Cornell Cooperative Extension
Cornell Garden-Based Learning

Introduction to Soils

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Relationship of Soil to Plant Growth and Development

It is not possible to grow plants and gardens well without the water, nutrients and support that are provided by the soil. Ignoring the soil or assuming that all soils are alike can lead to disappointments or poor choices of management practices. Remember that the soil is teaming with life and constantly changing. By putting the right plant in the right place you will be able to have more productive gardens and successful landscape plantings. Basic understanding of your soil will allow you to:

- select the right plant (and recommended variety) for your site,
- provide adequate nutrients and water (based on plant needs)
- maintain a proper soil pH
- avoid practices that cause compaction or erosion·
- improve poor drainage
- improve aeration

While we will discuss nutrients and pH in this module, we will discuss their management with more detail in the Soil Amendment and Fertilizer section, it is important to note that much of the success of your plants will be based on understanding the soil so that you can both choose the plants and manage the soil for success. Remember that the plants will only succeed if placed in the appropriate soil and when you manage the soil appropriately.

This section will serve to introduce you to important components of soil that effect water movement and storage, aeration and drainage as well as soil organisms and soil organic matter. We also discuss how soil develops as well as where and how distinct soil characteristics appear. Take particular note of this discussion as we can greatly impact, for good or ill, the inherent and dynamic characteristics through our management of the soil.

Finally, at the end of the module we visit the concept of Right Plant, Right Place. A concept that asks you to consider the distinct needs a plant requires to succeed. This is an approach that while not strictly about soil, introduces planting decisions based on 1) what is already present at the site, 2) how would we need to manage given the site characteristics and 3) what we could we do to change those site characteristics. In the long run it is a whole lot easier and generally more successful to put a plant in a suitable location, than manage the location so that you can grow a plant that is unsuitable.

Asking questions about the light, water, temperature and nutrient requirements of the plant and what is, or isn't provided by the site is a great way to understand where your plants will succeed and where they won’t.

Soils

Plants grow in soil. To be successful gardeners, we must understand, use and nurture this incredible resource. Soil is composed of mineral, organic matter, water and air and in partnership with plants and other soil organisms creates a dynamic living media.
The soil organisms may be as simple as bacteria and fungi or as complex as insects, earthworms and small mammals. With this interaction of plants and soil organisms with mineral, organic matter, water and air an incredible amount of chemical, physical and biological reactions take place. Through these dynamic interactions, soil provides plants with the water and nutrients that they need to grow. Soil also provides the medium for roots to anchor plants as well as acts to store and filter water as it moves into and through this dynamic environment. It turns out that there is a difference between soil and dirt. Dirt is soil material that is taken out of its native location. But dirt can, given time and care, become a healthy and productive soil.

Soil Development

Soil development is an on-going process that produces an ever-changing media that continues to develop over thousands and sometimes millions of years.

The process begins when water and temperature, sometimes in combination with organisms and organic matter, begin the transformation of mineral material from rocks into a developing soil. This mineral or organic matter is known as the parent material.

Mineral or rock parent materials include wind-blown sand (dunes), alluvium (deposits left as a result of river overflows), glacial till (ground up materials deposited by glaciers), glacial outwash (glacial deposits that were re-deposited by glacial melt waters) or even bedrock. When these materials are exposed at the surface of the planet they begin to weather. These weathering processes can be due to chemical reactions such as acid dissolution from rainfall and/or due to physical breakdown due to changes such as freezing and thawing (ice expansion), uneven heating, abrasion by ice, water and wind, shrinking and swelling and root activity.

Organic parent material can also be deposited at the soil surface as plants and other organisms die or defecate. This organic matter can also be added to soil at depth by the death of roots or the mixing of soil organisms. The decomposing organic matter produces organic byproducts or leachates which then further transform the soil.

The byproducts of weathering, decomposition and mixing, beside transforming the soil are often nutrients that were tied up in organic matter or minerals but are now available for uptake to soil organisms and plants.

These byproducts can be carried by water through the soil and moved to other parts of the soil where it can be taken up by plants as nutrients, stored or even lost as the ground water moves away from the local soil.

Over the years the weathering of mineral material, the decomposition of organic matter and the mixing of these materials by soil organism and other soil forming factors produce a medium that we recognize as a robust, mature soil with good tilth and fertility.

Soil is a critical natural resource that can be improved with thoughtful stewardship. A sustainable gardening ethic includes:

- the recycling of organic matter so that last season's yard and garden waste contributes to next season's plant nutrients.
- the regular incorporation of organic matter to improve our soil's physical condition **(tilth**) and to leave our soil in better condition than we found it.
- the prevention of soil erosion and nutrient run-off.

What are the Components of Soil?

Soils consist of four major components: minerals, organic matter, water and air. The solid components of the soil are made up of minerals and organic matter and are approximately 50% of the volume in a healthy soil. The remainder is void (or pore) space filled with water and air. In an ideal garden soil, water occupies about half (or a quarter of the total soil volume) of the void with air occupying the remainder.

Minerals
The origin of the mineral fraction in the soil is rock, which has weathered over many years into smaller particles. Sand, silt and clay are the three smallest size components of the mineral fraction of soil and range in size from 2 mm to smaller and make up what we call the soil's texture. While gravel is not considered a soil texture component it will affect the management of your garden. We place much importance on a soil's texture because the smaller the particles are in a handful of soil the more the surface area there is for biological, chemical and physical reactions. Texture, in combination with the pore spaces, controls water movement and storage, nutrient storage and availability as well as root penetration and other biological activities.

- Sand is predominately quartz minerals that are highly resistant to weathering. Sand is visible without magnification and is generally round in shape.
- Silt is derived from many different minerals and its somewhat resistance to weathering is due to its mineralogy. Silt is plate-like in shape and can't be seen with the naked eye.
- Clay particles are derived from many minerals and can't be seen without an electron microscope. They are platy in shape and generally have a negative electrical charge. They have an extremely important role in nutrient availability.

Organic Matter
Soil organic matter consists of dead and decaying plants and animals. Organic matter is critical for gardening success for two major reasons:

- It improves the soil's physical structure or tilth, which affects the soil's water holding capacity and aeration.
- It slowly releases plant nutrients.

In natural settings, plant nutrients are returned to the soil as plants, and organisms die and decompose. Soil organisms (e.g. microbes and earthworms) digest and transform the organic matter into humus; the dark, fluffy end product which is fairly stable and homogenous. Through this decomposition process, plant nutrients are released and made available for use by growing plants. The recycling of plant nutrients, driven by the soil's microbial inhabitants, is critical in maintaining fertile soils.

- Nearly all of the soil's organic matter content is in the upper part of the soil.
- The organic matter content of most mineral soils ranges from 1-6%.
- Organic matter is often higher in soils that have not been cultivated for a long time than in soils that are frequently cultivated or tilled, and/or where plant residues are less frequently returned to the soil.

Cultivating or tilling aerates the soil, which increases the rate that organic matter decomposes.

Water and Air
Water and air are found in the pore spaces between the mineral and organic components. Often called void space, these pore spaces account for up to 50% of total soil volume and allow for the movement of air and water. Air and water are essential for growth and health of plant roots and soil microbes. Water is also responsible for plant rigidity (turgor) and is the solvent in which most plant nutrients are dissolved. Air and water are used continuously by plant roots and microbes and must be replenished. Soils differ greatly in their capacity to provide air and water to plant roots.

Water in soil comes from precipitation and ground water. Falling rain enters the soil through cracks, holes, and openings between soil particles. As the water enters, it pushes air out. If air is unavailable to plant roots for too long, the plant will suffer from lack of oxygen and be unable to respire in the roots. Some water is used by plants, some is lost by evaporation, and some moves so deep into the soil that plant roots cannot reach it. If rainfall is intense or prolonged, some water may be lost to runoff.
Another source of water in our gardens is irrigation. Hoses, watering cans, drip irrigation, and sprinkler systems all deliver water to the garden. Proper placement, aim, timing and quantity delivered can be controlled.... or misused... more easily than rainfall.

Air comes from the surface atmosphere and must diffuse through the same pore pathways as water. This diffusion is controlled by soil water content, the size and number of pores, the pore continuity and temperature.
Soil porosity is a measure of the pore space volume of a given soil.

- Pore spaces are essential for the movement of air, water and plant roots.
- Sandy soils have large pore spaces which promote rapid drainage of water with little water storage but excellent aeration.
- Clayey soils are "tight" or "heavy". They contain many tiny pore spaces, which store water well but may impede root growth, aeration, and water drainage.

Imagine blowing through a straw. As the diameter of the straw diminishes, it becomes more difficult to blow through. Water and air have this same difficulty. Water and air travel at different rates as the pores change size and shape. This affects the speed that water and air travel to roots and other soil organisms and the storage of water and air in the soil. Now dip those same straws in water. As the diameter of the straw diminishes, it becomes increasingly better at holding water. Small pores hold water that plants can take up, but at the same time the water moves slower and less air is available to those same plants.

Plants and soil organisms need both water and air to survive. If a soil does not drain, air will not be able to move through the soil, limiting respiration. A byproduct of respiration is carbon dioxide (CO_2) which at high concentrations can be detrimental to soil life. A well aerated soil will allow sufficient oxygen to enter and excess CO_2 to exit the soil atmosphere.

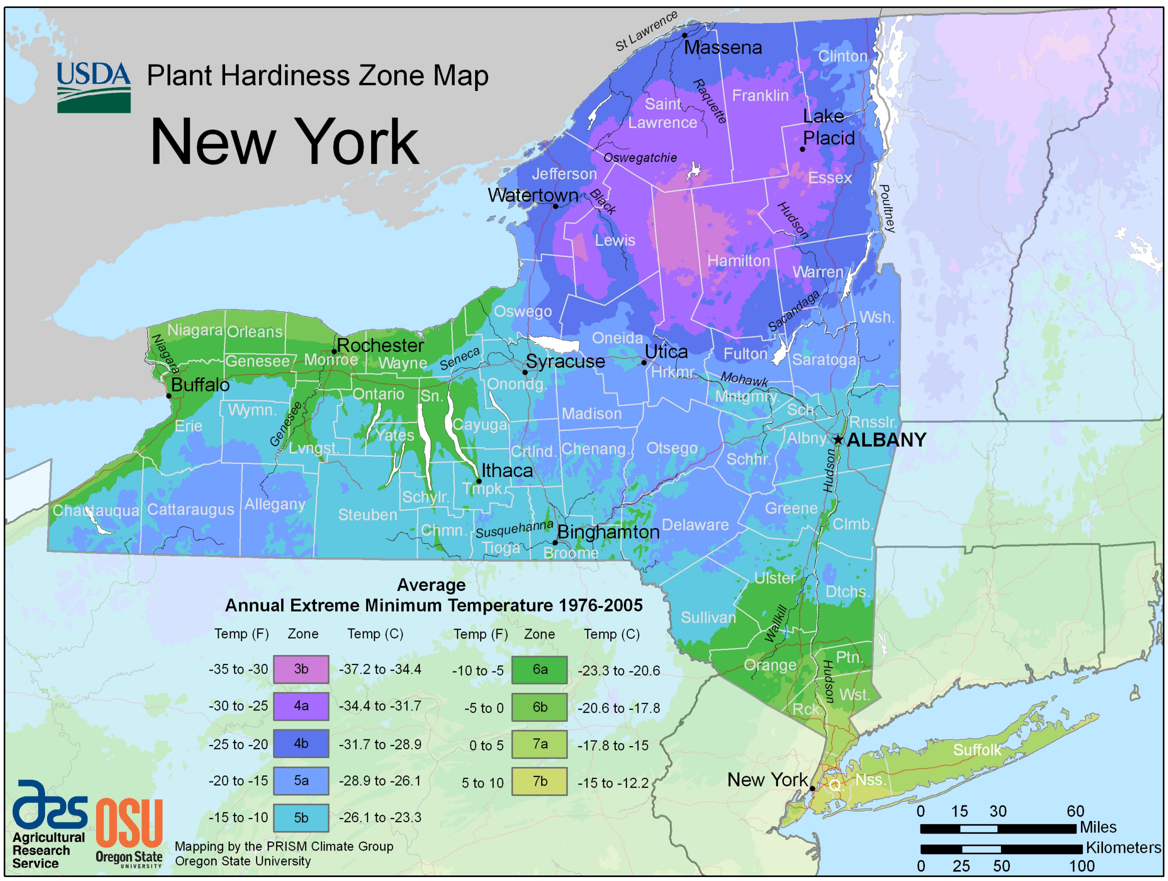
A balance of water and air must be maintained for most garden and landscape plants. If water drains too fast or is not stored on soil particles, soil organisms will not have the water they need to survive. If on the other hand, as water builds up in the soil less air is able to reach the roots and soil organisms, limiting their respiration.

Pore Spaces
How important are the shape and size of pore spaces? Much more important than most gardeners acknowledge. They can be large (macropores) or small (micropores). Macropores aid in drainage and aeration of the soil, but provide little water storage. While limiting drainage, Micropores play an important role in long-term water storage for plants. Having a balanced combination of macro and micropores in the soil is the key to a successful garden. Therefore, limiting garden practices that change pore balance and destroy structure (discussed below) are extremely important to a successful garden.

As an aside, we often recommend adding organic matter to soils as it can both increase your soil's water-holding capacity by providing small sponge like pores in sandy soils, while at the same time increasing drainage by creating large pores in clayey soils. The added benefit is that the organic matter will decompose and provide nutrients to your plants.

The soils of New York can be described as young (mostly developed after the last glacial advance some 25,000 years ago) and have a relatively high nutrient content. New York State generally has a short growing season (103 to 203 days) due to the cool climate with adequate moisture (averaging 30 to 40 inches of rainfall per year). The diversity of New York's topography, parent material, biota and climate has produced over 300 soil series (types of soils) in New York. New York State has a wide range of plant hardiness zones, as seen in Figure 1.

Figure 1: Plant Hardiness Zones in New York State
(Image source: http://planthardiness.ars.usda.gov/PHZMWeb/Images/300dpi/NY.jpg)



Soil Organisms

While not considered a component of soil, soil organisms play a critical role in soil creation and nutrient dynamics, and it is their dead and decomposing remains in combination with plant material that make up soil organic matter, as seen in Figure 2.

Figure 2: The Soil Food Web

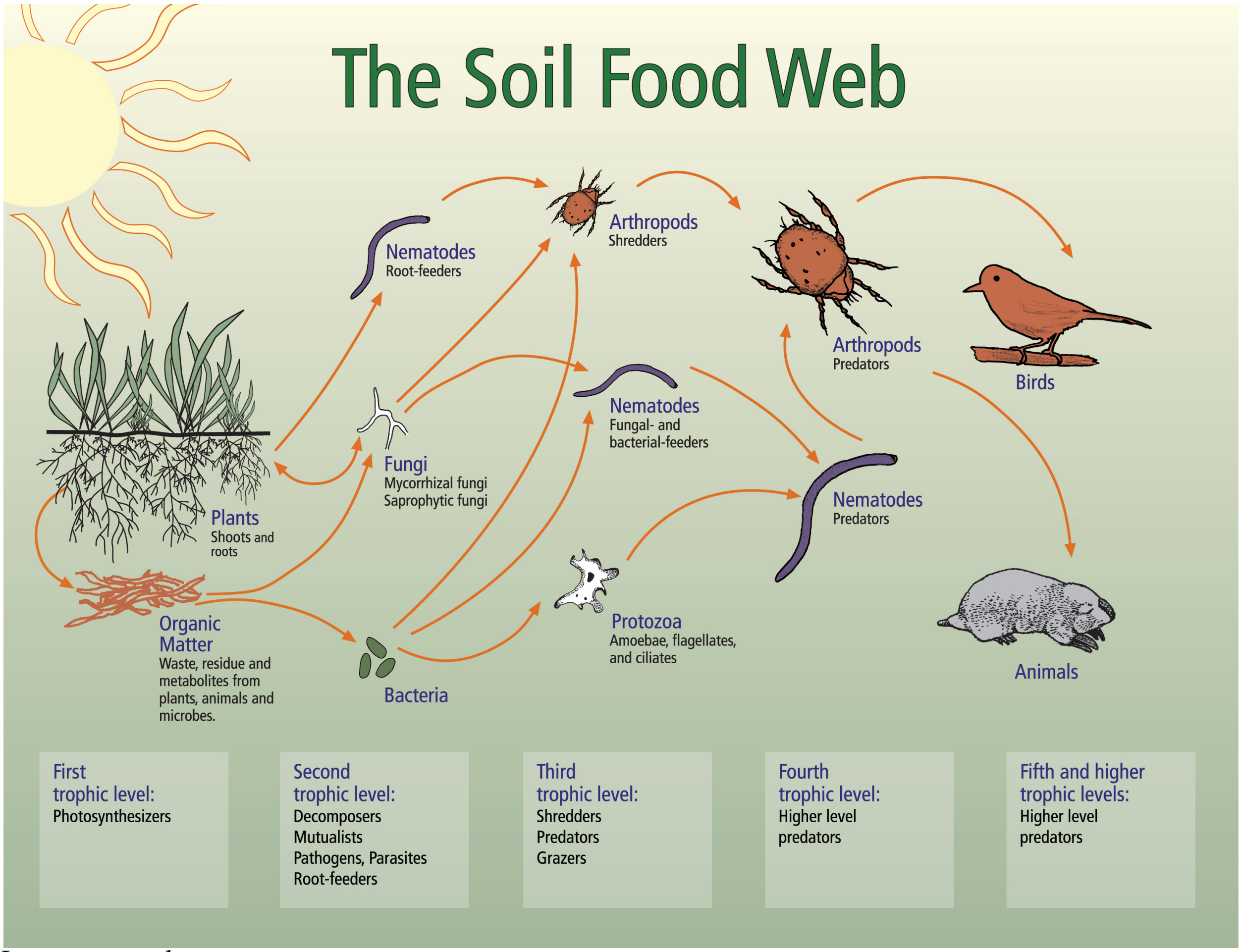


Image sourced:
https://www.nrcs.usda.gov/wps/portal/nrcs/photogallery/soils/health/biology/gallery/?cid=1788&position=Promo

Soil organisms include bacteria, fungi, actinomycetes, algae, protozoans, nematodes, earthworms, insects, mites, centipedes, millipedes, spiders, moles, shrews, mice and voles to name a few. Nematodes number from 10 to 1,000 per gram of soils. Most numerous are the bacteria (1 to 10 trillion per gram of soil); a single pinch of garden soil may contain 10,000 bacteria. The smaller organisms (bacteria and fungi) decompose the organic matter. The rest of the community of soil organisms feed on organic matter, bacteria, fungi and one another. They form a micro-community in the soil. After these materials pass through the gut of animals, they are more readily attacked by the bacteria and fungi because they have been broken down by enzymes and their surface area has been increased. Many of the microbes, worms and fungi in the soil secrete a slimy substance (mucopolysaccharide) which holds soil particles together, creating soil structure.

Practices that encourage biological activity:

- Additions of organic amendments that will readily decompose and provide nutrients and shelter for soil organisms
- Maintain moist soil condition (not too wet and not too dry)
- Maintain balanced pH and fertility levels

- Apply physical amendments to improve macroporosity which increases oxygen level
- Avoid compacting your soil and consider practices that alleviate compaction for both lawns and garden beds
- Limit the use of pesticides

As noted, there are a multitude of organisms in the soil. Some noteworthy ones are nematodes, earthworms, insects and spiders in the garden soil. Earthworms play a particularly important role as they wind their way in and out of the soil. Earthworms keep and restore soil fertility. There are different types of earthworms, including the night-crawler, field (garden) worm, and manure (red) worm, all of which have different feeding habits. They all feed and move plant residues or organic matter in the soil. The worms digest soil minerals, bacteria, and enzymes to create worm casts. Their casts are generally higher in available plant nutrients than the surrounding soil, such as nitrogen, calcium, magnesium and phosphorus, and are a readily available source of nutrients to plants. They also bring food down into their burrows, thereby mixing organic matter deep into the soil. Many earthworm types make burrows as deep as three feet. These macropores allow rainfall and air to easily infiltrate into the soil. These burrows or channels help to loosen the soil, helping with aeration and root growth. A modest garden of 100 square feet can have 1,600 worm channels in it.

Soil Texture and Textural Classes of Soils

The proportion of different sized soil mineral particles that are smaller than 2 mm - sand, silt and clay - is called soil texture. As discussed above we place great importance on these smaller particles, as they have so much more surface area in any given space than larger materials in soil such as gravel. The more surface area that a given volume of soil has, the more biological, chemical, and physical reactions can occur. This texture, in combination with the pore spaces, controls water movement and storage, nutrient storage, and availability as well as root penetration and other biological activities. This proportion remains fairly constant through time. The shape of the particles varies as well. In general, sand particles are round, while silt and clay particles are plate-like. The size and shape of these particles influence water infiltration and water storage.

Consider the relative sizes of these different textural components, reported by the USDA.

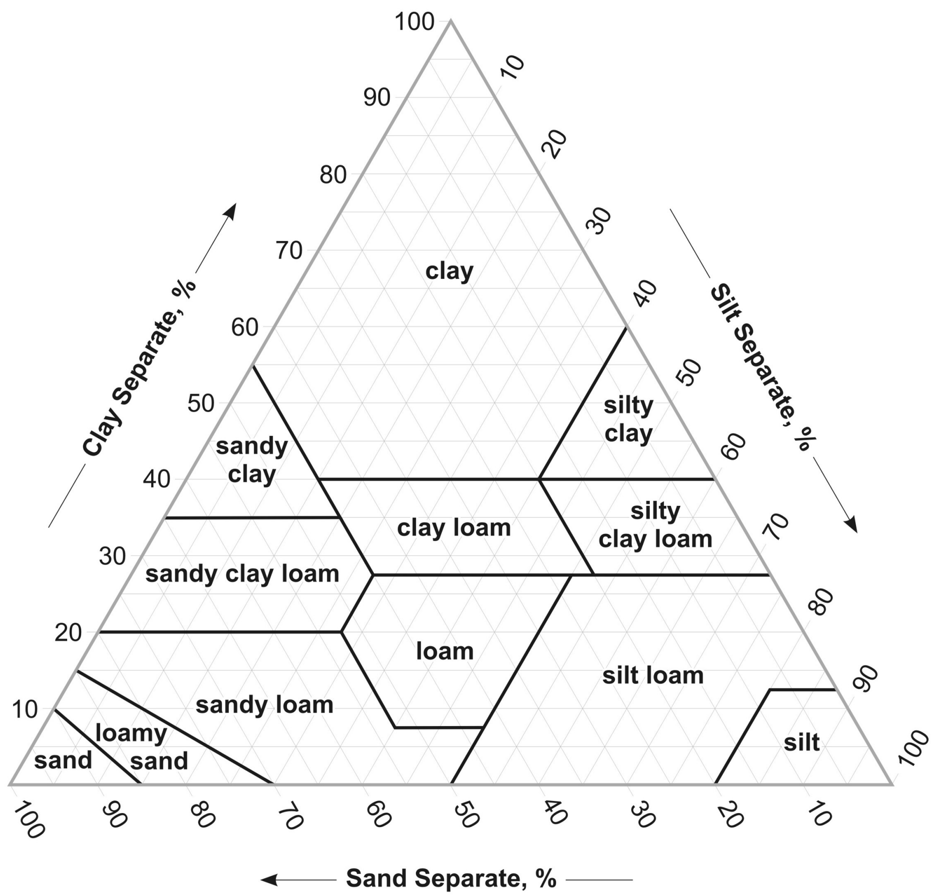
Soil Type	Diamter Size (mm)
Very coarse sand	2.00-1.00
Coarse sand	1.00-0.50
Medium sand	0.50-0.25
Fine sand	0.25-0.10
Very fine sand	0.10-0.05
Silt	0.05-0.002
Clay	<0.002

To illustrate these differences, if we imagine that a sand grain is the size and shape of a beach ball, a grain of silt would be the size and the shape of a Frisbee and a clay particle would be the size and shape of a dime. These shapes and sizes will affect the shape and size of the pore space. If we were to fill a room with beach balls (sand) there would be a lot of large pores between the balls. Filling the room with Frisbees (silt) would result in small, flat pore spaces, but the actual volume of pore space would be approximately the same. At the same time, by reducing the size of the particles we would create a greater total surface area on the soil solids. Reducing the particle size to that of a dime (clay) would reduce the pore space even more, and will also increase the surface area of the particles. The more surface area, the more reactions and interactions can occur. Soil texture also effects the type and distribution of pores (macropore and macropore), which in turn affects drainage, water holding capacity and soil aeration.

Although soils are generally a combination of different particle sizes, we do find many soils with only one particle size. (sand dunes, beaches, etc.). The proportion of soil composed of sand, silt and clay are used to determine the soil textural name or class. In each textural class, there is a range in the amounts of sand, silt and clay that can be present. See the diagram of the textural triangle in Figure 3.

Figure 3: Soil Texture Triangle

Soil Textural Triangle



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Each soil class name indicates relative amounts of sand, silt and clay in the soil. For example, a soil with 35% silt, 45% sand and 20% clay would be named a loam. A soil with 20% silt, 35% sand and 45% clay would be called a clay.

The basic textural components of soil have distinct properties:

- Sand -- coarse textured, light, easy to turn. It supports weight with little compaction, has abundant macropores, through which water and air and moves quickly. Roots penetrate it easily. These soils have poor water holding capacity.
- Silt - can have poor drainage and can be easily compacted, but is also easily worked.
- Clay -- fine textured, heavy and difficult to work. It has abundant micropores, which store water and nutrients, but limits water infiltration rates and often perch water after a rain.

To get a “feel” for these textures, you can begin practicing the “hand texturing” method and with experience you can come close to determining the kind of soil you have. Here are some examples of what different combinations of sand, silt and clay feel like. See Figure 14 on page 30 for the Soil Texture Feel Flow Chart.

Sand: Loose and single-grained. The individual grains can be seen or felt. Squeezed when dry, it will fall apart when pressure is released. Squeezed when moist, it will form a cast but will crumble when touched.
Sandy loam: Soil containing much sand but has enough silt and clay to make it somewhat cohesive. The individual sand grains can readily fall apart, but if squeezed when moist a cast can be formed that with careful handling will not break.
Silt loam: Soil having a small to moderate amount of sand and only a small amount of clay with over half of the particles being silt, and when pulverized will feel soft and floury. When wet, the soil readily runs together. Either dry or wet it will form casts that can be freely handled without breaking, but when moistened and squeezed between thumb and finger it will not "ribbon" but give a broken appearance.
Clay loam: A fine textured soil which usually breaks into clods or lumps that are hard when dry. When the moist soil is pinched between the thumb and finger it will form a "ribbon" which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will bear much handling. When kneaded in the hand it does not crumble readily but tends to work into a heavy compact clod.
Clay: A fine textured soil that usually forms very hard lumps or clods when dry and is quite plastic and usually sticky when wet. When the moist soil is pinched out between the thumb and fingers it will form a long flexible "ribbon". Some fine clays very high in colloids are friable and lack plasticity in all conditions of moisture.
Gravelly soils: If soils have a significant amount of larger material such as gravel (greater than 15%), they are designated as “gravelly” and the term will be placed in front of the texture designation. For example, a sandy loam with greater than 15% gravel would be called a “gravelly sandy loam”. When the gravel content is greater than 35%, the texture would be designated as “very gravelly” or even “extremely gravelly” when the gravel content is greater than 60%. It is important to note that the gravel isn’t considered part of the texture, just a modifier.

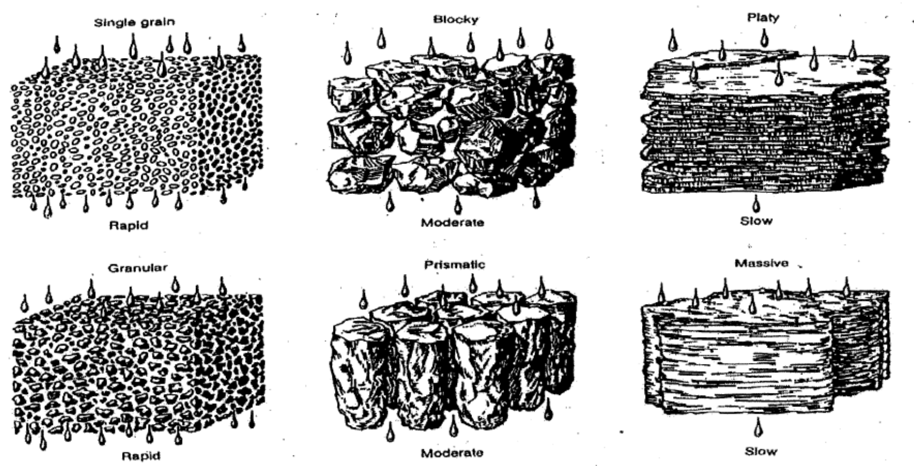
Soil test labs can perform a physical analysis on your soil sample to determine the amount of sand, silt and clay. This is the most accurate way to determine the soil texture, but hand texturing by feel can give you immediate results and are fairly accurate. We provide an introduction to hand texturing at the end of the module. Give it a try by going out to your garden and grabbing a handful of soil. Remember to ask your instructor if you have any questions you might have about this technique.

Soil Structure

Poor soil is a chief complaint for both novice and experienced gardeners. Fine textured, clayey soils tend to drain poorly, restrict root growth, and form impervious layers. Very sandy soils tend to be low in organic matter, are nutrient poor and require more frequent watering. Many symptoms of poor plant health can be traced, in part, to problematic soil characteristics.

While the amount of sand, silt and clay particles in the soil determines the soil texture, as soils develop, the soil particles can be grouped together creating larger structural aggregates called peds or soil structures. At and near the soil surface, the structure is usually granular unless it is disrupted. But as shown below in Figure 4, soil aggregates (or lack thereof) can come in a variety of sizes and shapes, ranging from granular through platy to columnar depending on soil depth, management, soil texture, amount of organic matter, and biological activity. Also note the effect of soil structure on water movement and storage. Large pores easily conduct water and air through the soil, while small pores hold and store water. Ideally, we would like a mix of large and small pores to allow for good infiltration and aeration, while at the same time providing water storage for the plants and soil organisms.

Figure 4: Soil Aggregate Shape and Water Movement



Soil structure also strongly affects the type and distribution of soil pores and allows for improved air and water movement within the soil. The lack of structure can impede the movement of air and water. Since plant roots grow in the same channels through which air and water move, a well-structured soil allows for extensive root development as well as water and air movement, while poor structure discourages it.

Different types of structure dramatically affect the movement of water, air, plant roots and organisms. For example, when a granular and blocky soil structure is developed and stable, the increased porosity allows water to infiltrate more easily, resulting in better aeration to the roots of plants. Platy structure on the other hand, formed by repetitive compaction events, limits infiltration and porosity which can create conditions of standing water. A strong soil structure is promoted by an adequate supply of organic matter, but can be destroyed by overworking the soil - this is particularly easy to do when the soil is too wet or too dry. When eager gardeners turn their soil over when it is still too wet in the spring or after a heavy rainstorm in the summer, the aggregates are more easily broken and beneficial soil structure can be destroyed. If the clay content is fairly high, such tilling can create large clods which do not easily break apart. Pick up a handful of soil before tilling and form it into a ball. If the ball breaks apart easily when it is gently bounced in your hand, then you are ready to till.

While working the soil can dramatically destroy soil structure, plants, organisms and the addition of organic matter also help develop beneficial soil structure. As plant roots grow they tend to enlarge the pore spaces in the soil. When roots die and decay, they leave channels (macropores) for the movement of air and water. Humus from decaying roots serves as a cementing agent and helps form stable aggregates. Soil organisms also encourage structural formation by releasing organic glues that create and stabilize structure. As gardeners and farmers we want to encourage granular and small blocky soil structures near the soil surface, as they benefit plant and soil organism health while at the same time allow for good water infiltration, as well as adequate aeration and water storage.

Figure 5 shows the importance of both macropores and micropores as water moves into and saturates the soil. After a rain event (or irrigation), water moves into the soil through the macropores. The water is then pulled into the micropores through capillarity. Capillarity is the attraction of water to surfaces and to other water molecules. It is the same reason that sponges work. Sponges have a large amount of surface area for their size. When you squeeze the sponge, you're reducing the pores spaces and forcing (squeezing) the water out. In soils, because the macropores have less surface for their size they do not hold water well, and as a result the water drains out and lets air in after the rain event. The small micropores hold the water against gravity and make it available for plants after the macropores have lost their water.

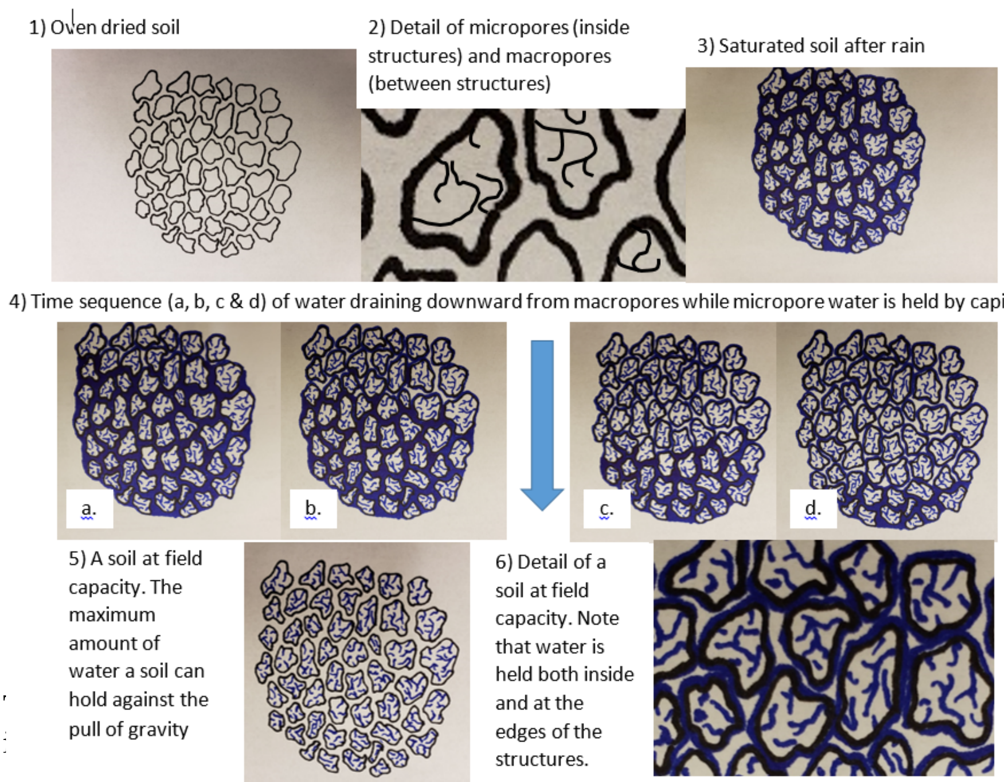


Figure 5: Sequence of Soil Saturation to Field Capacity

Source: Jonathan Russell-Anelli

il structure. These

- increases particle aggregation. For example, lignin in humus helps sand particles stick together (aggregation).

- Increases aggregate stability by increasing the strength of the aggregate structures to resist destructive forces (raindrops, traffic, cultivation, etc.).
- Increases in large pore space between aggregates in soil which improves soil drainage and penetration of plant roots. This is particularly important with clay soils by helping create macropore spaces between soil structures.
- Increased surface area and small pores within aggregates which improves water storage. This is particularly important with sandy soils, by helping increase surface area and create micropore spaces within soil structures.

Additionally, natural climatic factors like the freezing and thawing as well as the wetting and drying of soil can create structure.

Bulk Density and Compaction

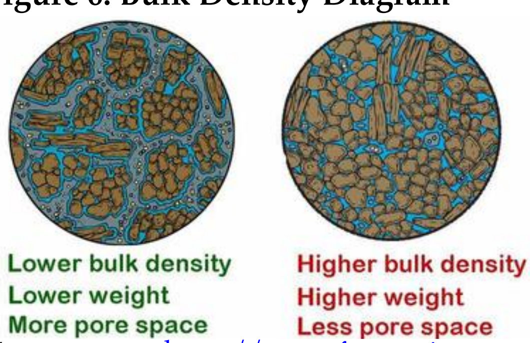
Figure 6 shows a bulk density diagram. Bulk density is a measure of the weight of a soil per total volume of that soil. As the density of a soil increases there is less macropore space for roots, air and water. This limits the productivity of the soil. The increase in density is due to the process of compaction which is the loss of pore volume in a soil.

As the soil is compacted, the large pores (macropores) become compressed, which makes it harder for plant roots to penetrate into the soil. Increased bulk density also decreases soil infiltration rates. Compaction can occur when gardeners turn a wet soil with hand tools or heavy equipment. It can also occur by beating a path into a garden by foot traffic. Figures 7 & 8 show some common clues of compaction.

For many plants, especially those that are in the ground for decades - such as trees and shrubs - soil compaction is the single most difficult and harmful environmental or abiotic condition that they can experience. No amount of skillful plant selection can remedy the problem. Quite simply, if a plant's roots can't grow into the soil, the soil might as well not be there.

The rule of thumb is that when a bulk density is below 1.65g per cm3, roots can penetrate and grow through a soil. As the density approaches 1.65g per cm3, roots growth becomes restricted. At a density greater than 1.65g per cm3, root growth is severely restricted.

Figure 6: Bulk Density Diagram



(Image source: https://www.forestryimages.org/browse/detail.cfm?imgnum=5377117)

Figure 7: Common "Looks" of Compaction

(Image Source: https://www.forestryimages.org/browse/detail.cfm?imgnum=5375311)

Figure 8: Emergence Problems in the Corn Field Due to Soil Compaction

(Image source: https://www.forestryimages.org/browse/detail.cfm?imgnum=5358733)

To remediate compacted soil, we generally do one or a combination of practices:

- remove and replace compacted soil
- amend it, most often with organic matter
- divert traffic from the location
- bury it under soil with better growing conditions (a minimum of 19 inches, but often as much as 3 feet)
- one-time tillage operation to break up compaction in combination with one of the above practices

Remediating compaction and providing adequate pore distribution allows for optimum physical and biological processes to take place.

Soil Color

Different soils have their own distinct color that come from the parent material, weathering and organic matter that is associated with the location of that soil. For example, you may find red shale soils in the Catskills, grey/black shale soils of the Southern Tier, or the yellow-white sandy soils of Long Island. Color can also tell you some important things about your soils' condition. Color is also determined by: (1) organic matter content, (2) drainage conditions, (3) degree of oxidation and (4) mineralogy. Colors vary from almost white, through shades of reds and yellows to brown and gray, and up to and including black. We can use then these colors to assess physical and chemical characteristics of soils. Some color indicators are listed and discussed below.

Color indicators:

- Light colors indicate low organic matter, low clay content, or may indicate a high sand content.

- Dark colors may indicate a high organic content. Dark colored soils absorb heat more rapidly than light colored soils, producing warmer soil temperatures during the day.
- Shades of red or yellow, particularly when associated with clay textures, usually indicate that subsoil material has been incorporated into the surface layer.
- Shades of red or yellow can also indicate the degree of iron oxidation in the soil. Iron is extremely common in soil and the red/yellow colors that we see are essentially rust (an iron oxide). Iron oxides are red and yellow in color and when these colors are found coating soil particles and aggregates, they are indicative of the high point of the water table.
- Small patches of red and yellow mottling (patches) mixed with soil colors of blues, greens and grays indicates slow drainage and poor aeration. These patterns are called redox (reduction/oxidation) mottles. Between the seasonal high and low ground water table in soils, water and oxygen levels constantly fluctuate and the iron is repeated chemically and biologically reduced then oxidized. This repeated cycle creates a distinct redoximorphic patterns of colors by dissolving, moving and then re-oxidizing iron, creating unique iron coatings and concentrations with colors ranging from red and yellow mixed with reduced zones of blues, greens and grays.
- Gray and blue soil color indicate very poor drainage where the soil is saturated (low to no oxygen) with water for the majority (if not all) the time.
- Manganese behaves similarly to iron, but creates small black bits or concretions indicating the presence of the high water table.

Drainage
The relative ability of a soil to permit drainage of excess water from the soil profile describes its drainage properties. This is one of the most important characteristics of a soil that affects plant growth.

Most plants will not grow well in soil that is poorly drained, even if it is rich and fertile. Soil drainage is not only important during the growing season, but also influences how well a perennial plant (tree, shrub, or herbaceous perennial) over-winters. Many cold hardy plants are lost during the winter because the stress (frost) on its root system is too intense in a soil that doesn't drain properly.

The moisture status during the growing season is determined either by observing the soil water table over years or by observing the redox mottling depth of a soil. As discussed above, mottling is a pattern of soil colors often produced by soil drainage and resembles rusty and or red/yellow patches intermixed with greys and blues in the soil profile. The depth at which this occurs indicates the drainage class.
Drainage classes in New York State are based on the depth where mottling occurs:
- 0 -6 " very poorly drained
- 6-12" poorly drained
- 12 -20" somewhat poorly drained
- 20-32" moderately well drained
- 32-42" well drained
- 42-52" somewhat excessively well drained
- >52" excessively well drained

For very poorly and poorly drained soils you may notice puddles on top of the soil long after a rainstorm, slimy green algae on the surface or you may smell a sulfur smell. Dry soils may get dusty on windy days or have grass that wilts or turns brown before other areas.

If your soil gives indications of poor drainage you should consider the following options:

- selection of plants adapted to moist or wet site
- consider creating raised beds and or
- drainage modification, which might include, installing tile or French drains, diversions, etc.

Soil Profile/ Morphology

Most soils have distinct layers, or horizons, that collectively form the soil profile. These horizons often differ in color, texture and structure. There are seven master soil horizons (O, A, E, B, C, R and W) which are best seen in relatively undisturbed soils. We have simplified these horizons into three generalized layers called topsoil, subsoil and substrata or parent material, as shown in Figure 9.

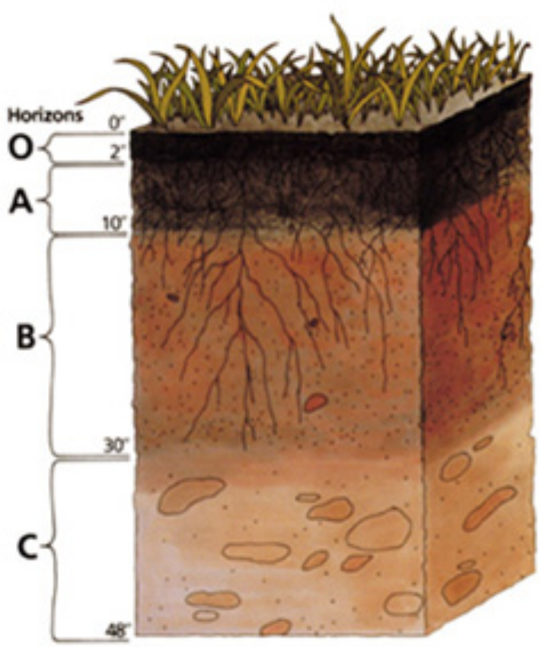


Figure 9: A soil profile. *Most soils have three major horizons - the surface horizon (**A**), the subsoil (**B**), and the substratum (**C**). Some soils have an organic horizon (**O**) on the surface, but this horizon can also be buried.* (USDA Natural Resources Conservation Service, Soils. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054308)

Topsoil

- Consists of the O and A horizons
- Contains most of the organic matter and highest concentration of plant roots.
- Herbaceous plants get most of their nutrients and water from the topsoil.
- Thickness will vary
- Most of the soil's biological activity is in this layer

- It is the layer most affected by the dramatic changes in the weather. These changes include the effect of sun, shade, clouds, wind, rain, snow and temperature.

Subsoil

- Consists of the B horizon
- Finer and often a finer texture than surface soil as very small clay particles can be carried downward through the soil by gravity and water.
- Lower in organic matter
- Stores water and plant nutrients
- Aids in regulating the soil temperature and air supply of plant roots.

Substratum (aka weathered bedrock or parent material)

- Consists of the C horizon
- Made up of parent materials that retains characteristics of the underlying bedrock or relict materials from which the top soil and subsoil may originate.
- Influences the soil's texture, natural fertility, acidity, and depth

Soil Layers in a Garden

While nature has provided us with soil layers, it is a common practice to add soil materials onto a garden in hopes of providing a deeper rooting zone. Plant roots vary in depth from a few inches (turfgrass, annuals and some shallow rooted perennial ground covers) to a few feet. Even tree roots rarely exceed a depth of 3 feet. As these plant roots predominate in the upper part of the soil, when we add layers of soil materials we hope to increase the plants' rooting depth.

But by adding an inch or so of "topsoil" to a garden or landscape, we can build layers in a garden which can be detrimental to plant growth, as these layers can create a barrier to water movement and root growth. When water infiltrates into the soil, it is often impeded by an abrupt change in the soil texture and structure. Water can back up, a phenomenon called perching, when it encounters a soil layer that is distinctly different. This can cause waterlogging or puddling. Often only when the entire layer is wet will water start moving down into the layer below.

When adding mineral soil materials it is important to thoroughly mix and incorporate soil and soil amendments, or add slowly over time to allow soil organisms and soil forming process to integrate the added material naturally to improve your garden and landscape soils.

Notes on Topsoil

Soil sold as topsoil in the market is nothing more than soil that came from the top of the ground. It usually has been screened and has had some organic matter, such as compost, added to it. Many people often infer that it is better soil (such as "top grade"). However, there is no legal definition of topsoil. Most soil sold as topsoil in bags is good quality but expensive. Be cautious when buying topsoil in bulk by the cubic yard, because while it is generally less expensive than a comparable quantity in bags, it may or may not be good quality. If possible, try to find out the source of the soil; it is important that it does not contain persistent herbicides, noxious weed seeds or other undesirable materials. If buying in bulk, it may help to request a soil test, to determine what the nutrient, pH and organic matter levels are.

Soil Depth
The effective depth of soil for plant growth is the vertical distance from the surface to a layer that essentially stops the downward growth of plant roots. The barrier layer may be rock, heavy clay or a cemented or a partly cemented layer.

Terms used to express effective soil depth are:
- very shallow - less than 10 inches
- shallow - 10 to 20 inches
- moderately deep - 20 to 36 inches
- deep - 36 to 60 inches
- very deep - 60 inches

Deep soils that tend to hold more nutrients and water allow for deep root penetration and produce larger crops than shallow soils with similar textures. Note that shallow water can also limit the effective depth of your soil.

Soil pH
Soil pH is a measure of the hydrogen (acid-forming) ion activity of soil or other plant growing media. The measure expresses the degree of acidity or alkalinity in terms of pH values, very much like heat and cold are expressed in degrees. The scale of measuring acidity or alkalinity contains 14 divisions known as pH units. A pH of 7 is neutral, values below 7 are acidic and values above 7 are alkaline.

The measurement scale is a logarithmic scale, not a linear scale. That is, soil with a pH of 4.5 is ten times more acidic than a soil with a pH of 5.5, and a soil with a pH of 4.5 is 100 times more acidic than a soil with a pH of 6.5.

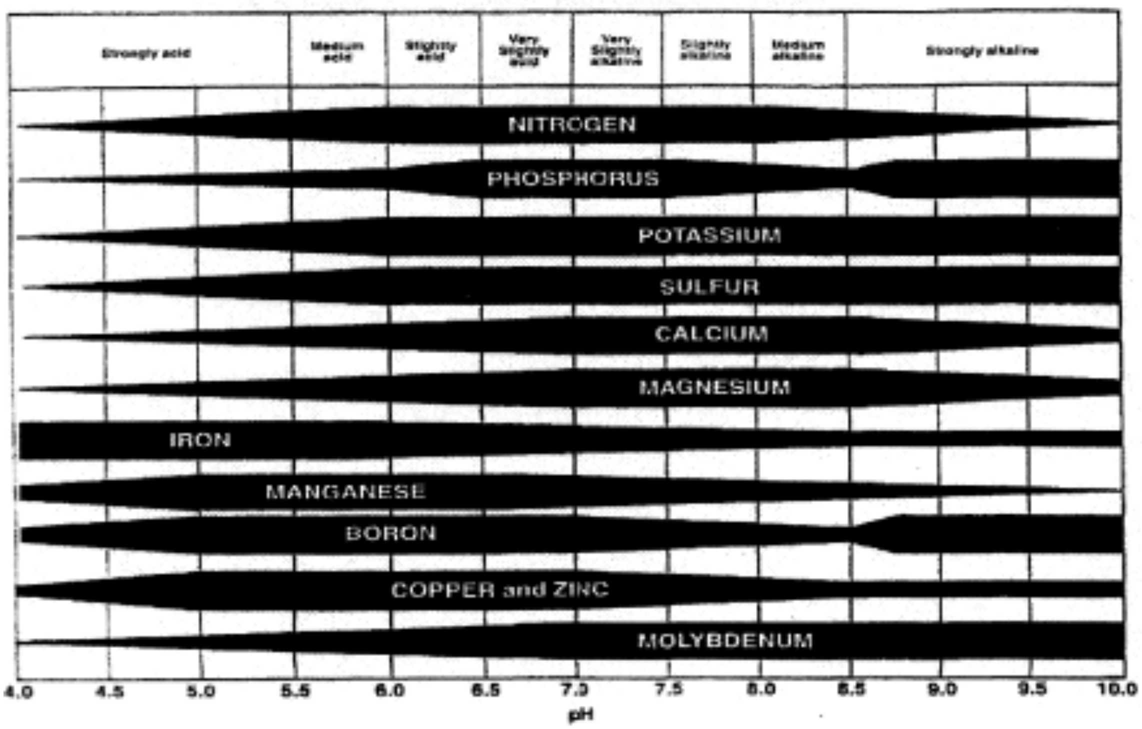
A near neutral or slightly acid soil is generally considered ideal for most plants. With some notable exceptions for particular plants, a soil pH from 6.0 to 7.0 requires no special liming or acidifying practices to improve plant growth.

While different nutrients are more or less available at different pH values, optimum availability for all nutrients is best at a pH around 6.5. This is shown in the following table in Figure 10. Extremes in pH have a major impact on the availability of plant nutrients and can cause plant-toxic concentration of ions in the soil solution. For example:
- At low pH values, calcium, phosphorus and magnesium become tied up and unavailable to plants.
- At pH values of 7.0 and above, phosphorus, iron, copper, zinc, boron, and manganese become less available.
- In highly acid soils (pH values under 5.0), concentration of aluminum ions can be found at toxic levels.

Also, most microorganisms do not thrive when the pH is very acidic or very alkaline, which further effect nutrient availability. By applying certain materials to the soil, adjustments can be made in pH values. Additions of materials to raise or lower pH should be based on soil test results and recommendations.

pH testing demonstration video: https://www.youtube.com/watch?v=eSnbo0J_99Y

Figure 10: Relationship Between pH and Nutrient Availability



Plant Nutrients

Plants need 18 nutrients for normal growth. Carbon forms the skeleton for all organic molecules and is the basic building block for life. Oxygen is needed for plant respiration and along with hydrogen forms water which is a major constituent of all plants. In fact, these 3 elements make up more than 90% of the plant. Some plant nutrients move within the plant to satisfy deficiencies in the total plant. Such nutrients are said to be mobile (e.g. phosphorus). Other nutrients, once incorporated into the plant tissue, are fixed (not mobile) and cannot be used by other plant parts to meet deficiencies (e.g. calcium). We generally are not concerned about a plant's nutrient requirements for carbon, hydrogen and oxygen as they are readily supplied by air and water.

Beside carbon, oxygen and hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium and sulfur are also considered major nutrients (called macronutrients). They are required in relatively large amounts and are supplied to the plant by soil minerals, organic matter and supplemental fertilizer. The other nutrients are needed in very small amounts and as such we call then micronutrients.

A major portion of nutrients in the soil are not available to plants. This is because many nutrients exist in complex organic or mineral structures which are not water soluble in that form, and are thus unavailable for uptake by the plants from the soil solution. Roots can only absorb simple forms, soluble in water. Nutrients which are bound up in complex forms can only be slowly released into the soil solution. One of the important ways these nutrients are released is through ion release from organic matter decomposition by microorganisms, from exchange on mineral and organic soil particle surfaces and chemical weathering of minerals in the soil. These ions are atoms or molecules that are positively or negatively charged – think miniature magnets. Most of the macro- and micronutrients are positively charged (called cations), though a few, such as nitrate (NO_3^-) are negatively charged (called anions).

Cation Exchange Capacity and Base Saturation

Cations compete for sites on the negatively-charged surfaces of clay mineral and organic particles. The particles are extremely small and are called colloids (< 1 micron in size). Due to their small size they have a larger surface area per volume than other soil particles which is conducive to exchange reactions. This is one reason why soil texture is so important. Anions with their negative charge are not attracted to the colloids, making them especially subject to leaching from the soil solution. Ammonium, NH_4^+, is held by the soil colloids against leaching, while nitrate nitrogen, NO_3^-, is readily leached. This has important implications for preventing nitrate, NO_3^-, pollution of groundwater and the lakes, ponds, rivers and creeks.

The total potential charge of the soil particles, which dictates the amount of cations a given amount of soil can hold, is called cation exchange capacity or CEC. Due to the surface area, it is easy to see that sandy soils can hold many fewer cations than clay soils. Adding organic matter will increase your soil's nutrient holding capacity as organic matter has an extremely high surface to volume ratio. CEC values in New York soils range approximately so: sandy 5-10, sandy loam 10-12, loam 12-18, silt loam 18-20, clay 20-25. Keep in mind that thoroughly decomposed organic matter can have a CEC ranging from 150-300, and as said before will affect the overall CEC.

Another measure of soil fertility is base saturation. This tells the percentage of the CEC is actually occupied by nutrients. These nutrients are then available for exchange into the soil solution for plant uptake. Therefore, while your soil may have a low CEC, by maintaining high base saturation (through proper nutrient management) it can still be very productive.

It is important to maintain a balance between the nutrients needed for good plant growth in the soil solution. When a nutrient is not absorbed by the plant in an adequate amount, the plant will show deficiency symptoms. A plant deficiency may also result from a nutrient being deficient in the soil or the nutrient may be present in the soil, but tied up because of an unfavorable pH.

Nitrogen-N

Nitrogen deserves special attention because it has a major effect on the growth and yield of crop plants and can be a source of groundwater pollution. After carbon, oxygen and hydrogen, nitrogen is required by plants in the greatest amount (plant proteins are 16% nitrogen). Nitrogen exists in the soil in organic and inorganic forms. Nitrogen in the soil is continually transformed between organic and inorganic forms through biological and chemical reactions. These processes constitute the nitrogen cycle. Organic N is unavailable to plants as it is tied up with other organic matter. But as the organic matter is decomposed ammonium is formed and can later be converted into nitrate – both are in ion forms. This is important as nitrogen can be taken up by the plants only in ion form, but these ions can also easily be lost to leaching, runoff, erosion and escape from the soil surface into the atmosphere (by volatilization) depending on its form. In fact, it was the discovery of an artificial procedure to fix nitrogen into ammonia and ultimately into fertilizer that allowed the Green Revolution to occur. It is this same process that provides the N fertilizer that drives much of our present-day agriculture.

Figure 11: Chemical Forms of Nitrogen Commonly Found in Soil

Compound group	Name	Symbol	Remarks
Inorganic	Ammonium	NH_4^+	Can adsorb onto clay and organic matter, preventing large amounts from moving with water. Plant available.
	Nitrite	NO_2^-	Mobile with water and can be toxic to plants, but is generally not found in large amounts.
	Nitrate	NO_3^-	Typically present in relatively large amounts and very mobile with water. Form preferred by most plants.
Organic	Proteins, Amino Acids	$R\text{-}NH_2$	Contained in manure, organic wastes, nucleic acids, and living and dead plants and animals. Immobile. Not available to plants.

Source: Van Es, H, S.D. Klausner, W.S. Reid, 1991, from Nitrogen and the Environment, 1B 218, Cornell Cooperative Extension.

There is a large and ongoing discussion concerning the benefits and detriments of natural versus artificial N fixation in the scientific and policy community. With pros and cons on both sides of the argument, what is important to us should be the realization that we need to nitrogen for productive plants, but excess use does have dramatic and detrimental environmental consequences. There will be some discussion of this in the Soil Amendment and Fertilizer module, but here are several important terms related to Nitrogen:

<u>Nitrogen Fixation</u> - although the air we breathe is 78% nitrogen, the gaseous form (N_2) is useless to plants as they can only take up nitrogen in ion forms. However, certain bacteria (e.g. Rhizobium) living in nodules on the roots of legume plants can convert atmospheric nitrogen into plant available forms. There are hundreds of different species of nitrogen fixers in the world, with all the world's nitrogen fixers relying on the same enzyme, nitrogenase, to do the job. Our planet's entire supply of nitrogenase could fit into a single large bucket. Consider the fact that all the nitrogen contained within proteins and genes of plants (as well as animals, including humans) at one time or another has been funneled through these nitrogen fixing microbes.

Immobilization - ("robbing the soil of nitrogen") occurs when highly carbonaceous materials, such as straw, woodchips and sawdust, are incorporated into the soil. Microbes need nitrogen to digest the organic matter. Soil microbes "eat first at the nutrient table" and convert plant available inorganic forms of N to organic forms (proteins). There is a potential to create a nitrogen deficiency in your garden plants at the interface of woody mulch and the soil, but this is greatly overstated, and if present is generally brief as plants quickly root into the underlying nutrient rich soil. This type of nitrogen deficiency is generally only seen when growing directly in wood chips or hay bales without any nutrient amendments. Nitrogen remains immobilized in the microbes until they die and decompose. Add about 1.0 to 1.5 pounds of nitrogen for each 100 dry pounds of these low nitrogen materials or mix in green wastes. Fresh green wastes, such as grass clippings, are higher in nitrogen than dry materials. Immobilization may also be caused by manure with large amounts of undecomposed bedding.

Mineralization - the conversion of organic N from plant and animal remains to inorganic ammonium, which is then held by soil colloids, used by plants or transformed into nitrate N.

Nitrification - the conversion by soil microbes of ammonium to nitrite N and then to nitrate N. The process is accelerated when your soil is warm, moist and well-aerated.

Denitrification/Volatilization - in poorly drained soils, nitrates are converted by bacteria to nitrogen gas, which escapes into the· atmosphere (denitrification). Ammonia gas can also be lost to the atmosphere when manure is dropped on the garden and not incorporated (volatilization).

Phosphorus - P

Phosphorus is very important in many biochemical functions needed to have a healthy plant. Phosphate compounds are involved in making and storing energy in the plant. This nutrient is found at plant growth centers (root tips, and shoots) so overall plant growth suffers when P is deficient. Phosphorus is especially critical at establishment. Availability in the soil is affected by pH. At pH's lower than 6.0 and higher than 8.0, phosphorus is tied up in mineral forms that are not available to plants. The range for highest availability is 6.5 to 7.0.

Potassium - K

Potassium helps regulate the enzyme activity in plants, carbohydrate production and transport, and regulates water content in cells and water loss from stomates on leaves. It is needed to help improve the plant's tolerance to drought, high and low temperature and wear stress.

Micronutrients

Micronutrients, or minor elements, are essential for good plant growth, but are required in very small quantities. For example, a productive, 1,000 square foot vegetable garden might require "pounds" of nitrogen (a macronutrient) each year, but only a few teaspoons of a micronutrient. Because most micronutrients are not mobile, deficiency symptoms are usually found on new growth. Micronutrient availability in the soil is highly dependent on pH and the presence of other nutrient ions. A proper balance between micronutrients because of an excess of one element may show up as a deficiency of another.

Nutrient Uptake by Plant Roots

Plant nutrients must be dissolved in the soil's water solution before root hairs can absorb them for transport to plant tissue. As discussed previously, the dissolved nutrients are called ions, which are charged components of individual molecules – again think of them as little magnets and remember positively charged ions are called cations and negatively charged ions are called anions. Ions typically enter the soil solution as dissolved salts. For example, potassium nitrate, $KN0_2$, dissolves into K^+ and $N0_2^-$.

Figure 12: Plant Nutrients: Macronutrients

Element	**Function in Plant**	**Excess in Symptoms**	**Deficiency Occurrence and Symptoms**
Nitrogen (N)	• Gives dark green color to plant. • Increases growth of leaves. • Stimulates rapid early growth.	Dark green colors; succulent, spindly growth. Retarded maturity; bud and fruit drop.	Occurs mostly on sandy soils which are easily leached. Stunted growth. Light green to yellow (lower leaves first). Firing of leaf tips and margins.
Phosphorus (P)	Stimulates early root growth. Gives plants a rapid and vigorous start. Is important in flowering and seed formation.	Possible tie up of zinc, iron and cobalt.	Is not easily leached from the soil. On acid soils, temporary deficiency occurs on cold, wet soil. Red or purple leaves and stems. Stunting; reduced flowering and fruiting.
Potash (K)	Increases plant vigor. Stimulates production of strong, stiff stalks, sugars, starches and oils. Enhances flavor, color and cold and disease hardiness.	Coarse, poor colored fruit. Reduced absorption of Mg and Ca.	Leaches from sandy soils. Leaf margin scorch. Thin skin and small misshaped fruit. Reduced vigor and yield; susceptibility to diseases.
Sulfur (S)	Protein building block.	Sulfur burn from too low pH.	New leaves are light green or yellowish.
Calcium (Ca)	Essential for cell wall structure and formation of new cells.	Reduces the intake of K and Mg.	On acid soils with high K levels. Very dry soils become deficient. Stops the growing point of

			plants. Causes cell breakdown (blossom end rot).
Magnesium (Mg)	Aids photosynthesis. Key element in chlorophyll.	Reduced absorption of Ca and K.	On acid soils, light soils easily leached and high potassium soils. Interveinal chlorosis. Whitish patches on older leaves.

Figure 13: Plant Nutrients: Micronutrients

Element	**Function in Plant**	**Excess in Symptoms**	**Deficiency Occurrence and Symptoms**
Manganese (Mn)	In enzyme system.	Small dead areas in the leaves with yellow halos. Associated with excessive use of hardwood mulch.	On soils with pH above 6.8 and high Ca. Poorly drained with acid-loving plants. Mottled chlorosis of the leaves. Stunted growth.
Copper (Cu)	Enzyme activator.	Prevents the uptake of iron. Causes stunting of roots.	On muck or peat soils.
Zinc (Zn)	Aids in cell division; needed for enzyme and auxin formation.	None known.	On wet, heavy soils in early spring; may be due to excess phosphorus fertilization. Small, thin, yellow leaves.
Iron (Fe)	A catalyst in the enzyme system.	None known.	On soils with pH above 6.8. Problem with acid-loving plants. Interveinal chlorosis.
Boron (B)	Affects absorption of other elements. Affects germination of pollen tube.	Leaves turn yellowish red.	On light, sandy soils with pH above 6.8. Small leaves. Heart rot and corkiness. Multiple buds.
Molybdenum (Mo)	Aids in the utilization of N.	Poisonous to livestock.	On very acid soils. Looks like nitrogen deficiency; symptoms in plants vary greatly.
Chlorine (Cl)	Osmotic + cation neutralization		Partial wilting + loss of leaf turgor

Cobalt (Co)	Essential for N fixation.		As pH increases on coarse-textured soils with heavy rainfall.

The Value of Soil Testing

Soil tests can supply the homeowner with enough information to make informed decisions about applying fertilizers and soil amendments. They are snapshots of the macro and micronutrient levels of the soil as well as pH and organic matter content. Results from soil tests from one part of the garden/landscape may differ from results from another area because the soils may differ and/or past management practices. For that reason, it may be necessary to submit samples for unique situations.

Soil tests done at Cornell University provide information on soil pH, soluble salt content, and nutrient levels (phosphorus, potassium calcium, and magnesium and micronutrients) and give recommendation for nutrient and pH management based on the plants and soil. Nitrogen levels are not reported because they change so rapidly that the results would be out of date by the time you got the report. At county Cornell Cooperative Extension facilities, a pH and soil texture analysis is available. For most home gardeners, it is best to get the soil tested for pH first to determine if any changes need to be made before embarking on a full nutrient analysis.

However, if you have never had a full nutrient analysis soil test done on your garden or landscape before, you may want to have one done to obtain a base-line of information about your soil. A soil test is generally not needed more often than every 3 or 4 years in most circumstances, especially if your plants are growing well. It is often advisable to do soil testing before starting on a new garden project.

The accuracy of the soil test depends on how well the soil sample is taken. Be sure the sample is representative of the area. Sample from 10-20 random areas of the garden to a depth of 2-3 inches for lawns, and 6 to 8 inches for garden and landscape plantings. Avoid sampling unusual sites such as those near gravel roads, manure or compost spots, brush piles, or under eaves. Place the sample in a clean pail or container, mix the soil thoroughly and allow it to air dry. Then transfer the required amount into the sample bag for testing. Provide as much background information as possible to receive the best recommendation. Information needed includes: setting (garden, lawn, flower bed), crop (specific fruit, general vegetables, lawn), species and cultivar (if known), clippings: returned or removed (for lawn situations), irrigation practices, previous management practices and whether or not this is for establishing a planting or maintaining a planting. For more information about collecting samples for a soil test visit Cornell Nutrient Analysis Laboratories website at: https://soilhealth.cals.cornell.edu/testing-services/collecting-samples/

Soil tests to determine contaminants in the soil are possible with special requests from labs that have the equipment to perform such tests. Most soils labs are well equipped to do nutrient analysis, but not all can test for pesticide residue, heavy metals, petroleum products and other contaminants. Contact the Cornell Nutrient Analysis Laboratories if you have any questions. If you suspect a particular contaminant and are willing to pay extra to test for it, you may inquire about having the test run. The more general the suspected contaminant (e.g. somebody poured something in my garden and now the plants don't grow there), the harder it is for a lab to accommodate you.

Soil Health

The terms ‘soil health’ and ‘soil quality’ are becoming increasingly familiar worldwide. A modern consensus definition of soil health is “the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans” (USDA-NRCS, 2012).

In general, soil health and soil quality are considered synonymous and can be used interchangeably, with one key distinction conceptualized by scientists and practitioners over the last decades: soil quality includes both *inherent* and *dynamic* quality.
Inherent soil quality relates to a soil’s natural composition and properties influenced by geologically long-term factors and processes including the type of parent material, topography, organisms, climate, and time. Changing just one of the factors will produce a different soil. Inherent soil quality cannot generally be influenced by human activity.
In contrast, *dynamic* soil quality, which is equivalent to soil health, refers to soil properties that transform as a result of soil use and management over the human time scale.

Characteristics of Healthy Soil

Good soil tilth: Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production. Soil with good tilth is crumbly, well structured, dark with organic matter, and has no large and hard clods.

Sufficient depth: Sufficient depth refers to the extent of the soil profile through which roots are able to grow to find water and nutrients. A soil with a shallow depth as a result of a compaction layer or past erosion is more susceptible to damage in extreme weather, thus predisposing the crop to flooding, pathogen attack, or drought stress.

Good water storage and good drainage: During a heavy rain, a healthy soil will take in and store more water in medium and small pores, but will also drain water more rapidly from large pores. Thus, a healthy soil will retain more water for plant uptake during dry times, but will also allow air to rapidly move back in after rainfall, so that organisms can continue to thrive.

Sufficient supply, but not excess of nutrients: An adequate and accessible supply of nutrients is necessary for optimal plant growth and for maintaining balanced cycling of nutrients within the system. An excess of nutrients can lead to leaching and potential ground water pollution, high nutrient runoff and greenhouse gas losses, as well as toxicity to plants and microbial communities.

Small population of pathogens and pests: Plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low or is less active. This could result from direct competition from other soil organisms for nutrients or habitat, etc. In addition, healthy plants are better able to defend against a variety of pests.

Large population of beneficial organisms: Soil organisms help with cycling nutrients, decomposing organic matter, maintaining soil structure, biologically suppressing plant pests, etc. A healthy soil will have a large and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.

Low weed pressure: Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can block sunlight, interfere with stand establishment and harvest and cultivation operations, and harbor disease causing pathogens and pests.

Free of potentially harmful chemicals and toxins: Healthy soils are either devoid of excess amounts of harmful chemicals and toxins, or can detoxify or bind such chemicals. These processes make these harmful compounds unavailable for plant uptake, due to the soil's richness in stable organic matter and diverse microbial communities.

Resistance and resilience to degradation: A healthy, well aggregated soil, is resilient, full of diverse organisms and is more resistant to degradation from wind and rain erosion, excess rainfall, extreme drought, vehicle compaction, disease outbreak, and other potentially damaging influences.

For a more comprehensive overview of soil health concepts including a guide on conducting in-field qualitative and quantitative soil health assessments, please download the Cornell Soil Health Manual at bit.ly/SoilHealthTrainingManual

Right Plant, Right Place

Start by asking the important questions of what are the plant needs and what are the site characteristics. Think along the lines of the following:

- Different types of plants have different needs. Think about a plant's needs?
    - How much light?
    - How much water?
    - How much nutrients? And what type?
    - What temperatures does it like?
    - How much space will it need?
- What are the characteristics of the site?
    - Light
        - Duration
        - Full sun, partial sunny or full shade
    - Climate
        - Temperature
        - Water quality and variability
    - Soil properties: While there are many physical characteristics you should look at a few important ones: texture, structure, bulk density, pH and nutrient status to get started. Remember soil properties are either inherent or dynamic (defined on the top of page 27) and it is critical to know what you can change through management and what you cannot.

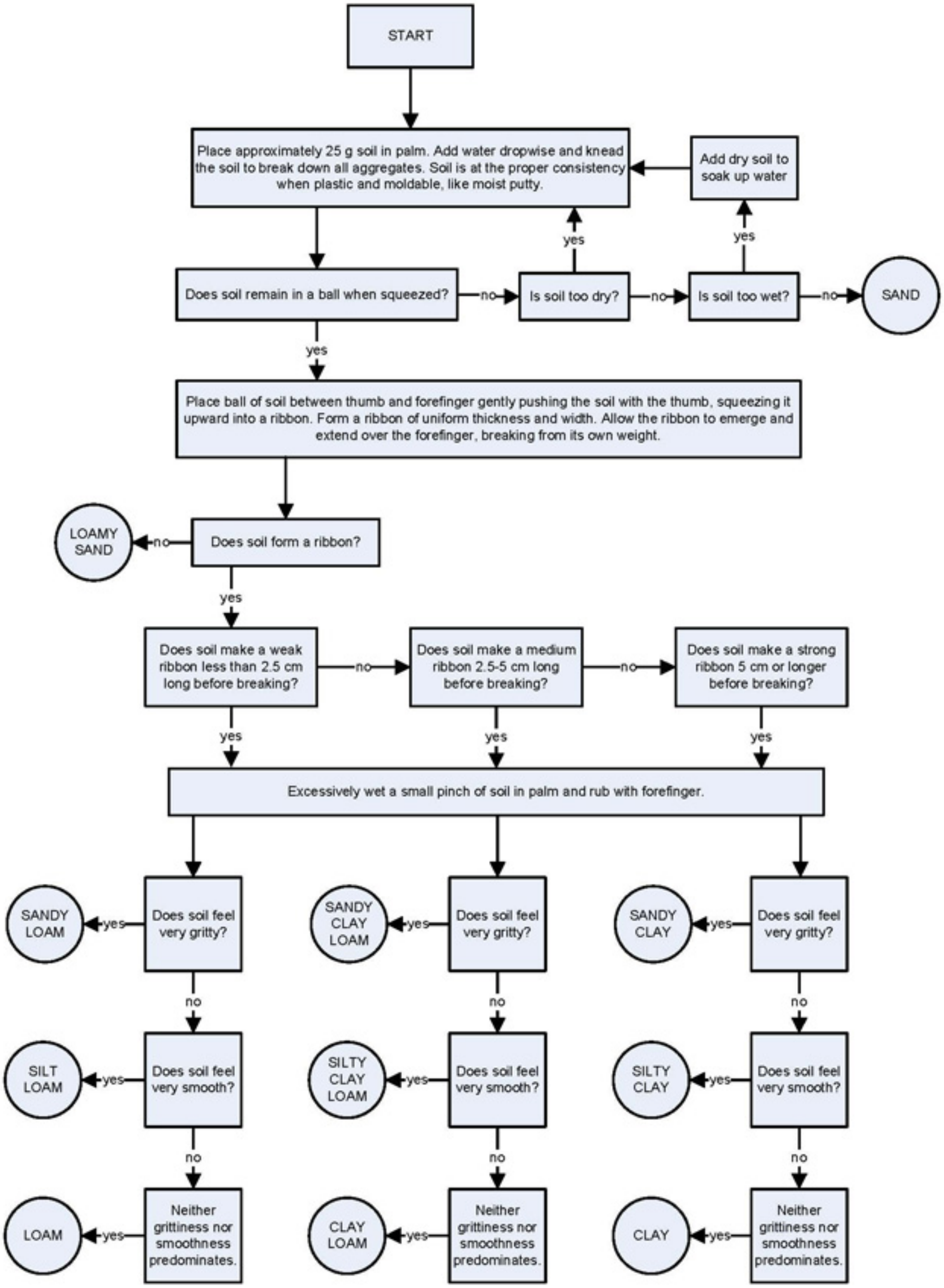
Questions and Review

Once you've answered these questions, then you can determine your ultimate goal and how manage your plants and soil to get there. Asking questions is a good way to figure it out.

- What is your goal?
- What plant(s)? What other uses? (e.g. pathway, deck, etc.)
- What do you want to do with your soil?
    - To grow food or plants for ecosystem services?
    - To get "good" soil?
    - What other goals could I achieve?
- What do you need? (What site characteristics are needed for those plants or goals?)
- What do you have? (What site characteristics do you currently have?)
- What can you do? Given what you have, or can get, what is possible for the site.

In the Soil Amendment and Fertilizers module we will further explore how these questions might impact our management.

Figure 14: Determining Soil Texture by Feel



https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311

Glossary

Base saturation is defined as the percentage of the soil exchange sites (CEC) occupied by basic cations, such as potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na).

Bulk density is the weight of soil in a given volume.

Capillarity is the primary force that enables the **soil** to retain water, as well as to regulate its movement.

Cation exchange capacity (CEC) is the total capacity of a soil to hold exchangeable cations. CEC is an inherent soil characteristic and is difficult to alter significantly. It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification.

Dynamic soil properties are properties that change with land use, management, and disturbance over the human time scale (decades to centuries).

Inherent soil properties (e.g., soil texture) change little, if at all, with changes in land use and management.

Macropores are large soil pores, usually between aggregates, that are generally greater than 0.08 mm in diameter.

Micropores are small soil pores, usually found within structural aggregates, that have diameters less than 0.08 mm in diameter.

Mottling refers to a layer that is marked with spots or blotches of different color or shades of color.

Respiration allows plants and other living things to release the energy stored in the chemical bonds of carbohydrates such as sugars made from carbon dioxide and water during photosynthesis.

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The space between the aggregates provide pore space for retention and exchange of air and water.

Tilth generally refers to the physical condition of the soil as it relates to plant growth.

Turgor refers to the water pressure within a plant’s cells. The turgor of the plant is what keeps the plant’s stem upright and keeps its leaves expanded to absorb adequate sunlight.

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