CHAPTER **FIVE**

SOILS AND FERTILIZERS

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Contents

5 SOILS AND FERTILIZERS

Learning Objectives

- Understand what soil is and how it's formed
- Understand texture and structure and how they influence management
- Understand the importance of organic matter
- Understand aggregation and soil pores
- Understand the role of soil life and soil health
- Understand how to incorporate soil health principles in the garden
- Understand pH
- Understand plant nutrients, their functions and mobility
- Understand how to take a soil sample
- Understand different fertilizer sources
- Understand how to read a fertilizer label
- Understand fertilizer application and timing

The Five Soil-Forming Factors

What is soil? Soil is basically weathered rock, the decaying remains of living organisms — plants and animals — and microorganisms. Soil is also commonly described as a medium for plant growth because it provides physical support and nutrients for plants.

Have you ever noticed how soils can vary within a short distance as well as regionally? Five soil-forming factors are at work on all soils and determine their physical and chemical properties. Where all five factors are the same we can expect the soils will be very similar. The following is a description of the soil-forming factors: parent material, climate, topography, living organisms, and time.

PARENT MATERIAL

The term **parent material** refers to where the soil came from. The source of the soil has a large influence on soil texture (particle size) and minerals present. Soil surveys include the parent materials in the soil descriptions; therefore, it is important to learn the common terms.

There are six basic types of parent material:

1. **Alluvium** — Parent material that has been transported by water, such as in floodplains and washes.
2. **Colluvium** — Parent material that has been transported by gravity (talus), such as in toeslopes or debris at the base of a cliff.
3. **Eolian** — Parent material composed of sand-sized particles that have been transported by the wind.
4. **Loess** (pronounced "luss") — Parent material composed of silt-sized particles that have been transported by the wind. The Palouse area of northern Idaho and eastern Washington is a good example of a loess deposit.
5. **Lacustrine and marine sediments** — Parent material that has been deposited by streams into freshwater lakes or ponds is lacustrine. Parent material that has been deposited by oceans or seas, sometimes found in saltwater basins, is marine.
6. **Residual/residuum** — Parent material that has weathered, in place, from the bedrock below. These materials have not been transported.

CLIMATE

Temperature and precipitation are major factors influencing the rate of weathering of a soil. They also control the rate of chemical and physical processes. Water is the medium by which things are moved into and through a soil profile.

Less annual precipitation means that soluble components, such as calcium carbonate (lime), will accumulate, which is why soils in arid regions are more alkaline. Conversely, soils in high-moisture areas will have faster rates of leaching (removal) of soluble components, which is why soils in humid regions are more acidic.

TOPOGRAPHY

Topography includes both the gradient (steepness) and the aspect (direction) of a slope. The gradient influences how quickly water enters the soil or runs off, which directly influences the amount of soil loss or erosion. The aspect of the slope influences the amount of solar radiation and temperature fluctuations in the soil, which directly influences the type of plants that will grow in the soil.

LIVING ORGANISMS (BIOTA)

Living organisms include plants, animals, and microorganisms that live in and on the soil. Biota have a significant impact on soil formation due to factors such as nutrient cycling, production of organic matter, and vegetative cover of the soil surface. Human activities such as farming and construction also impact the soil.

TIME

How "old" a soil is makes a difference in its development. Soils are dynamic in that they are "a work in progress," constantly under the influence of soil-forming factors. The older a soil is, the more "developed" it is. Therefore, "young" soils are very different from "old" soils chemically and physically. An example of a young soil is new soil deposits from a flood.

Each of the five soil-forming factors has a powerful influence on the characteristics of a soil. This helps explain why soils a very short distance apart can be different. It takes a change in only one of the five soil-forming factors to differentiate the classification of one soil from another.

The consistency of the soil-forming factors is demonstrated in a soil survey. Most soil surveys are done by a county and they are a good source of general soils information, including information on climate and land-use suitability.

The first step in developing a soil survey is to gather topographic data on the area to be surveyed. Lines are drawn to delineate areas of similar slope and major changes in vegetation are noted. Each delineated area or mapping unit is then given a soil-classification designation or name. A soil scientist will do fieldwork to verify a few of these mapping units. Extrapolations can be made without field verification because the soil-forming factors have such consistent effects on soil characteristics.

Major Components of a Mineral Soil

Only 48% of the soil is made up of minerals; the other 52% is organic matter and pore space filled with water or air (Figure 1). Water is the medium of transport for nutrients to reach the plant roots. Air is required for chemical processes in the plant roots as well as for the microorganisms that live in the soil. Too much water can not only cause plants to die but can kill microorganisms as well. Generally, the mineral soils in Idaho have about 2% organic matter, plus or minus 2%–3% in some areas of the state. That 2% organic matter affects the soil's water-holding capacity, soil structure, and fertility. Every bit of organic matter counts.

There is a vast array of microorganisms living in the soil. Microorganisms play a major role in nutrient cycling — the retention and release of nutrients in the soil. The main categories of microorganisms are listed below, with a conservative estimate of their concentration in soil:

- Bacteria — 500 million per gram of soil
- Actinomycetes — 1–20 million per gram of soil
- Fungi — large variation up to 1 million per gram of soil
- Algae — up to 500,000 per gram of soil
- Protozoa — up to 500,000 per gram of soil
- Nematodes — 50 or more per gram of soil

Have you ever noticed the smell of freshly tilled soil? That is the smell of microorganisms at work!

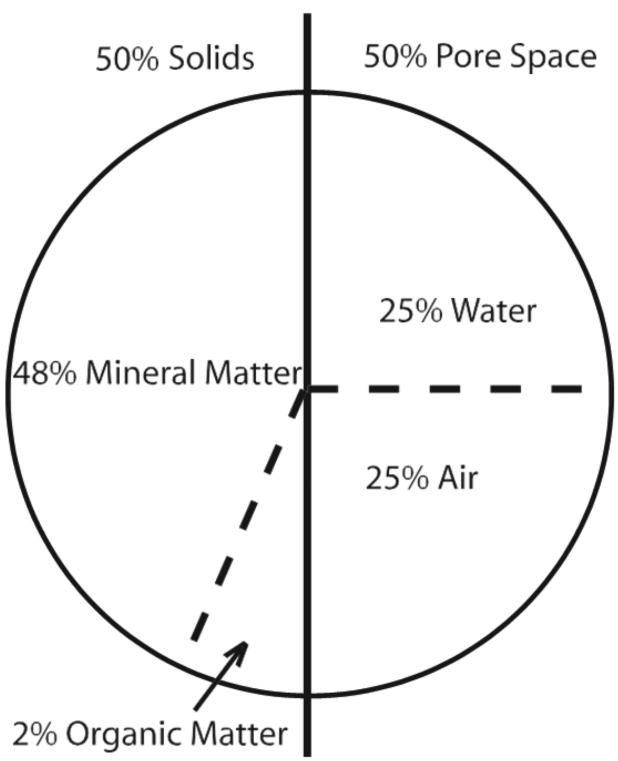


Figure 1. Major components of a mineral soil. The percentage will vary depending on the soil. Under wet conditions, there is less air. Under dry conditions there is less water.

Soil Texture

The texture (particle size distribution) of a soil is determined by the relative amounts of sand, silt, and clay present. There are many possible combinations of these particles and distinct textural classes to describe all possible particle-size combinations or distributions. See the soil texture triangle (Figure 2) to determine the textural class of a particular soil. The three major particle size classes are sand, silt, and clay.

SAND

Sand particles range in size from 2.0 to 0.02 millimeters (mm). Sand particles are the largest particles in the soil. Any particle larger than the sand particle (>2 mm) is considered part of the rock fraction (gravel, stone, cobble, etc.), not part of the soil. Sand particles provide the most stable medium for engineering purposes. Sand particles are relatively inactive chemically. The large spaces between the particles (pore space) mean that water and some nutrients cannot be retained very long and readily move out of the soil profile. This is why sandy soil is often referred to as a "droughty" soil.

SILT

Silt particles range in size from 0.02 to 0.002 mm. Silt particles carry a very weak negative charge and are capable of holding small amounts of plant nutrients. Silty soils hold more water than sand and water movement through silty soils is generally slower. A good example of silt is talcum powder.

CLAY

Clay particles are smaller than 0.002 mm and there are many types of clays. Clay particles carry negative charges capable of attracting all positively charged ions in the soil; as a consequence, clays attract positively charged plant nutrients. The very tiny, flat clay particles lead to high water-holding capacity and can result in slow movement of water through the soil. Although there may be more total pore space in a given volume of clay soil than in sandy soil, most of the pore space in a clay soil will hold water. In contrast, most of the pore space in sand is large so water moves through rapidly rather than being held. Compaction can be a problem in clay soils more so than in sandy soils.

TEXTURE AND SOIL MANAGEMENT

By knowing the texture of a soil and understanding the influences of sand, silt, and clay on the soil, you

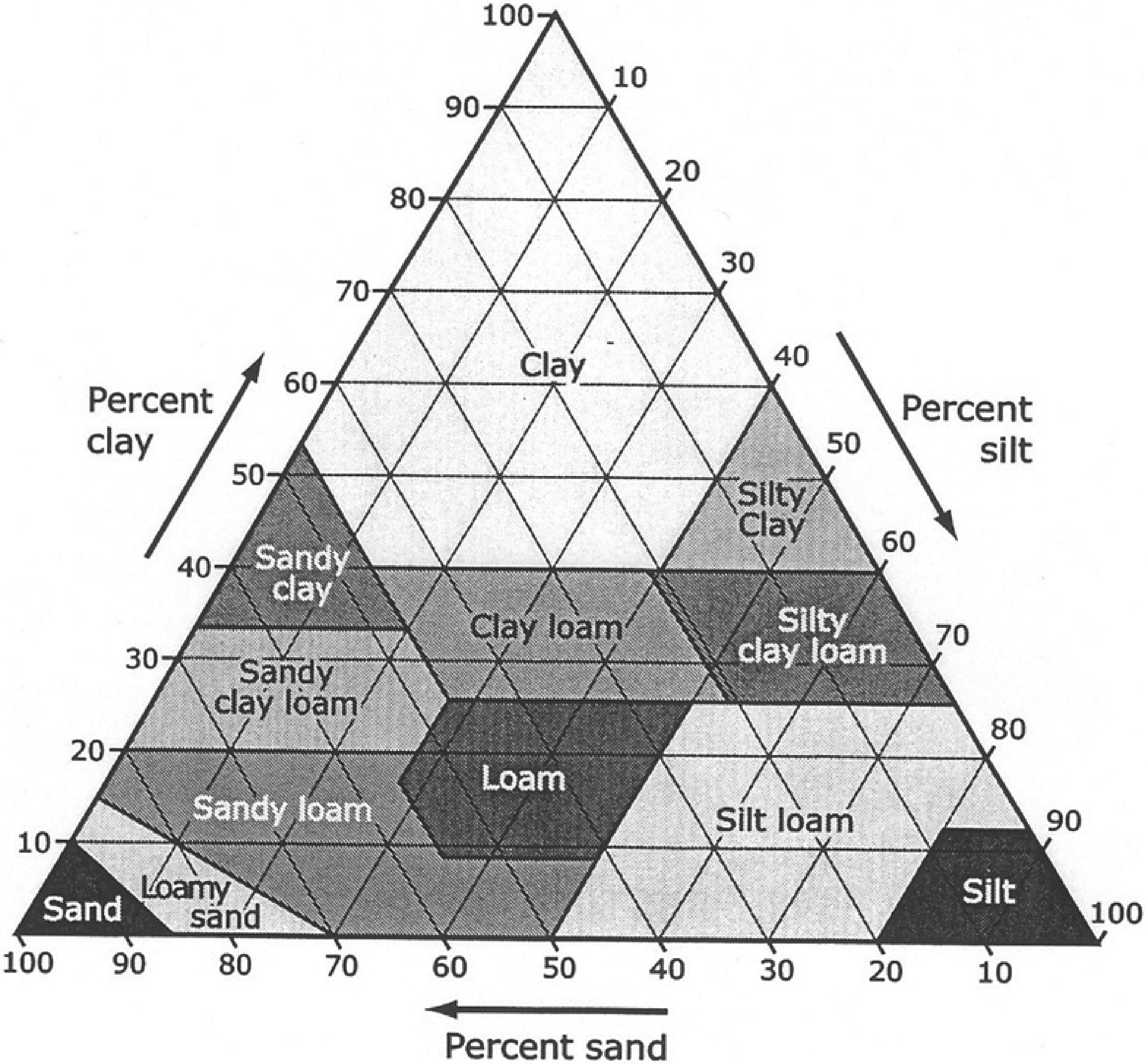


Figure 2. Soil texture triangle.

can make inferences about the management of that soil. Soils with a high sand content will need to be watered more often than soils with a high clay content. Soils with a high clay content have to be watered less often or there is a risk of waterlogging the soil.

A loam does not have equal percentages of the three soil separates (sand, silt, and clay) but is influenced by them equally. A loam has the characteristics of a clay for water- and nutrient-holding capacities, while the sand and silt provide pore space for air and water movement. Notice that a small amount of clay can strongly influence the soil texture class (Figure 2).

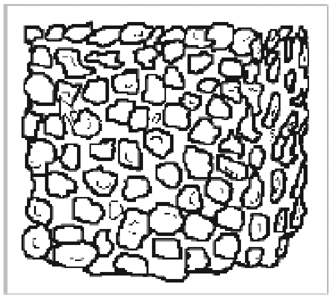
SOIL STRUCTURE

The arrangement of soil particles or aggregates is referred to as soil structure. Soil structure is the aggregation of sand, silt, and clay into shapes with distinct sizes and strengths (Figure 3). Soil structure provides additional pore space and open channels for movement of water, nutrients, air, and plant roots. Soil structure can give an indication of the age of the soil, parent material, vegetation, and land use.

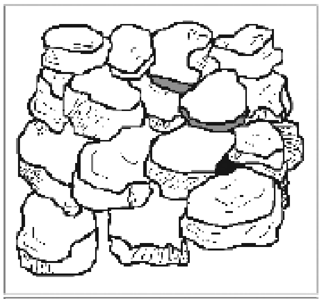
Soils that have organic matter and are properly managed will have good soil structure. If soils are cultivated when they are too wet, they can become very compacted and lose structure until reaggregation occurs. Plant roots and the addition of organic matter to the soil will help improve soil structure or tilth (soil workability).

Organic Matter

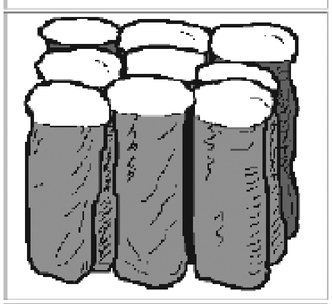
Organic matter in soil is made up of the remains of plants and animals. Residue from previous crops must be broken down to provide soil fertility and structure benefits. Moist and warm soil is ideal for microbes to work at breaking down plant tissue.



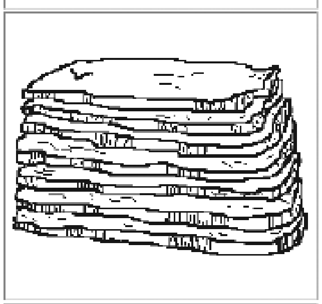
Granular: Resembles cookie crumbs usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.



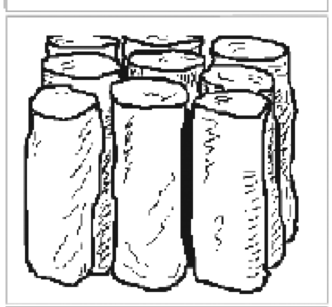
Blocky: Irregular blocks usually 1.0–5.0 cm in diameter.



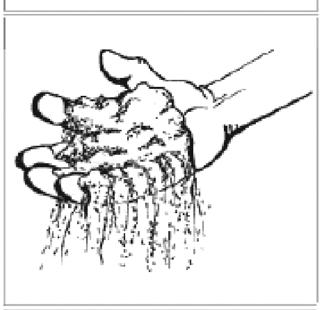
Columnar: Vertical columns of soil that have a salt “cap” at the top. Found in soils of arid climates.



Platy: Thin, flat plates that lie horizontally. Usually found in compacted soil.



Prismatic: Vertical columns that might be a number of centimeters long. Usually found in lower horizons.



Single Grained: Individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.

Figure 3. Various types of soil structures.

The organic matter content of a soil is an important factor related to overall productivity for the following reasons:

- Contributes to well-structured soil
- Is a source of three nutrients — nitrogen, phosphorus, and sulfur
- Increases water-holding capacity
- Increases soil aeration
- Provides an energy source for soil microorganisms (plants and animals)

Carbon:Nitrogen (C:N) Ratio

The carbon:nitrogen (C:N) ratio is an important consideration whenever you add organic material to your production system (Table 1). Plant residues and manures are made up largely of the following:

- Sugars, starches, and simple proteins that decompose rapidly
- Crude proteins
- Hemicelluloses
- Celluloses
- Lignin, fats, waxes, etc. that decompose slowly

Their rates of decay and release of nutrients to the soil vary greatly, as do the demands of living soil microorganisms as they “break down” plant residue.

In order to break down the carbon compounds in the plant tissue, microorganisms consume N. If the C:N ratio in the organic material is too high, greater than 25:1, there will be a net loss of N available for plant growth in the short term because the microorganisms will consume any N added with the organic material. However, if the C:N ratio is low, less than 20:1, sufficient N will be available to meet the microorganism’s needs with some left over for plant growth. Thus organic material such as straw (C:N = 80:1) added to the soil will need to have N added or the plants will suffer.

Table 1. Carbon:Nitrogen ratio of common organic materials.

Material	C:N
Wheat straw	80:1
Pine needles	90:1
Sawdust	625:1

Soil/Water Relationships

WATER-HOLDING CAPACITY

One of the main functions of soil is to store moisture and supply it to plants between rainfalls or irrigations. Water in the soil is held in pores, the spaces between soil particles. If the soil's water content becomes too low, plants become stressed.

The water-holding capacity of a soil and the amount of water available for plants to use are dependent on the number and size of its pore spaces, which is directly related to soil texture and organic matter content. Water is held by the soil in various ways and not all water in the soil is available to plants (Table 2).

Capillary water is held in pores that are small enough to hold water against gravity but not so tightly that roots cannot absorb it. This water occurs as a film around soil particles and in the pores between them and is the main source of moisture for plants. As this water is withdrawn, the larger pores drain first. The finer the pores, the more resistant they are to removal of water. Capillary water can move in all directions for several feet as the particles and pores of the soil act like a wick.

When soil is saturated, all the pores are full of water and the water that drains out of the soil in the first few hours is called **gravitational water**. Gravitational water is available to plants only for a short time. When the gravitational water is gone, the soil is at **field capacity**. Plants then draw water out of the capillary pores until no more can be withdrawn and the only water left is in the micropores. The soil is then at the **wilting point** and if water is not added to the soil the plants will die.

Table 2. Water-holding capacity of main soil texture groups (inches per foot).

Texture	Field capacity	Wilting point	Available water
Sand	1.3	0.6	0.7
Sandy Loam	2.5	1.3	1.2
Loam	3.6	1.8	1.8
Silt Loam	4.4	2.3	2.1
Clay Loam	4.6	2.6	2.0
Clay	4.7	2.8	1.9

Note: Figures are averages and vary with structure and organic matter.

A soil dominated by large particles (sand) has a lower water-holding capacity than a soil dominated by small particles (clay). Although a soil dominated by fine particles can hold more water, that water is not necessarily available (wilting point) because it takes more energy for plants to remove the water from the tiny pores.

WATER INFILTRATION RATE

Infiltration specifically refers to water movement into the soil from the surface. The rate of infiltration is measured in inches (or cm) per hour. The finer the soil texture (more clay), the slower the infiltration rate and vice versa. The infiltration rate of a soil will determine how much and how often to apply water. The infiltration rate also affects how much rainfall or irrigation water will enter the soil or run off, which relates to erosion hazard.

PERMEABILITY RATE

Permeability specifically refers to water movement within and through the soil profile (after infiltration). The permeability rate is the speed at which water moves in the soil profile and like infiltration is measured in inches (or cm) per hour. Soil compaction, plow layers, hardpans, clay layers, rock, or changes in soil texture all can influence the permeability rate of the soil. When a homeowner seeks a permit to have an on-site septic leach field, a "perc test" is required. This is a test of the permeability rate of the soil. If the rate is too slow then the site is not suitable for a septic leach field.

SOIL COMPACTION

Compacted soils have low water infiltration/ perme-ability rates. When the soil air spaces are compacted there is less space for air and water. Compacted soils also make root penetration and plant growth more difficult. Compaction can best be avoided by keep-ing heavy equipment off the soil when it has a high moisture content. Soil compaction can be remedied mechanically with deep tillage equipment.

WATER AND AIR

Under irrigated conditions, regulating the soil water (moisture level) is an important management consideration. Excessive soil moisture or saturated conditions can be as harmful as limited-water conditions. Soil pore space and soil temperature are directly related to soil water content. For instance, a wet soil takes longer to warm up and will have a greater incidence of fungal and bacterial plant diseases.

Plant roots need oxygen and get it from the air in the soil pore space. When a soil is saturated, water displaces all the air in the pore space. If the wet condition persists, plant roots will die from lack of oxygen.

NUTRIENT LEACHING

Leaching can best be described as the "flushing" of water and soluble nutrients out of the soil profile, specifically, out of the plant root zone. Factors that affect the rate of leaching in soils include:

- Amount of rainfall/irrigation
- Intensity (rate) of rainfall/irrigation
- Soil texture
- Quantity and type of clay minerals present
- Amount of organic matter

SOLUBLE SALTS

Soluble salts are described in terms of soil salinity and are measured by determining the electrical conductivity of a soil extract. Salinity problems can occur where there are excessive applications of fertilizer, fresh manure, wood ash, or irrigation water or in areas with high water evaporation. High soil salinity is detrimental to plant growth.

pH

The term pH refers to the concentration of hydrogen ions (H+) present in the soil. As the concentration of H+ increases, the soil becomes more acidic. As the concentration decreases, the soil becomes more basic (alkaline). The pH scale is 0 (acidic) to 14 (alkaline). A pH of 7 is considered neutral. The pH scale is logarithmic:

- pH 8 — 10 times more alkaline than pH 7
- pH 7 — Neutral
- pH 6 — 10 times more acidic than pH 7
- pH 5 — 100 times more acidic than pH 7
- pH 4 — 1,000 times more acidic than pH 7

Plant species have various adaptations to specific acidic, neutral, or alkaline soil conditions. When plants fail to thrive, even after a fertilizer application, it may be an indication that there is a pH problem.

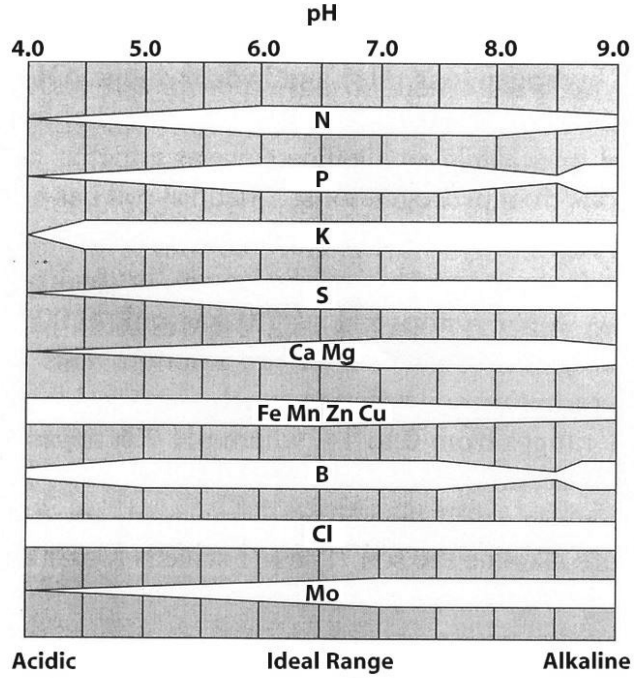


Figure 4. Relative availability of nutrients as affected by soil pH. The bar width for each nutrient indicates its relative availability to plants at a particular pH. The wider the bar, the more available the nutrient.

When pH is too low, applied lime can raise the pH. When pH is too high, applied sulfur can lower the pH. The change will be only temporary, however. Eventually, the soil pH will go back to what it was originally if amendments are not applied regularly. This ability of the soil to chemically revert to the way it was is referred to as buffering capacity. A soil that is high in clay content has a greater buffering capacity and will require a larger quantity of an amendment, such as lime, to change the pH. A sandy soil will require less lime to change the pH.

Soil pH greatly affects the availability of nutrients in the soil for plants to utilize. When pH is too acidic or alkaline then nutrients become unavailable to plants (Figure 4).

Plant Nutrients

ESSENTIAL NUTRIENTS

Plants obtain from the soil 14 of the 17 elements essential to their growth. The other three elements — carbon, hydrogen, and oxygen — come from the water and from the air.

Macronutrients

Large quantities are required. Nitrogen generally is for leaf or vegetative growth, phosphorus is for root and fruit production, and potassium is for cold hardiness, disease resistance, and general durability.

Primary macronutrients

- Nitrogen (N)
- Phosphorus (P or in fertilizers, designated as phosphate, PO)
- Potassium (K or in fertilizers, designated as potash, K_2O)

Secondary macronutrients

- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

Micronutrients

Small quantities are required. Deficiencies in these nutrients are less common.

- Boron (B)
- Iron (Fe)
- Molybdenum (Mo)
- Chlorine (Cl)
- Copper (Cu)
- Manganese (Mn)
- Zinc (Zn)
- Nickel (Ni)

FUNCTIONS OF MACRONUTRIENTS

Nitrogen (N)

Nitrogen can be taken up by plants as ammonium (NH_4^+) or nitrate (NO_3^-). Nitrogen is essential for the synthesis of proteins. It is essential to chlorophyll, which gives green color to plants; induces rapid vegetative growth; increases yields of leaf, fruit, or seed; improves the quality of leaf crops; increases the protein content of food and feed crops; and feeds soil microorganisms. Nitrogen tends to extend the length of the plant's maturity period, but too much will cause plants to fall over.

Phosphorus (P)

Phosphorus plays an important role in the metabolic processes of the cells such as cell division and expansion, respiration, and photosynthesis. In addition, P is important for early root growth and development. Phosphorus is significant in plant reproductive functions such as reducing the maturity period and stimulating flowering and seed formation. For some species, P improves winter hardiness.

Potassium (K)

Potassium is vital to water relations in the plant. It is responsible for the movement of water in and out of the guard cells that open and close the stomata and the movement of water in and out of the plant leaf. It also serves as a nutrient regulator; increases vigor, strength, and disease resistance; makes stalks and stems stronger; helps early roots form and grow; and improves winter hardiness.

Sulfur (S)

As part of several amino acids, S is essential for protein synthesis. It is also involved in nodule formation and N fixation in legumes.

Calcium (Ca)

Calcium aids in the development of leaves and roots. It is an essential part of the cell wall structure and must be present for the formation of new plant cells.

Magnesium (Mg)

Magnesium is essential for photosynthesis because it is the central atom in the chlorophyll molecule. Magnesium is also involved in phosphate metabolism and plant respiration and serves as an activator for many plant enzymes required in growth processes.

FUNCTIONS OF MICRONUTRIENTS

The content of micronutrients in the soil is variable, as is their availability to plants. Soil pH is a significant factor in micronutrient availability. In very acidic soils, micronutrients can be toxic to plants.

Boron (B)

Boron is probably the most commonly deficient micronutrient. Boron is essential for germination of pollen grains, growth of pollen tubes, and the formation of seeds and cell walls. Boron may also be involved in carbohydrate transport.

Chlorine (Cl)

Chlorine, usually as the chloride ion, is active in the energy reactions of the plant, specifically in the breakdown of water during photosynthesis. Chloride is present in the stomatal guard cells that regulate the loss of water from leaves through transpiration. Chloride has also been linked to increased resistance to fungal diseases in roots.

Copper (Cu)

Copper is necessary for chlorophyll production and may play a part in vitamin A production. Copper is also a component of several plant enzymes.

Iron (Fe)
Iron is a catalyst of chlorophyll formation and acts as a carrier of oxygen. It is also involved in the formation of some respiratory enzymes.

Manganese (Mn)
Manganese is part of the enzyme systems and metabolic reactions of the plant. It is also directly involved in the synthesis of chlorophyll.

Molybdenum (Mo)
Molybdenum is required in the smallest quantity of all the essential nutrients. Plants need it to use N, particularly for N fixation in the root nodules found on legumes.

Nickel (Ni)
Nickel is the most recent nutrient to be added to the essential nutrient family. It is an important component in N metabolism, particularly in the conversion of urea to ammonia.

Zinc (Zn)
Zinc is necessary for the production of chlorophyll and carbohydrates. Zinc is involved in the synthesis of plant growth hormones and in some metabolic reactions.

NOTE: Cobalt (Co) is not considered an essential nutrient, but root-nodule-forming bacteria in legumes need it for fixing N.

GENERAL NUTRIENT DEFICIENCY SYMPTOMS
Nutrient deficiency symptoms are an indication of severe starvation. A nutrient deficiency will limit plant production before deficiency symptoms actually show. Deficiency symptoms are sometimes difficult to distinguish visually and may resemble disease or insect problems.

General nutrient deficiency symptoms are categorized here according to whether or not the nutrient is translocated in the plant. Deficiencies of translocated nutrients exhibit symptoms in the lower or older leaves because the nutrients are mobilized and moved to new, growing parts of the plant.

Translocated Nutrients
Nitrogen. Plants are light green in color; older leaves yellow starting at the leaf tips.

Phosphorus. Plants are small and dark green with purple coloration.

Potassium. Yellow or brown discoloration appears along the outer margins of the older leaves.

Magnesium. Yellow discoloration occurs between the leaf veins. Reddish-purple discoloration extends from the outer edge of the leaf inward.

Nontranslocated Nutrients — Terminal Bud Dies
Calcium. Primary leaf emergence is delayed and terminal buds deteriorate.

Boron. Leaves near the growing point (meristem) are yellow and buds look like white or light brown dead tissue.

Nontranslocated Nutrients — Terminal Bud Remains Alive
Sulfur. The whole leaf turns pale green to yellow starting with the younger leaves.

Zinc. Distinctive yellowing appears between the leaf veins; some plants show a broad band of discoloration on each side of the midrib. The plant is stunted and has short internodes.

Iron. Leaves are pale yellow or white between leaf veins.

Manganese. Leaves are yellowish gray or reddish gray with green veins.

Copper. Young leaves are pale yellow and/or are wilted or withered; seedheads may not form.

Chlorine. Upper leaves wilt then yellow.

Molybdenum. Young leaves wilt and die along the margins; older leaves yellow due to their inhibited ability to utilize N.

Nickel — The Exception
Deficiency symptoms have not been observed in field conditions, only in research settings, but include yellowing of young leaves and the death of meristem tissue.

Mulches
Mulch is any material, organic or inorganic, that is spread upon the surface of the soil to protect it and plant roots from the impact of raindrops, crusting, freezing, and evaporation.

ORGANIC MULCHES
Organic mulches include grass clippings, hay, straw, bark, sawdust, wood shavings, leaves, and

newspapers. You can use almost any plant material for mulching as long as it allows air and water to penetrate to the soil below. Coarse-textured material, such as coarse-textured hay, straw, wood shavings, and chips, are more desirable than fine-textured materials such as leaves, pine needles, and sawdust. When using fine materials, loosen them occasionally to keep them from sealing the soil surface.

INORGANIC MULCHES

Inorganic mulches include plastic films, mat-type weed barriers, aluminum foil, and even old carpet. Although inorganic mulches provide some of the same benefits as organic mulches, they cannot be incorporated into the soil at the end of the growing season and must be removed where you plant annual crops. Perforated plastic film or spun-bound material, such as landscape cloth, allows water and air to easily reach the soil.

SEASONAL MULCHES

A thin layer of mulch will conserve soil moisture and 2 or more inches of mulch will control most weeds. Mulch effectiveness depends upon the material you are using and the weed species to be controlled.

Summer Mulches

Use summer mulches to control weeds, reduce water evaporation from the soil, stabilize water temperature, and reduce fruit rot on bare soil. Incorporate organic summer mulches in the fall to improve soil structure.

Winter Mulches

Use winter mulches to reduce water loss from evergreen plant tissue and to stabilize soil temperatures. Stable soil temperatures will minimize soil heaving caused by alternate freezing and thawing. Winter mulch applied too early in the fall can cause more winter injury than none at all.

PROBLEMS WITH MULCHES

Organic mulches, such as cereal grain straw, can introduce weed seeds. The mulch may attract rodents, insects, and other pests as an overwintering site. Mulching too soon in the spring can prolong cool soil temperatures, which will delay the growth of warm-season crops. Material with a high C:N ratio such as bark, wood shavings, sawdust, or straw may temporarily reduce soil N available to plants unless you incorporate additional N fertilizer into the soil.

Fertilizers

Fertilizer is defined as any substance added to the soil or sprayed on plants as a foliar fertilizer to supply one or more plant nutrients. Every mixed fertilizer or individual material sold has a guaranteed analysis written on the bag. The analysis gives the amounts of available nitrogen (N), available phosphate (P_2O_5), and soluble potash (K_2O), in that order. The three numbers are always percentages by weight. Certain secondary macronutrients and micronutrients may also be included in the analysis.

Many brands and formulas of fertilizer are on the market. Select a brand that supplies N, P_2O_5, and K_2O in approximately the same ratio your soil test indicates. For example, if your test indicates you should use 1 pound of N, 2 pounds of P_2O_5, and 1 pound of K_2O, the ratio indicated is 1-2-1. You could use a 10-20-10, a 5-10-5, a 6-10-4, or an 8-17-7 analysis fertilizer. All of these are in approximate 1-2-1 ratios.

FERTILIZER TERMINOLOGY

- **Mixed fertilizer** — A fertilizer that contains two or more of the macronutrients (N, P, K).
- **Complete fertilizer** — A fertilizer that contains all three macronutrients (N, P, K).
- **Incomplete fertilizer** — A fertilizer that is missing one or more of the major components found in a complete fertilizer.
- **Grade** — The guaranteed minimum analysis in percent of plant nutrients in a fertilizer expressed as total N, available P_2O_5, and soluble K_2O.
- **Chelates** — The word chelate comes from the Greek word for “claw.” Chelates are organic substances or chemicals that act like claws and help hold metal ions in solution in an available form so that plants can absorb them. The solubility of metals, particularly Cu, Fe, Mn, and Zn, is greatly increased when they are held by chelating agents.
- **Soil amendment** — A substance added to the soil to change its pH or physical properties. A common example is the use of lime to increase soil pH.

NUTRIENT SOURCES AND FERTILIZER TYPES

Common nutrient sources and contents of fertilizers appear in Table 3.

Table 3. Common sources and nutrient contents of fertilizers.

Nutrient and source	Nutrient content of fertilizer (% by weight)
Nitrogen (N)	
Anhydrous ammonia (gas)	82
Ammonium nitrate	33–34
Ammonium sulfate (24% sulfur)	21
Urea	46
Urea-ammonium nitrate solution (UAN)	28–32
Sulfur-coated urea (slow release)	39
Monoammonium phosphate (MAP)	10–11
Diammonium phosphate (DAP)	18
Potassium nitrate	13
Calcium nitrate	15
Phosphorus (P_2O_5)[1]	
Normal or single superphospate (NSP or SSP)	20
Concentrated (CSP) or triple superphosphate (TSP)	46
Monoammonium phosphate (MAP)	48–55
Diammonium phosphate (DAP)	46
Ammonium polyphosphates (APP)	40–70
Potassium (K_2O)[2]	
Potassium chloride	60–62
Potassium sulfate (SOP)	50
Potassium nitrate	44
Sulfate of potash-magnesia (Sul-Po-Mag or K-Mag)	22
Calcium (Ca)	
Calcitic limestone	32
Dolomitic limestone	22
Gypsum	22
Burned lime	60
Magnesium (Mg)	
Dolomitic limestone	3–12
Magnesium oxide (magnesia)	55–60
Magnesium sulfate	9–20
Potassium-magnesium sulfate	11
Sulfer (S)[3]	
Ammonium sulfate	24
Potassium sulfate	18
Gypsum	12–18
Magnesium sulfate	14
Boron	
Borax	11
Boric acid	17
Chlorine (Cl)	
Potassium chloride	47
Copper (Cu)	
Copper sulfate	22
Copper ammonium phosphate	30
Iron (Fe)	
Iron sulfate	19–23
Iron chelate	5–14
Manganese (Mn)	
Manganese sulfate	26–28
Manganese chelate	12
Molybdenum (Mo)	
Ammonium molybdate	54
Molybdic acid	47
Nickel (Ni)	
NA	
Zinc (Zn)	
Zinc sulfate	23–36
Zinc chelate	9–14

[1] Rock phosphate is the basic material used in all P fertilizer production. Phosphate for use in fertilizers is either acid treated or thermal processed. Acid treatment is the most important and utilizes sulfuric and phosphoric acids.

[2] Elemental K is not found in nature due to its chemical reactivity. Potash (K_2O) is the primary source of potassium for fertilizer use. Potash is found beneath the surface in salt beds or in the brine of salt lakes and seas. Many minerals contain potassium, but the most important are sylvinite (20%–30% K_2O) and langbeinite (23% K_2O).

[3] The primary source of S is soil organic matter.

FERTILIZER APPLICATION AND TIMING

Fertilizer Timing

The timing of fertilizer application depends somewhat on the type of fertilizer and the plant being fertilized. In addition, soil texture determines application frequency and the amounts to apply. For soils with high sand content, the recommended fertilizer application may need to be divided into smaller quantities applied more frequently. The opposite is true for soils with high clay content.

As a general rule, the best time to apply any nutrient is close to the time the plant is growing the most and thus needs the nutrients. This prevents environmental losses and the nutrient's becoming unavailable in the soil before the plants can use it. It is best to apply foliar fertilizers when the weather is cool, but not cold, and when there is adequate soil moisture.

Phosphorus, K, and lime can be applied in the fall or as part of a tillage operation. It is important to apply N early in the spring during the active growth period. If your plants need a lot of N, it is best not to apply it all at once but rather to split the application into smaller amounts at two or three intervals. Some forms of N are very soluble and do not stay in the rooting zone very long. As a general rule, apply no more than 50–75 lb/acre of N in one application. Plants are more likely to utilize N applied in smaller amounts more frequently and our groundwater and streams will be protected from nitrate pollution.

Fertilizer Application

There are several methods for applying fertilizers. The most common is to broadcast granular formulations on the surface or till them into the seedbed. Another method is banding — placing the fertilizer below the surface in a band below or beside a seed at planting time. Some fertilizers can be applied through an irrigation system. Fertilizers can also be applied in liquid or powder form. Micronutrients are usually most effectively applied as foliar sprays.

Salt Accumulation and Soil Leaching

Fertilizer is more likely to burn a plant in hot, dry conditions when the plant is stressed. If there is insufficient moisture after fertilizer application, then the salt concentration can increase, making it even harder for plants to take up water. Adequate water will help prevent high salt accumulations.

Potted plants should be leached every 4–6 months and garden soils at least once a year. Leach the soil by saturating it with water and letting it drain completely. A rule of thumb is to apply water in an amount that is double the volume of the pot. For instance, a 6-inch pot will hold about 10 cups of water, so use 20 cups of water to leach out accumulated salts. Different plants have different levels of tolerance for salt accumulation.

GREEN MANURE AND COVER CROPS

By definition, green manure crops are grown and incorporated into the soil to improve the latter. Cover crops are grown primarily to reduce soil erosion and nutrient leaching.

Usually, green manure crops are annuals and cover crops are perennials, either legumes or grasses. Cover crops can be incorporated into the soil and used as green manure crops.

When managed properly, both green manure and cover crops add N to the soil for use by the crops planted later. They tend to increase the level of soil fertility and soil humus. They improve the soil's physical properties of aggregation, porosity, bulk density, and permeability. Their effects are more pronounced in clay soil than in sandy soil.

Green Manure

The benefit of using green manure crops depends on the soil, climate, and species of plants grown. Environmental conditions that affect microbial growth determine the rate of decay of organic residues. Warm soil, proper aeration, and ample soil moisture increase microbial activity, thereby increasing the rate of decomposition of organic matter. Decomposition releases carbon dioxide and weak acids that help release nutrients. The chemical composition of the plants affects their value as a green manure crop.

Green manure crops have little influence on soil organic matter content if cultivation is continuous. In cooler climates, green manure crops can increase soil organic matter and N. In warmer climates, cultivation speeds up the rate of decomposition so an increase in soil organic matter content is difficult to achieve. Using green manure crops can improve soil structure, which enhances aggregation and increases the space between soil particles.

Any fast-growing annual crop is a good choice for a green manure crop, such as ryegrass, wheat, barley, vetch, or field peas. A legume is a great choice because of its ability to fix N. Green manure crops should be seeded immediately following the harvest of the main crop and not allowed to go to seed. Incorporate them at least 2 weeks before planting the next crop. As grasses and cereal grains reach maturity they can tie up N, so they should be incorporated into the soil early in the growing season.

Cover Crops

Use cover crops for alleyways in orchards and vineyards to prevent weed growth and in gardens for pathways. Cover crops may require some maintenance such as mowing and fertilization. Cover crops are good for fall gardens in-between the rows and in any other cleared areas.

Cover crops provide organic matter and store nutrients, which helps reduce nutrient losses from the soil profile by leaching of N, K, and other nutrients. Legumes add N to the soil and reduce erosion because they are deep rooted. Leaching is more of a problem on soils with high sand content.

A good ground cover reduces soil erosion by reducing raindrop impact on soil particles. Plant cover increases the water infiltration rate and minimizes water runoff. Leaves and stems "catch" the rain and roots create channels for water movement in the soil.

Negative aspects of cover crops include competing with the main crop for nutrients and moisture and encroaching on the main crop. Cover crops may also provide a safe haven for gophers, mice, insects, and diseases that can attack the main crop.

ORGANIC FERTILIZERS

Research has found no difference in the nutrient contents of organic food and regularly produced food. However, organic foods are less likely to have chemical residues. As far as the plant is concerned, it does not matter if nutrients are supplied by decaying plant material or from commercial fertilizers: N is N is N. Plants are self-contained biochemical factories. All they need are raw materials (nutrients).

Generally, organic fertilizers release nutrients slowly. Organic fertilizers depend on microorganisms to break them down in order to release their nutrients. Therefore, most are effective only when soil moisture and temperature are suitable for microorganisms to be active. Some examples of organic fertilizer sources are listed below:

- **Cottonseed meal** — Approximate analysis: 7-3-2. It can be somewhat acidic so it is often used to fertilize acid-loving plants.
- **Blood meal** — Dried, powdered blood collected from slaughterhouses is a rich source of N and may contribute some trace elements, including iron. Issues associated with animal by-products used in food sources may be a concern.
- **Fish emulsion** — A partially decomposed blend of finely pulverized fish, it is high in N, a source of some trace elements, and has a strong odor.
- **Manure** — Nutrient content is generally low and varies with animal source and feed. Manures are best used as soil conditioners rather than as sources of nutrients. Fresh manure can damage young plant material due to its high mineral salt content if irrigation is not managed properly.
- **Sewage sludge** — A by-product of municipal sewage treatment plants, it generally comes in two forms, activated and composted. Activated sludge has a higher nutrient content (approximately 6-3-0) than composted sludge (approximately 1-2-0). There is some concern that long-term use could lead to the buildup of certain heavy metals. Another concern focuses on its use in a garden around edible plants. The origin of the sludge determines its nutrient and heavy metal contents. A sludge-based nutrient source should be analyzed for heavy metals before use.

Further Reading and Resources

BOOKS

Havlin, J. L., J. D. Beaton, S. L. Tisdale, and W. L. Nelson. 1999. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*. 6th ed. Englewood Cliffs, NJ: Prentice Hall.

Minnich, J., and M. Hunt. 1979. *Rodale Guide to Composting*. Emmanus, PA: Rodale Press.

Soil Improvement Committee, California Fertilizer Association. 1997. *Western Fertilizer Handbook: Second Horticulture Edition*. Prentice Hall.

BOOKLETS AND PAMPHLETS

BUL 915 *Soil Testing to Guide Fertilizer Management*

CIS 787 *Liming Materials*

CIS 815 *Northern Idaho Fertilizer Guide: Blueberries, Raspberries, and Strawberries*

CIS 853 *North Idaho Fertilizer Guide: Grass Pastures*

CIS 863 *Fertilizer Primer*

CIS 911 *Northern Idaho Fertilizer Guide: Northern Idaho Lawns*

VIDEOS

How Water Moves through Soil. University of Arizona. Available for checkout from the Benewah County Extension Office, St. Maries, ID.

Soil Monolith Collecting and Preserving. 1987. Available from the UI Soil and Land Resources Division, College of Agricultural and Life Sciences, Moscow, ID.

WEBSITES

Idaho State Department of Agriculture. https://agri.idaho.gov/main/.

Natural Resources Conservation Service. Published Soil Surveys for Idaho. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Smithsonian Environmental Research Center. "Dig It! The Secrets of Soil." https://forces.si.edu/soils/.

University of Idaho. Idaho Master Gardener Program. https://www.uidaho.edu/extension/master-gardener.

University of Idaho Pedology Laboratory. https://www.uidaho.edu/cals/soil-and-water-systems/research/pedology-laboratory.

INSTRUCTOR RESOURCES

Soil Texture Kits. Nine 2-lb texture samples can be purchased from the UI Soil Evaluation Team, Moscow, ID, (208) 885-7554. ($75.00)

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