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SOIL
Physical Environment and how it affects plant growth

Division of Agricultural Sciences — LEAFLET 2280
UNIVERSITY OF CALIFORNIA — Revised August 1978

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PHYSICAL ENVIRONMENT
and how it affects plant growth

INTRODUCTION

Soils physically support plants, and act as reservoirs for the water and nutrients needed by plants. Soils are complex mixtures of mineral particles of various shapes and sizes; living and dead organic materials including microorganisms, roots, and plant and animal residues; air; and water. In the soil, physical chemical, and biological reactions occur constantly and are closely interrelated. The physical form of the soil plays a large role in influencing the nature of biological and chemical reactions. Optimum plant growth depends as much on a favorable physical environment as it does on what we call soil fertility.

The discussion of soil physical characteristics begins with the sizes (texture) and arrangements (structure) of individual soil particles. These two characteristics intimately affect the pore space between the particles. The pore space is important as the conveyor of water, dissolved mineral nutrients, and air, as well as for providing space in which rots can grow. Soil color is discussed because it often provides information about the chemical makeup or status of drainage in the soil. Finally, it is important to consider the whole soil mass, and how it changes with depth below the surface.

SOIL TEXTURE

Soil texture is a term which describes the mixture of different sizes of mineral particles. The mineral particles, originally from solid rock, assumed their present form because of physical and chemical processes called weathering. At some stage in the weathering process, mineral particles became a favorable medium for plant growth, that is, they were able to provide storage of water, air, and mineral nutrients, as well as space in which roots could grow. Organic matter then accumulated near the soil surface due to the decomposition of plant residues. Generally, organic matter further improved the properties of the soil as an environment for plant growth.

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The percentage of organic matter in soils is quite variable. Well drained soils in the warm, dry regions of California often contain less than 1 percent organic matter. Soils in the cool, moist regions contain more than 1 percent but less than 10 percent. Poorly drained valley soils originating in swamps may contain from 5 percent to more than 50 percent organic matter.

Soil texture relates primarily to particles smaller than 2 millimeters (.080 inches) in diameter -- sand, silt, and clay -- since these are the particles most active in soil processes which support plant growth. Coarser particles, gravel and stones, are either inert or detrimental to plant cultivation. Mineral particles are grouped by sizes into the classes shown in table 1.

Sand, the coarsest of the active particles, feels gritty when rubbed. Sandy soils usually have rapid water infiltration and good aeration but low water holding and nutrient storage capacity. However, there is a considerable range in these properties within the sand fraction.

Silt, the intermediate size, feels smooth when dry, and slippery but not sticky when moist.

Because the smaller particle size promotes smaller pore spaces between particles, silty soils have a slower water intake rate but a higher water holding capacity than sandy soils. A few California soils are very high in silt. These are difficult for storage because they often lack aggregation. (See section on Soil Structure.) This results in high density and a pore size too small for suitable water percolation and aeration. Nevertheless, silt is an essential component of the medium textured, versatile soil called loam.

Clay, the finest size fraction, gives the soils a sticky or plastic feel. Clay exhibits some unusual properties, unexpected if it were merely composed of smaller particles or the same minerals that make up sand and silt. Clay is largely composed of a different set of minerals, called secondary minerals. These are weathering products of the primary minerals -- quartz, feldspar, and mica -- of which sand and silt are largely composed.

One unusual property of clay is its attraction (called adsorption) for positive ions, such as calcium, magnesium, potassium, ammonium, and others. Because of this adsorption, the clay in _______________________ as quantities of the plant _______________________ ions. On the other ___, negative plant nutrient ions such as nitrate, phosphate, and sulfate are repelled by clay particles, and can only be stored for plant use to the extent that they occur dissolved in the water held in soil pores.

Clay has a very high affinity for water, partly because of its small particle size and partly because the aforementioned positive ions associated with clay also attract water. Montmorillonite clay, the type found in many California soils, swells greatly when wetted, and shrinks -- leaving wide cracks when dry. While soils high in clay are difficult to manage because of their great strength and sticky nature, an intermediate amount of clay in a soil improves its capacity to hold water and plant nutrient ions (either in solution or by adsorption). The swelling and shrinking of clay also helps form favorable structure in medium textured soils.

Soil textural classes have been defined to describe the relative amounts of sand, silt, and clay in soils. Each class is represented by an area in the textural triangle diagram in figure 1. If the percentage of each particle size in a soil is known, these values may be plotted on the diagram. The soil can then be assigned the textural name corresponding to its location on the diagram. For example, a soil containing 13 percent clay, 41 percent silt, and 46 percent sand would have a loam texture, as shown in point A in figure 1.

Another useful and often used grouping of soil textures includes the following three categories:

Coarse-textured soils - Sands, loamy sands, and some sandy loams.

Medium-textured soils - Loams, sandy loams, silt loams, and some sandy clay loams and clay loams.

Fine-textured soils - Clays, sandy clays, silty clays, and some sandy clay loams, silty clay loams, and clay loams.

With experience, the texture of a soil can be felt and determined fairly simply by rubbing moist soil between thumb and forefinger, and noticing its characteristics -- how it ribbons or is pushed out into a thin strip -- how it hangs together, and how sticky, smooth, or gritty it is. Samples of soil ribbons for different soil textures are shown in figure 2. The amount of sand, silt, and clay in a soil can more accurately be determined in a laboratory to check fields estimates.

SOIL STRUCTURE

Soil structure refers to the arrangement of soil particles. Sand, silt, and clay seldom occur as separate units in the soil; rather, they combine into aggregates held together by small binding forces of clay and organic matter. The size and form of aggregation is known as the structure of the soil. Soil structure is one of the more important physical characteristics of soil, yet perhaps the least understood. Plant growth is strongly influenced by soil structure. Soil structure affects movement of water, air, and roots through the soil.

Soil structural aggregate may vary from a fraction of an inch to several inches in diameter; may be approximately spherical, elongated, or platelike; and may be held together strongly or weakly. An illustration of five general shapes of aggregates is given figure 3.

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A granular structure provides an ideal environment for plant roots, and is particularly helpful for establishing plants from seeds or transplants. The larger pores between the granular aggregates are continuous, and roots may penetrate them with ease.

Water drains readily through this soil, yet moisture is held back sufficiently in the aggregates to supply root needs. Granular structure occurs in loam soils and in some clay soils near the surface. One of the good things about clay is its promotion of granular structure (by swelling and shrinking) in medium textured soils. A greater organic matter content also results in better granular structure of a soil.

Sandy soils are low in both organic matter and clay, and aggregation is very weak to nonexistent. The structure is called single-grained; such a soil drains well but doe not retain much moisture. Single-grained soils require more frequent irrigation and fertilization for plant roots to thrive.

Prismatic and blocky structures most often occur as the result of shrinking and cracking of clay loams and clay soil layers (called horizons) upon drying. The large cracks that are visible at the surface of dry clay soils may occasionally extend to three feet or more in depth. The elongated chunks of soil between these vertical cracks are called prisms. The lower portions of the prisms often have horizontal cracks intersecting the vertical ones so that more or less equidimensional blocky structure results. Prismatic or blocky aggregates may vary considerably in size but are always coarser than those of granular structure. The aggregates swell when wet and fit together so tightly that water drains through them rather slowly. Plant roots may follow cracks downward but do not usually penetrate to the centers of prismatic or blocky aggregates. Thus, the roots may not have access to a significant portion of the water and nutrients in these soils.

Platy structure refers to the occurrence of thin layers of soil stacked on top of one another. These most often occur when silty soil materials are deposited in thin layers by stream overflow. The discontinuities caused by this minute layering may interrupt the movement of water, air, and roots into the soil. Artificial platy structure may be caused by repeated compression of soils in farm roadways.

Many medium textured soils in California do not have well defined structural aggregates. This is true because of a much lower organic matter content than most midwestern soils. If particles are weakly bound together in the whole soil mass, soils are said to have a massive structure. If open and porous, these soils may still provide a favorable root environment. Many massive soils, however, are dense and nonporous providing only slow water and air movement. Compact, massive layers occur naturally in the subsoils of some old terrace* soils, but farming activity has caused similar compaction near the surface of many cultivated soils that originally had granular or single-grained structure.

* Terrace soils are stream laid soil deposits on longer receiving any deposition of soil materials because of the lowering of stream channels. They occur near the edges of the stream channels. They occur near the edges of the central and coastal valleys, and may be 10,000 to 100,000 years old

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Intensive cultivation usually results in some breakdown of the natural soil structure. Forces holding soil particles together in aggregates may not be strong enough to resist the crushing effect of heavy equipment, or the shearing effect resulting from working the soil at too high a moisture content. Excessive traffic over the land results in a compact soil mass in which large pores have collapsed due to crushing of the granules (figure 4). In the absence of large pores, water penetration becomes very slow. The small pores, still present, may fill slowly with water after irrigation, and drain even more slowly because water is held strongly by particle surfaces. This has two serious effects. Water movement to lower depths is very slow; and little or no airspace is left in the compacted soil. Feeder roots of most crops will die if deprived of air for only a few hours.

The more dense layers resulting from man-made soil compaction usually show up within the surface foot of soil. However, compression by tractor wheels and tillage equipment may cause some compaction as deep as two feet below the soil surface. Regardless of soil permeability beneath the compact layer, water cannot percolate or infiltrate faster than the limiting rate set by the compacted layer (figure 5). Compaction can develop in almost all soils, although some soils seem more susceptible than others.

PREVENTING SOIL STRUCTURE BREAKDOWN

Although some breakdown of structure within the surface foot may be inevitable where land is intensively cultivated, and understanding of soil texture and structure enables the cultivator to apply solid cultural practices with a minimum of structural breakdown. Structural breakdown is easier to prevent than to cure. The following recommendations will help prevent structural breakdown.

1. Plow and cultivate soil at an intermediate moisture content -- not to wet, not too dry.

2. It is especially important to avoid recompaction of freshly plowed or loosened soil. The less tillage after loosening the better.

3. Make tractor and implement tracks on the smallest amount of land possible and use the same tracks for all operations.

4. Harvest and spray when the soil is as dry as possible, within the limitations of weather and timely schedule of operation.

REJUVENATING GOOD SOIL STRUCTURE

If compaction is severe, there is some possibility of rejuvenating structure. The method used for such rejuvenation will depend on the crop and the soil. The factors favoring formation of granular structure are:

1. Wetting and drying of soils cause swelling and shrinking, resulting in improved aggregation.

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2. Bacterial decomposition of plant residues produces gums that help band soil particles together.

3. Planting fibrous rooted cover crops, particularly grasses, helps to push soil particles together and makes aggregates with continuous pore spaces between them.

The effect of swelling and shrinking on improving granulation is particularly noticeable with medium and fine textured soils in fall plowed fields left rough through winter. To be most effective, the compacted layers should be brought to the surface by deep plowing. If compacted layers come up in large chunks or slabs, they will be able to undergo swelling and shrinking in three dimensions due to alternating wetting and drying. By spring the soil should be in much better physical condition.

Incorporating crop residues should be included as a management practice whenever possible in field or vegetable crop production. Although it is difficult to build up the percentage of soil organic matter because of rapid decomposition in the hot regions of California, regular additions of crop wastes can only have a beneficial effect on maintaining or improving soil structure.

Cover crops or permanent sod in orchards and vineyards can provide some structural improvement is these plant roots can penetrate the compacted layer. Often, however, the root penetration of the cover or sod crop itself is restricted by the compaction, so it may be advisable to break up the compaction mechanically (for example, by deep chiseling -- perhaps best done in alternate orchard or vineyard rows so as not to damage a large portion of the roots in any one year) before planting the cover or sod.

SOIL COLOR

Soil color is obvious and easily determine is one of the most useful characteristics in classification and identification. Determination of soil color with a Munsell color chart provides a standard method of describing solid ______. Although color has no direct influence on the functioning or productivity of the soil, a great deal may be inferred about a soil from its color. A few broad generalizations may be made about soils of different colors.

Gray and brown soils form the largest group of California soils. They are moderately low in organic matter but include some of the most productive alluvial* soils. In the Central Valley, gray soils of the eastside, formed from granite alluvium, tend to be coarse to medium textured. The brown soils of the westside formed from sedimentary alluvium, tend to be medium to fine textured. In all areas within each group, there is a wide variation in productivity and other characteristics.

*Alluvial soils are formed by periodic flooding by streams and accompanying decomposition of soil materials. Nearly all soils on the floors of the Central and coastal valleys of California are alluvial, as opposed to residual soils formed in place from underlying rocks in upland areas.

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Black soils are relatively high in organic matter but the amount may vary from less than 5 percent (mineral soils) to more than 50 percent (peats and mucks). In the Central Valley, black soils formed under poorly drained conditions and are either peaty or clayey in texture, but may with good management, be highly productive for field and vegetable crops. In upland or coastal areas, black soils with strong granular structure have formed under native grassland, on fine textured parent materials, and cool climates.

Red soils are generally older soils that have undergone intensive weathering. In valleys, red soils occur on terraces or bench lands much older than the soils of the recent alluvial fans. These older soils often have restrictive clay pans or hardpans in the subsoil. In the mountains, red soils occur in the lower timber zone where a combination of high winter rainfall and warm summer temperatures prevail. Red soils are often deficient in phosphorous, zinc, and sulfur, in addition to nitrogen.

White or light gray soils are usually sandy or calcareous (contain lime). In sandy soils, look for possible waterholding and nutrient problems; in calcareous soils, iron deficiency may be a problem to some crops and ornamental plants, but particularly to orchard crops.

Blue of blue-gray layers are usually found in poorly aerated subsoils where organic matter is decomposing anaerobically (without air). Often, such soils have a sewer-like odor. These soils contain gases and dissolved materials toxic to plant roots. Extensive aeration is necessary to restore these soils to a condition suitable for plant growth.

SOIL DEPTH

Soil depth is important to the management of plant growth. The deeper the soil, the greater the total water and nutrient storage capacity available to plants.

Soil depth can be observed in roadcuts, stream banks, or by digging holes. A soil auger is useful where exposed cuts are unavailable. Holes are normally dug at least 5 feet deep unless hard rock or hardpan is encountered. In making soil surveys, the soil is investigated to a depth of 5 to 6 feet. In special cases, investigation to a greater depth, possibly 10 to 20 feet, may be desirable, particularly where salty layers or a fluctuating water table may damage deep rooted crops.

Root and water penetration through a soil are altered by layers having a distinctly different texture from the layers above or below. If a sub-soil layer has a noticeable increase in clay (as in a claypan soil, figure 6), water may accumulate above this layer, and roots may be injured because of poor aeration. This condition is often called waterlogging.

Very sandy or gravely layers can also interrupt the normal downward penetration of roots or percolation of water. For example, water does not drain freely from a loamy layer into a sandy or gravely layer until the loamy layer becomes saturated for some depth above

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the coarser layer. When drainage has ceased, a saturated layer remaining just above the textural change will have an adverse effect on roots. The lingering saturated zone remains because particle-to-particle flow of water is poor from the loamy layer into sand or gravel (figure 7).

Very dense, unfractured rocklike layers (hardpan) sometimes occur in older alluvial soils on relatively flat terraces. These cemented hardpans are impervious to both water and roots. Winter rainfall accumulates above the hardpan but cannot soak through it. Unless the hardpan is shattered and drainage is improved, native grasses or crops grow very poorly on the shallow root zone left as water slowly evaporates from saturated soil.

Many of the soils in the uplands (foothills and mountain areas) rest on hard rock. The density, as well as the degree of fracture of the rock, is quite variable. As a rule, the rock under the soil is more dense in the lower foothills than in the mountainous areas. The density and degree of fracture of the rock are important to moisture storage, drainage, and runoff. A dense, nonfractured, hard rock does not allow water to drain readily from the soil above, nor does the rock store water. A highly fractured rock stores water and allows soil drainage. In a soil underlain with fractured rocks, forest tree roots may extract water to a depth of more than 20 feet.

The term effective root depth has been used to describe that portion of the soil favorable for roots. In an alluvial soil, with no noticeable stratification, effective root depth may be more than five feet; in a claypan soil it may be as little as 12 inches, or the depth of soil above the clay layer. Thus, to determine soil depth, it is necessary to determine which layers in the soil will be restrictive to root and water penetration. Table 2 gives the terms used to describe relative soil depth in relation to average root zones.

CONCLUSIONS

Soil consists of mineral particles, organic matter, and pore spaces filled with air or water. The mixture of particle sizes (texture) and their arrangement in aggregates (structure) determine how well plant roots may grow in the soil and obtain from it the necessary water, air, and mineral nutrients. Soil color does not directly affect plant growth but sometimes indicates conditions that affect plant growth. The layering of soil affects water penetration, aeration, and rooting depth. Soils deep and uniform in texture and structure are usually more productive and easier to manage than soils with barriers or abrupt changes in texture or structure within the normal plant root zone.

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