement or bind soil 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. In a sense you could say, “Knock ‘em down, stir ‘em up and knock ‘em down again and again . . .”

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.



Cathy Genetti Reinhard

Tools of the trade: D-handle spade, tilthing fork, metal bow rake. Use the fork and rake to create appropriate surface tilth via tilthing and raking.

A Word Regarding Texture and Structure, the Two Most Fundamental Physical Properties of Soil

Soil texture is a given. A clay is a clay, a sand a sand. Don't try to alter it. Live with it—you have to anyhow. 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.

Vocabulary Terms

Aggregates (aggregation): Many soil particles bound together in a single mass or cluster.

Cation Exchange Capacity (CEC): The capacity of a soil for ion exchange of positively charged ions between the soil and the soil solution. A positively-charged ion, which has fewer electrons than protons, is known as a cation due to its attraction to cathodes. Cation exchange capacity is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination.

Consistency: Ability of a soil (stable aggregates) to resist the pressure of crushing and its ability to be molded or shaped. Descriptive terms for consistency include loose, friable, loamy, plastic, sticky, etc.

Field capacity: The maximum amount of water that a particular soil can hold.

Infiltration (infiltrate): Downward movement of water into and through a soil; the rate at which water moves in a soil.

Particle size: Diameter of a single unit (separates) of soil.

Permeability: Ease with which liquids, gases or plant roots can penetrate or pass through a soil.

Soil Separates: Individual particles of soil composed of either sand, silt or clay

Structure: Refers to the grouping or binding together of soil particles (sand, silt, clay) into aggregates. Preferred

types of structure = granular – nonporous; crumb – more porous.

Texture: Term referring to the relative proportions (%) of the three sizes of soil particles—sand > .05 mm in diameter, silt .05–.002 mm, clay < .002 mm—present in a soil, as in a sandy soil, a clay soil, etc.

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