Soils and Fertilizers

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Learning Objectives

1. To appreciate the importance of soil for planting success
2. To recognize the wide range of soil types we have in New York
3. To understand some important physical and chemical properties of soil
4. To make informed decisions about the wide range of fertilizers and how to apply them
5. To understand the value of soil testing
6. To understand the various terms used in soil science to foster further reading and learning

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Soils

Plants grow in soil. To be successful gardeners, we must understand, use and nurture this incredible resource. It is a dynamic material composed of mineral, organic matter, water and air. In this dynamic material plants and other soil organisms interact to create a 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 dynamic chemical, physical and biological reactions take place. Through these interactions, soil provides the plants with the water and nutrients that they need to grow. Soil also provides a medium for roots to anchor the plant as well as storage and filtration of the water as it moves into and through this dynamic environment.

There is a difference between soil and dirt. Dirt is soil material that is taken out of its native location. But it can, given time and care, become a healthy and productive soil.

Soil Development

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

The process begins with the transformation of the mineral material from rocks and organic matter from plants into a developing soil. This mineral or plant material 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), bedrock, and others. These materials weather over the years. 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 is deposited at the surface as dead and decaying plant materials as well as other waste products. Organic matter is also added to soil at depth by the death of roots and soil organisms. The decomposing organic matter produces organic acids which then move through the soil. Water and these organic acids move soil leachates through the soil, re-depositing the materials to other parts of the soil or into the ground water where it can leave the soil. Soil organisms also mix the organic matter with the mineral materials.

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

- the recycling of nutrients so that last season’s yard and garden waste contributes to next season’s plant nutrients.
• the regularly 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.

Soil scientists classify and describe soils by their components, texture, structure and other physical properties. We will introduce these concepts as well as examine fertilizers, lime and soil building techniques and close with suggestions for nutrient management and soil conservation at home.

New York Soils

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 the New York’s topography, parent material, biota and climate has produced over 300 soil series (types of soils) in New York.

Much of the information about the soils in your area can be found in your county Soil Survey. The Soil Survey includes lots of useful information for gardeners, including soil physical and chemical properties as well as use and management. Soil Surveys of your area are available at your local Cornell Cooperative Extension office, your local Soil and Water Conservation District office or the Natural Resource Conservation Service.

What is soil or 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. 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 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. Sand, silt and clay are three size components of the mineral fraction of soil and range in size from 2 mm to smaller while gravel is not considered a soil texture component it will effect the management of your garden.

• 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 resistance to weathering is due to its mineralogy. Silt is platy 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 contents of most 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. These pore spaces account for up to 50% of total soil volume. 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, sprinkler systems all deliver water to the garden. Proper placement, aim, timing, 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 and leaching of nutrients and organic matter.
- "Tight" or "heavy" soils, high in clay, contain many tiny pore spaces, which may impede root growth and water drainage.
- Increasing the organic matter content increases your soil’s water-holding capacity.

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.

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, which will limit respiration. A byproduct of respiration is carbon dioxide (CO₂) which at high concentrations can be detrimental to soil life. A well aerated soil will allow sufficient oxygen to enter and excess CO₂ 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, water builds up in the soil less air is able to reach the roots and soil organisms, limiting their respiration.

How important are shape and size 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. Micropores while limiting drainage 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. So limiting garden practices which change pore balance and destroy structure (discussed below) are extremely important to a successful garden.
Physical Properties of Soil

A soil’s physical properties are characteristics we can often see or feel. Soil is formed by the interaction of five soil forming factors: parent material, climate, organisms, topography and time. Physical properties evolve as parent material is transformed by the soil forming factors. While there are many physical characteristics we are going to look at a few important ones: texture, structure, bulk density, drainage as well as color.

Soil Texture and Textural Classes of Soils

The proportion of different sized soil mineral particles – sand, silt and clay – is called soil texture. This proportion remains fairly constant through time. The shape of the particles vary, 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 U.S.D.A.

<table>
<thead>
<tr>
<th>SEPARATE</th>
<th>DIAMETER SIZE (mm)</th>
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<tbody>
<tr>
<td>Very coarse sand</td>
<td>2.00-1.00</td>
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<tr>
<td>Coarse sand</td>
<td>1.00-0.50</td>
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<tr>
<td>Medium sand</td>
<td>0.50-0.25</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.25-0.10</td>
</tr>
<tr>
<td>Very fine sand</td>
<td>0.10-0.05</td>
</tr>
<tr>
<td>Silt</td>
<td>0.05-0.002</td>
</tr>
<tr>
<td>Clay</td>
<td>&lt; 0.002</td>
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</table>

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. Also 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, but would also increase the surface area of the particles still more. Therefore soil texture 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 diagram of the textural triangle.
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.
- 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.
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 class and name of the soil. This test usually costs about $40.

You can begin practicing the "texture by feel" method and with experience you can come pretty close to determining the kind of soil you have. Here are some examples of what different combinations of sand, silt and clay feel like.

**Sand.** Is 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.** Is a soil containing much sand but which has enough silt and clay to make it somewhat coherent. 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.** Is a soil having a moderate amount of the fine grades of sand and only a small amount of clay with over half of the particles being broken, and when pulverized it feels soft and floury. When we 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.** Is 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.** Is 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.** All of the above classes of soil, if mixed with a considerable amount of sand gravel, are designated as sandy clay loams, sandy clays, etc. and as gravelly sandy loams, gravelly clays.

Now take a soil sample of your own, follow the instructions below using the "texture by feel" guide and determine your soil type.
Determining Soil Texture by Feel

Begin by taking a handful of soil. Remove any sticks, roots, or pebbles. Add water drop by drop and knead the soil until a smooth and plastic consistency is obtained. The soil should now be moldable like moist putty and does not stick to your hand. Squeeze the soil into a ball.

Add more water  Add dry soil to soak up water

Does the soil remain in a ball when squeezed?  if yes  if yes  if yes
if no  Is soil too dry?  Is soil too wet?

Place the ball of soil between your thumb and forefinger. Gently push the soil forward with your thumb, squeezing it upward into a ribbon. Try to keep the ribbon of uniform thickness and width. As the ribbon forms, allow it to drape over your forefinger until it breaks from its own weight. Measure the length of the ribbon that drops away from your hand. Repeat the ribboning several times to arrive at an average ribbon length.

Does the soil form a ribbon?  if no  Loamy Sand
if yes

What kind of ribbon does the soil form?

Take a small pinch of the soil ribbon in your palm and add a few drops of water. Make liquid slurry of the soil and water and, using the forefinger of your other hand, approximate how much sand is in your soil. Do this by circling your finger around your now-muddy palm and estimate the sand percentage. Hint: Think of the circle of slurry in your palm as a pie. What percent of the pie feels gritty? What percent of the pie feels smooth?

<table>
<thead>
<tr>
<th>Forms a weak ribbon</th>
<th>Forms a medium-length ribbon</th>
<th>Forms a strong ribbon</th>
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<tbody>
<tr>
<td>less than 1” long</td>
<td>1-2” long</td>
<td>2” or longer</td>
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<tr>
<td><strong>Loam</strong></td>
<td><strong>Clay loam</strong></td>
<td><strong>Clay</strong></td>
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<table>
<thead>
<tr>
<th>Does the soil feel very gritty?</th>
<th>Does the soil feel very gritty?</th>
<th>Does the soil feel very gritty?</th>
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<tbody>
<tr>
<td><strong>Sandy loam</strong></td>
<td><strong>Sandy clay loam</strong></td>
<td><strong>Sandy clay</strong></td>
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<thead>
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<th>Does the soil feel equally gritty and smooth?</th>
<th>Does the soil feel equally gritty and smooth?</th>
<th>Does the soil feel equally gritty and smooth?</th>
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<tbody>
<tr>
<td><strong>Loam</strong></td>
<td><strong>Clay loam</strong></td>
<td><strong>Clay</strong></td>
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<th>Does the soil feel very smooth?</th>
<th>Does the soil feel very smooth?</th>
<th>Does the soil feel very smooth?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Silt loam</strong></td>
<td><strong>Silty clay loam</strong></td>
<td><strong>Silty clay</strong></td>
</tr>
</tbody>
</table>
Characteristics of Several Soil Textures

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Drainage</th>
<th>Susceptibility to Compaction</th>
<th>Water and Nutrient Holding Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Excellent</td>
<td>Little to None</td>
<td>Limited</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>Excellent</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>Good</td>
<td>Limited to moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Loam</td>
<td>Good to Fair</td>
<td>Moderate</td>
<td>Moderate to Substantial</td>
</tr>
<tr>
<td>Silty loam</td>
<td>Fair to Poor</td>
<td>Substantial</td>
<td>Substantial</td>
</tr>
<tr>
<td>Clay loam</td>
<td>Fair to Poor</td>
<td>Substantial</td>
<td>Substantial</td>
</tr>
<tr>
<td>Clay</td>
<td>Poor</td>
<td>Substantial</td>
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Soil Structure

Poor soil is a chief complaint among 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 and require more frequent watering and feeding. Many symptoms of poor plant health can be traced, in part, to poor physical 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. In top soil, the structure is usually granular unless it is disrupted. As shown below, soil aggregates can come in a variety of sizes and shapes, ranging from granular through platy to columnar. Also note the effect on water movement based on soil structure.

![Soil Structure Diagram](image-url)
Soil structure also strongly affects the type and distribution of soil pores and allows for improved air and water movement within the soil. Please review soil water and air section. 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, 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 true 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 our working the soil can dramatically affect soil structure, plants and organisms 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.

The addition of organic matter is an important practice for improving soil quality, which includes the improvement of soil structure:

- Increases pore space in soil which improves soil drainage and penetration of plant roots. For example it lightens clay soils by macropore formation.
- Increases particle aggregation. For example lignin in humus helps sand particles stick together (granulation).
- Increases aggregate stability by increasing the strength of the aggregate structures to resist destructive forces (raindrops, traffic, cultivation, etc.)

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

**Bulk Density and Compaction**

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 pore 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 with heavy equipment. It can also occur by beating a path into a garden by foot traffic.

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 cm$^3$, roots can penetrate and grow through a soil. As the density approaches 1.65g per cm$^3$, roots growth becomes restricted. At a density greater than 1.65g per cm$^3$, root growth is severely restricted.

To remediate compacted soil, you can do one of three things:

- remove and replace compacted soil
- amend it, most often with organic matter
- bury it under soil with better growing conditions (a minimum of 19 inches, but often as much as 3 feet)

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 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, and (3) degree of oxidation. Colors vary from almost white, through shades of reds and yellows to brown and gray, and then to black. We can use 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. While dark colors may indicate a high organic content.
- 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 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.
- Manganese behaves similarly to iron, but creates small black bits or concretions indicating the presence of the high of the water table.
- Red and yellow mottling (patches) with a dominant soil color of gray indicates slow drainage and poor aeration. In these wet soils, with low oxygen levels, the iron has been chemically and biologically reduced removing the iron coating and changing the colors of iron from red and yellow to blue and greens.
- Dark colored soils absorb heat more rapidly than light colored soils, but they also lose heat faster at night, producing a greater daily variation of soil temperatures.

**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 it also influences how well a perennial plant (tree, shrub, or herbaceous perennial) over-winters. Many a cold hardy plant has been lost during the winter because the stress 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 mottling depth of a soil. Mottling is a soil color change often produced by soil drainage and resembles rusty and or red/yellow patches in the soil profile. The depth at which this occurs indicates the drainage class. Contact your local Cornell Cooperative Extension office, local Soil and Water Conservation District office or the Natural Resource Conservation Service to view photos or soil profiles of these drainage features.

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

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

Most soils have distinct layers, or horizons, that collectively form the soil profile. These horizons often differ in color, texture and structure. Soil horizons are best seen in relatively undisturbed forest soils. We have simplified these horizons into three generalized layers called topsoil, subsoil and parent materials.

Topsoil

- 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

- Firmer 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
Parent Material

- Made up of weathered rock that can retains characteristics of the bedrock
- 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 thin layers of soil 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 make thin layers we often limit the plants’ rooting depth.

By adding an inch or so of “topsoil” to a garden or landscape we build thin 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.

It is important to thoroughly mix and incorporate soil and soil amendments 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 added to it such as compost. 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 and expensive, but that sold in bulk by the cubic yard may or may not be good quality, but is often less expensive than a comparable quantity in bags. If possible, try to find out the source of the soil; it is important that it does not contain persistent herbicides or noxious weed seeds. 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 tend to hold more nutrients and water allow for deep root penetration and produce larger crops than shallow soils with similar textures.

**Soil Health**

Historically, soil has been assessed by chemical and physical properties and/or plant yield. In the decades ahead, we expect that scientists will focus more attention on the living organisms in the soil and determine ways of measuring their effectiveness in creating a vibrant and dynamic soil environment for supporting plant growth and yield.

To see soil as having a “healthy” component recognizes that a healthy soil has numerous, biologically active organisms constantly revitalizing the soil. The vast majority of soil organisms are beneficials – important in suppressing disease, re-cycling essential plant nutrients, and/or improving soil structure. The number and diversity of organisms, such as saprophytic nematodes, earthworms, mychorrizal fungi, nitrogen-fixing bacteria within legume root nodules – in a specified volume of soil is important. The measure of activity of a broad community of organisms is also important. Soil health may also be characterized by how soil chemical or physical properties reflect microbial activity.

**Soil organisms**

While not considered a component of soil, soil organisms play a critical role in soil creation and nutrient dynamics.

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 microorganisms (or microbes) in the soil secrete a slimy substance (mucopolysaccharide) which cements soil particles together giving it structure.
Important Microbiological Activity in Soils

<table>
<thead>
<tr>
<th>Microbial activity</th>
<th>Major Benefit to Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient-cycling</td>
<td>Making nutrients available to plants.</td>
</tr>
<tr>
<td></td>
<td>Preventing nutrients from leaching.</td>
</tr>
<tr>
<td>Organic matter degradation</td>
<td>Thatch maintenance. Making nutrients available to plants.</td>
</tr>
<tr>
<td></td>
<td>Production of humates, stimulating plant growth.</td>
</tr>
<tr>
<td></td>
<td>Indirect effects on soil pest control.</td>
</tr>
<tr>
<td>Nitrogen fixation</td>
<td>Increased availability of nitrogen.</td>
</tr>
<tr>
<td>Production of polysaccharides</td>
<td>Improve soil structure.</td>
</tr>
<tr>
<td>Production of antibiotic compounds</td>
<td>Production of antibiotic compounds.</td>
</tr>
<tr>
<td>Michorrizal symbiosis</td>
<td>Increased phosphorus nutrition.</td>
</tr>
</tbody>
</table>

Practices that encourage microbial life:

- use organic amendments composed of readily available carbon (i.e. composted manures)
- maintain soil moisture at constant levels
- maintain balanced pH and fertility levels
- physical amendments can be used to improve porosity which increases oxygen level
- consider practices that alleviate compaction (for lawns aeration)
- limit the use of pesticides

Other organisms in the soil

There are nematodes, earthworms, insects, and spiders in the garden soil. Let us focus here on the earthworms, which wind their way in and out of the soil at times. Earthworms keep and restore soil fertility. Different types of earthworms, including the night-crawler, field (garden) worm, and manure (red) worm, have different feeding habits. They can feed on plant residues or organic matter in the soil. Nightcrawlers digest soil minerals, bacteria, and enzymes to create worm casts. Worm casts are generally higher in available plant nutrients, such as nitrogen, calcium, magnesium and phosphorus, than the surrounding soil, contributing to the nutrient needs of 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 that allow rainfall 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.
Relationship of soil to plant growth and development

It is not possible to grow plants and gardens well without the support, water and nutrients 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 teeming with life and constantly changing. By understanding your soil and by

- selecting the right plant (and recommended variety) for your site,
- providing adequate nutrients and water (based on plant needs)
- maintaining a proper soil pH
- avoiding practices that cause compaction or erosion
- improving poor drainage

you will be able to have more productive gardens and successful landscape plantings.

Soil pH and Liming

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, a soil with a pH of a 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, 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 pHs, optimum availability for all nutrients is best at a pH around 6.5. This is shown in the following table. 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 pHs, 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.

<table>
<thead>
<tr>
<th>Relationship between pH and nutrient availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly acid</td>
</tr>
<tr>
<td>NITROGEN</td>
</tr>
<tr>
<td>PHOSPHORUS</td>
</tr>
<tr>
<td>POTASSIUM</td>
</tr>
<tr>
<td>SULFUR</td>
</tr>
<tr>
<td>CALCIUM</td>
</tr>
<tr>
<td>MAGNESIUM</td>
</tr>
<tr>
<td>IRON</td>
</tr>
<tr>
<td>MANGANESE</td>
</tr>
<tr>
<td>BORON</td>
</tr>
<tr>
<td>COPPER and ZINC</td>
</tr>
<tr>
<td>MOLYBDENUM</td>
</tr>
</tbody>
</table>

**Liming**

The process and reactions by which ground limestone reduces soil acidity are very complex.

When calcium and or magnesium carbonate (lime) \( \text{Ca}^{++} \text{CO}_3 \) is added to the soil the calcium ions (\( \text{Ca}^{++} \) and \( \text{Mg}^{++} \)) flood the soil solution and replace hydrogen ions (\( \text{H}^+ \)) found on the surface of soil and organic matter. The hydrogen ions then combine with hydroxyl ions (\( \text{OH}^- \)) to form water. This decrease in hydrogen ion concentration produces an increase in soil pH. The reverse of the above process can also occur. An acid soil can become more acidic if a liming program is not followed. As basic ions such as \( \text{Ca}^{++} \), \( \text{Mg}^{++} \), and \( \text{K}^+ \) are removed, usually by crop uptake, they can be replaced by \( \text{H}^+ \). These basic ions can also be lost by leaching, again being replaced by \( \text{H}^+ \). The \( \text{H}^+ \) activity will steadily increase, lowering soil pH, if the soil is not limed properly.
To make soils less acid, apply a material that contains some form of lime.

- Ground limestone is most frequently used and is economical.
- The neutralizing value of the specific liming material determines the amount needed to make the pH change.
- Dolomitic limestone also contains magnesium and is recommended when soil with a low pH is also low in Mg.
- The finer the grind, the more rapidly it becomes effective.
- Different textured soils will require a different amount of lime to adjust the pH. More clay means more lime will be needed.
- Soils low in organic matter content (lower CEC) require much less lime than soils high in organic matter to make the same pH change.
- Lime must be in contact with the soil. It should be incorporated into the soil.
- Since lime does not move much in the soil, applying lime before planting is always better. If you apply lime to an established bed, limit the application at any one time (e.g. 50 pounds of lime per 1000 square feet for turfgrass). If needed, it might be worthwhile to make a lime solution and apply near the roots of established trees, shrubs and herbaceous perennials.

**To raise soil pH to 6.5**

Pounds of ground limestone per 100 square feet

*incorporated into upper 6 inches of soil*

<table>
<thead>
<tr>
<th>Existing pH</th>
<th>Sandy loam</th>
<th>Loam</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>12.6</td>
<td>25.3</td>
<td>34.8</td>
</tr>
<tr>
<td>5.0</td>
<td>10.6</td>
<td>21.1</td>
<td>29.0</td>
</tr>
<tr>
<td>5.5</td>
<td>4.2</td>
<td>8.4</td>
<td>11.6</td>
</tr>
<tr>
<td>6.0</td>
<td>1.7</td>
<td>3.3</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Lowering pH**

If pH is too high, a sulfur source can be added to the soil to reduce alkalinity. Do not use large amounts of aluminum sulfate to lower the soil pH. At low soil pHs aluminum is quite soluble and can injure plants. The best source to use is elemental sulfur.

**To lower soil pH to 6.5**

Pounds of elemental sulfur per 100 square feet

*incorporated into upper 6 inches of soil*

<table>
<thead>
<tr>
<th>pH</th>
<th>Sandy loam</th>
<th>Loam</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 8.0 to 7.0</td>
<td>1.2</td>
<td>2.4</td>
<td>3.3</td>
</tr>
<tr>
<td>From 7.5 to 7.0</td>
<td>0.5</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td>From 7.0 to 6.0</td>
<td>1.0</td>
<td>2.1</td>
<td>2.8</td>
</tr>
<tr>
<td>From 6.5 to 5.0</td>
<td>3.4</td>
<td>6.8</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Other acidifying agents, such as iron sulfate, will require larger amounts (as much as 3 to 4 times more) to achieve the same effect as elemental sulfur.
Blueberries and many ornamental plants require slightly to strongly acid soil to thrive. These species develop iron chlorosis when grown in alkaline soils. Iron chlorosis is often confused with nitrogen deficiency because the symptoms (a definite yellowing of leaves) are similar. Iron chlorosis can be corrected by reducing the soil pH. Applying chelated iron formulations to the soil or spraying foliage with solutions of iron chelate or iron (ferrous) sulfate is a temporary solution.

The term chelate (pronounced key-late) comes from the Greek word for claw. Chelates are chemical claws that help hold metal ions, such as iron, in solution, so that the plant can absorb them. Different chemicals can act as chelates from relatively simple natural chelates like citrate to more complex manufactured chemicals. When a chelate metal is added to the soil, the nutrient held by the chelate will remain available to the plant.

Most nutrients do not require the addition of chelate to aid absorption. Only a few of the metals, such as iron, benefit from added chelates. The type of chelate used will depend on the nutrient needed and the soil pH.

**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.

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.

A major portion of nutrients in the soil are not available to plants. This is because many nutrients exist in a complex structure 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 organic matter decomposition by microorganisms and ion release from mineral and organic soil particle surfaces.
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. Anions with their negative charge are not attracted to the colloids, making them especially subject to leaching from the soil solution. Ammonium nitrogen, NH₄⁺, is held by the soil colloids against leaching, while nitrate nitrogen, NO₃⁻, is readily leached. This has important implications for preventing nitrate, NO₃⁻, pollution of groundwater and the lakes, ponds, rivers and creeks.

The total potential charge of the soil particles, which dictates the cation holding capacity of the soil, 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 effect the overall CEC.

![Cations compete for sites on a negatively charged soil particle](image)

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. The nutrient may also 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, it is required by plants in the greatest amount (plant proteins are 16% nitrogen). It is found only in the organic fraction of soil and is easily leached in the nitrate form. Annual plants need nitrogen most about 3-4 weeks after seedlings have emerged or after transplanting.

Nitrogen can be taken up by the plants, but can also be lost to leaching, runoff, erosion and escape from the soil surface into the atmosphere (by volatilization) depending on its form.

Chemical forms of Nitrogen commonly found in soil

<table>
<thead>
<tr>
<th>Compound group</th>
<th>Name</th>
<th>Symbol</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic</td>
<td>Ammonium</td>
<td>NH₄⁺</td>
<td>Can adsorb onto clay and organic matter, preventing large amounts from moving with water. Plant available.</td>
</tr>
<tr>
<td></td>
<td>Nitrite</td>
<td>NO₂⁻</td>
<td>Mobile with water, but not found in large amounts</td>
</tr>
<tr>
<td></td>
<td>Nitrate</td>
<td>NO₃⁻</td>
<td>Typically present in relatively large amounts and very mobile with water. Form preferred by most plants.</td>
</tr>
<tr>
<td>Organic</td>
<td>Proteins,</td>
<td>R-NH₂</td>
<td>Contained in manure, organic wastes, nucleic acids, and living and dead plants and animals. Immobile. Not available to plants.</td>
</tr>
<tr>
<td></td>
<td>Amino Acids</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Nitrogen exists in the soil in organic and inorganic forms. Nitrogen in your soil is continually transformed between organic and inorganic forms through biological and chemical reactions. These processes constitute the nitrogen cycle.

There are several important terms related to Nitrogen.

- **Nitrogen Fixation** – although the air we breathe is 78% nitrogen, the gaseous form is useless to plants. However, certain free-living bacteria (e.g. *Rhizobium*) living in nodules on the roots of legumes can convert atmospheric nitrogen into plant available forms. There are no more than 100-200 different species of free-living 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). This may cause a nitrogen deficiency in your garden plants. 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. 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/Volitization* – 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, phosphorus is tied up in forms that are not available to plants.

**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 an excess of one element may show up as a deficiency of another.
## Plant Nutrients: Macronutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Function in Plant</th>
<th>Excess Symptoms</th>
<th>Deficiency Occurrence and Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus (P)</td>
<td>Stimulates early root growth. Gives plants a rapid and vigorous start. Is important in flowering and seed formation.</td>
<td>Possible tie up of zinc, iron and cobalt.</td>
<td>P 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.</td>
</tr>
<tr>
<td>Potash (K)</td>
<td>Increases plant vigor. Stimulates production of strong, stiff stalks, sugars, starches and oils. Enhances flavor, color and cold and disease hardness.</td>
<td>Coarse, poor colored fruit. Reduced absorption of Mg and Ca.</td>
<td>Leaches from very light soils. Leaf margin scorch. Thin skin and small misshaped fruit. Reduced vigor and yield; susceptibility to diseases.</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>Protein building block.</td>
<td>Sulfur burn from too low pH.</td>
<td>New leaves are light green or yellowish.</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>Essential for cell wall structure and formation of new cells.</td>
<td>Reduces the intake of K and Mg.</td>
<td>On acid soils with high K levels. Very dry soils become deficient. Stops the growing point of plants. Causes cell breakdown (blossom end rot).</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Aids photosynthesis. Key element in chlorophyll.</td>
<td>Reduced absorption of Ca and K.</td>
<td>On acid soils, light soils easily leached, and high potassium soils. Interverinal chlorosis. Whitish patches on older leaves.</td>
</tr>
</tbody>
</table>
## Plant Nutrients: Micronutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Function in Plant</th>
<th>Excess Symptoms</th>
<th>Deficiency Occurrence and Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper (Cu)</td>
<td>Enzyme activator.</td>
<td>Prevents the uptake of iron. Causes stunting of roots.</td>
<td>On muck or peat soils.</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>Aids in cell division; needed for enzyme and auxin formation</td>
<td>None known.</td>
<td>On wet, heavy soils in early spring; may be due to excess phosphorus fertilization. Small, thin, yellow leaves.</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>Aids in the utilization of N.</td>
<td>Poisonous to livestock.</td>
<td>On very acid soils Looks like nitrogen deficiency; symptoms in plants vary greatly.</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>Osmotic + cation neutralization</td>
<td></td>
<td>Partial wilting + loss of leaf turgor</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td>Essential for N fixation</td>
<td></td>
<td>as pH increases on coarse-textured soils with heavy rainfall</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 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. The dissolved nutrients are called ions, which are charged components of individual molecules. 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, $\text{KNO}_2$, dissolves into $\text{K}^+$ and $\text{NO}_2^-$.
Soil Testing

Soil tests 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 may. 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). 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 pH information and an estimate of textural information can be done. 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 need not be performed 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 in the fall before starting on a new garden project, adjust the pH if the results recommend it…and then add the fertilizer the following spring just before major planting.

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.

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. 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.
Fertilizers

Fertilizers are salts, much like table salt, except that they contain various plant nutrients. When a fertilizer (salt) is applied to a soil, nearby water begins to move very gradually towards the area where the fertilizer has been applied. Salts and fertilizers begin to diffuse, or move away from, the place where they have been applied. This dilutes the fertilizer and distributes it through a much larger area.

Soluble salts build up when fertilizer is applied repeatedly without sufficient water to leach (wash) the old fertilizer (salts) through the soil. If tender plant roots are close to the fertilizer, water is drawn from these roots, as well as from surrounding soil. This causes plant cells to begin to dehydrate and collapse, and the roots may burn to a point where they cannot recover. If soil moisture is limited, most of the water drawn towards the salt will come from plant roots, and the damage will be severe.

When applying fertilizer during dry, hot weather:
- do not over-apply nitrogen or potassium fertilizer
- make sure adequate moisture is present after applying fertilizers high in salts.

Soluble salt problems commonly occur on plants in containers but are rarely a problem in the garden. The best way to prevent soluble salt injury is to leach the salts out of the pots. When applying water, allow some to drain through and then empty the drip plate. Some water should drain through each time you water the pot.

The Nature of Fertilizer

There is much confusion over the terms inorganic, synthetic, organic, natural and special purpose when it refers to fertilizers. It is important to keep in mind that nutrients are available to plants in only one or two forms, regardless of the source. Put in another way, “a nitrate molecule is a nitrate molecule,” whether from manure or ammonium nitrate.

Inorganic Fertilizers

Some natural inorganic fertilizers exist in nature as insoluble parent/rock materials, for example: rock phosphate, sodium nitrate and potassium sulfate. Others are manufactured products made from non-living material and are referred to as synthetic or chemical fertilizers. Examples include ammonium sulfate (21-0-0), commonly used on acid-loving plants like blueberry and azalea; superphosphate (0-20-0), phosphate rock treated with sulfuric acid; granular fertilizers, such as 10-10-10 and 10-6-4; liquid fertilizers, such as Miracle-Gro.

They are mineral salts with the nutrients in soluble form which makes uptake easy. But because they can be soluble they can leach easily in the soil. Generally the nutrient analysis of inorganic fertilizers is high making them economical to use.
Organic Fertilizers

The term natural organic is applied to fertilizers derived solely from remains, or by-products, of a once-living organism. Various wastes and by-products of the plant and animal processing industries can be used as fertilizers. Cottonseed meal, blood meal, bone meal and horn meal, and all manures are examples of natural organic fertilizers. When packaged as fertilizers, these products show the fertilizer grades on the label.

Human-made organic materials used for fertilization are termed synthetic organics. Examples are urea (a water-soluble nitrogen under controlled conditions); ureaform (made by reacting urea and formaldehyde) and IBDU (made by reacting urea and isobutyraldehyde)

- Some organic materials, particularly composted manures and sludges, are sold as soil conditioners and do not have a nutrient guarantee although small amounts of nutrients are present.
- There are no state or federal standards regulating the use of terms like organic, natural, or natural organic, when applied to fertilizers. But they are listed on the OMRI (Organic Materials Review Institute) Brand Name Products list.
- Organic fertilizers may not release enough of their principal nutrients at a time to give the plant what it needs for best growth.
- Because organic fertilizers depend on soil organisms to break them down to release nutrients, they are only effective when the soil is moist and warm (activity begins when soil temperatures reach 50°). Microbial activity is also influenced by soil pH and soil aeration.
- Organic fertilizers are beneficial for improving the soil’s physical structure, and increasing bacterial and fungal activity, (particularly by the mycorrhizal fungi that help make phosphorus more available to plants.)
- Even though fresh manures have the highest amount of nutrients they also contain high soluble salt levels which can burn tender plant roots or plants. Also, heat and acetic acid from improperly composted manure can cause plant damage. It is always best to use aged (preferably a year old) compost for gardening purposes. Aged compost should contain fewer viable weed seeds. (Typical rates of manure applications vary from a moderate 200 pounds (5 bu. per 1000 sq. ft. to as much as 1 ton per 1000 sq. ft. (50 bu.).
- Sewage sludge (or bio-solids as they are called now), is a recycled product of municipal sewage treatment plants. Three forms may be available; heat-dried activated and composted. Activated sludge has a higher concentration of nutrients (approximately 6-2-0) then composted sludge (1-2-0). Although these materials can be used on turf and landscape plants they are not recommended for use on edible crops.
Organic and Inorganic sources of fertilizers and the nitrogen, phosphorus ($P_2O_5$) and potassium ($K_2O$)** control of each material

<table>
<thead>
<tr>
<th>Material</th>
<th>% Nitrogen</th>
<th>% $P_2O_5$ *</th>
<th>% $K_2O$ **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic 5-10-5</td>
<td>5.0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Rock phosphate</td>
<td>0.0</td>
<td>25-30</td>
<td>0.0</td>
</tr>
<tr>
<td>Alfalfa meal $^m$</td>
<td>2.5</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Bat guano $^m$</td>
<td>10</td>
<td>6.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Bone meal (25% Ca)</td>
<td>0.0</td>
<td>20-25</td>
<td>0.0</td>
</tr>
<tr>
<td>Compost (yard) $^m$</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Earthworm castings $^m$</td>
<td>varies</td>
<td>varies</td>
<td>varies</td>
</tr>
<tr>
<td>Fish emulsion $^m$</td>
<td>5.0</td>
<td>4.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Wood ashes</td>
<td>0.0</td>
<td>1-2</td>
<td>3-7</td>
</tr>
<tr>
<td>Greensand (glaucinite)</td>
<td>0.0</td>
<td>1.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Granite meal</td>
<td>0.0</td>
<td>0.0</td>
<td>3-5</td>
</tr>
<tr>
<td>Seaweed (kelp)</td>
<td>0.6</td>
<td>0.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Kelp meal $^m$</td>
<td>1.0</td>
<td>0.0</td>
<td>9.64</td>
</tr>
<tr>
<td>Apple pomace</td>
<td>0.2</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Blood, dried</td>
<td>8-12</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Cocoa shell meal</td>
<td>2.5</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Coffee grounds (dried)</td>
<td>2.0</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Cottonseed meal</td>
<td>6.0</td>
<td>2-3</td>
<td>1-2</td>
</tr>
<tr>
<td>Egg shells</td>
<td>1.2</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Fish scrap</td>
<td>6-10</td>
<td>7.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Olive pomace</td>
<td>1.2</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Peanut hulls</td>
<td>1.5</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Pine needles</td>
<td>0.5</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>7.0</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Oak leaves</td>
<td>0.8</td>
<td>0.4</td>
<td>0.02</td>
</tr>
<tr>
<td>Leaf mold $^m$</td>
<td>0.6</td>
<td>0.45</td>
<td>0.48</td>
</tr>
<tr>
<td>Tankage</td>
<td>5-10</td>
<td>3-13</td>
<td>0.0</td>
</tr>
<tr>
<td>Tea grounds</td>
<td>4.0</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Winery pomace</td>
<td>1.5</td>
<td>1.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Winery pomace</td>
<td>1.5</td>
<td>1.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Animal manures $^a$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cow $^x$</td>
<td>0.6</td>
<td>0.15</td>
<td>1.5</td>
</tr>
<tr>
<td>Cow (dried)</td>
<td>2.0</td>
<td>2.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Cow $^m$</td>
<td>2.5</td>
<td>0.45</td>
<td>0.5</td>
</tr>
<tr>
<td>Horse $^x$</td>
<td>0.7</td>
<td>0.25</td>
<td>0.55</td>
</tr>
<tr>
<td>Poultry $^{o}$</td>
<td>4.5</td>
<td>3.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Sheep $^{o}$</td>
<td>2.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

These analyses will vary depending on source, processing method, age of material, protection against leaching, etc.

*Sources of information: Dr. Len Topoleski, Cornell University
  $^m$ University of Maryland
  $^x$ = commercial, pulverized
  $^{o}$ = fresh
  $^a$ = Dried manure may have a nutrient content 4x p 5x greater than fresh manure.

* The percentage of $P_2O_5$, multiplied by 0.44 equals the amount of elemental phosphorus.
  **The percentage of $K_2O$, multiplied by 0.83 equals the amount of elemental potassium.
Special Purpose Fertilizers

When you are shopping for fertilizers, you will find them packaged for certain uses or types of plants, such as Rhododendron and Azalea Food, Holly Tone or Rose Food. The rhododendron, azalea, and holly fertilizers belong to the acid-loving plant fertilizer group, which have been available for a long time. The compounds used in these fertilizers leave an acid residue, so they are especially beneficial for acid loving plants, where the soil is not acidic enough. It is not expected that these “acidic” fertilizers can permanently change an alkaline soil to an acid one. There are limitations on how much a fertilizer can alter the soil pH.

So be sure to select the right plant for the soil you have. (Blueberries will never thrive in an alkaline soil no matter what you do to lower the soil pH).

Other fertilizers packaged for specific plants, such as roses, often do not have a valid research basis for being called “special.” Perform a soil test before purchasing any expensive special-purpose fertilizer. It is not possible to make a blanket statement that one fertilizer is best for every area of the state. It is true that different plants use different nutrients at different rates. What is unknown is the reserve of nutrients already in the soil. This changes with every soil type and location.

Fertilizer Forms

Granular Fertilizers

These fertilizers are conventional, traditional, or synthetic chemicals. They are manufactured and packaged into bags (5 lb., 10 lb., 25 lb. 50 lb. or more). They can be organic or inorganic in composition, and are applied by broadcasting them over the soil and incorporating them into the soil to prepare for planting.

Water Soluble Fertilizers

These fertilizers are sold as liquids or powders in small packages. The fertilizer is dissolved in a bucket or watering can, filled with water and applied as a solution. Brands like ‘Miracle Gro’ or ‘Rapid Gro’ are familiar to most shoppers, although there are other brands on the market. They must be applied much more frequently than any other form of fertilizer (frequently every 1-14 days during the growing season for fast growing annual plants), as they can quickly move through the soil and are lost from the root zone. If it rains immediately after applying water-soluble fertilizer, the rainwater can leach the fertilizer altogether from the root zone, sometimes requiring that it be reapplied after the rain.
Slow-Release Fertilizers

These fertilizers are sold in pellet form and applied in very small amounts on the top of the soil or incorporated into the top layer of soil. Plants take up fertilizers continuously, so it is beneficial to provide them with a balance of nutrients throughout their life. Perhaps the most efficient way to achieve this is to apply a slow-release fertilizer. Slow-release fertilizers contain one or more essential nutrients, which are released or made available to the plant over an extended period of time (e.g., 3 mo, 6 mo., or 9 mo.) The fertilizer has layers of coatings which degrade due to temperature, moisture and microbial activity. As the coating breaks down nutrients are released into the soil.

Use caution when applying slow-release fertilizers around trees and shrubs, as they may keep the plant growing late in the summer. Late season growth may not harden off completely, and result in excessive winter damage.

WIN and WSN

The initials WIN and WSN on fertilizer labels stand for “water insoluble nitrogen” and “water soluble nitrogen” respectively.

- WSN dissolves readily and is usually in very simple forms of nitrogen (usually ammonium or nitrate). Nitrogen in organic forms in fertilizer or organic matter must be broken down by microbial activity into an ammonium or nitrate form before it can be used by plants.

- WIN is referred to as a slow-release nitrogen source, delivering nitrogen at different rates according to slow release source. Slow-release N may also exist as coated soluble N sources, often referred to as controlled-release N (CRN)

- Slow-release N may also exist as coated soluble N sources, often referred to as controlled-release N (CRN).

Analysis and Grade

Fertilizer analysis provides information on how much of a nutrient is in a formulation. It is based on a percentage of the weight. All fertilizers are labeled with three numbers that indicate the guaranteed analysis, or the fertilizer grade. These three numbers give the percentage of nitrogen (N), phosphate (P\textsubscript{2}O\textsubscript{5}), and potash (K\textsubscript{2}O).

State regulations require that actual analysis values must be within certain limits of the labeled grade. To simplify matters, these numbers are often said to represent nitrogen, phosphorus, and potassium, or N-P-K. We should remember that it is not N-P-K, but N-P\textsubscript{2}O\textsubscript{5}, K\textsubscript{2}O. If we have a 100-pound bag of fertilizer labeled 5-10-10, there are 5 pounds of N, 10 pounds of P\textsubscript{2}O\textsubscript{5}, and 10 pounds of K\textsubscript{2}O. To calculate the amount of P in this fertilizer take the percentage of P\textsubscript{2}O\textsubscript{5}, multiplied by 0.44 equals - there are 2.2 lbs. of P in
this fertilizer. To determine potassium take the percentage of K₂O, multiplied by 0.83 - there are 8.3 lbs. of potassium in this fertilizer.

These nutrient amounts do not add up to 100 pounds for several possible reasons. The nutrients are in a compound or material that contains other elements. Much of K used in fertilizers is in the form of potassium chloride. A fertilizer may also contain materials other then N, P, K. These additives they may contain clay based fillers or conditioners to ensure good physical properties and light weight absorbents to give slow release of nutrients. In addition they also can make it easier to spread and apply the fertilizer to the soil. In some cases, limestone is added as filler to neutralize the acidifying effects of some N sources.

The information contained in fertilizer labeling has been well standardized, and the consumer is protected by state laws requiring manufacturers to guarantee the claimed nutrients. If you are unable to purchase the fertilizer you wish, you may have to settle for one with a different analysis. When you do this, you will have to adjust the amount of fertilizer applied per unit area to compensate for difference in analysis.

**Complete Fertilizers**

Complete fertilizers contain each of three major plant nutrients: nitrogen, phosphorus, and potassium. Grades such as 10-10-10, 16-8-8- and 5-10-10 represent complete fertilizers. Grades such as 0-25-25 and 20-1-10 represent incomplete fertilizers (one or more of the major nutrients is missing from the fertilizer), and 45-0-0-, 0-20-0, 0-0-60 are single nutrient fertilizers.

**Fertilizer Ratio**

Fertilizer ratio refers to the relative amounts of N, P₂O₅, and K₂O in a fertilizer

<table>
<thead>
<tr>
<th>Grade</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-10-10</td>
<td>1:1:1</td>
</tr>
<tr>
<td>5-10-5</td>
<td>1:2:1</td>
</tr>
<tr>
<td>12-24-12</td>
<td>1:2:1</td>
</tr>
<tr>
<td>12-4-8</td>
<td>3:1:2</td>
</tr>
<tr>
<td>0-25-25</td>
<td>0:1:1</td>
</tr>
</tbody>
</table>

Your soil test results may indicate a need for nutrients in a particular proportion. Select a fertilizer as close to the recommended ratio as possible.

**Application Methods**

**Broadcasting**

Broadcasting is used over large garden areas or when time or labor is limited. It is spreading a recommended rate of fertilizer over the growing area, incorporating it into the soil with a rototiller or spade or watering it into the soil.
**Banding**

This method is used primarily in the vegetable garden. It is applying narrow bands of fertilizer in furrows several inches to the side and below the seeds or transplants. The best technique is to stretch a string where the seed row will be. With a corner of a hoe, dig a 3-inches deep furrow, 3-inches to one side of and parallel with the string. Spread the fertilizer in the furrow and cover with soil. Repeat on the other side of the string. Seeds are sown under the sting after the fertilizer is applied.

For widely spaced plants, such as tomatoes, place fertilizer in bands 6-inches long for each plant or in a circle around the plant. Place the bands 4-inches from the plant base. If fertilizer is used in the hole itself, place the fertilizer at the bottom of the hole, work it into the soil, and place a layer of soil about 2-inches deep over the fertilized soil before putting the plant in the hole.

**Side Dressing**

This is also used primarily in a vegetable garden, but could be adapted for other annual plants. Dry granular fertilizer is scattered on both sides of a row 6-8 inches from plants after plants are up and growing. Work it into the soil and water thoroughly. Timing of side dress applications is important and depends on the specific plant. The best time to side dress for beans - when in bloom, carrots - when 4" tall, cucus - when vines spread, potatoes - when 8" tall and tomatoes at fruit set.

**Foliar Feeding**

Foliar nutrition supplements soil nutrition at a critical time for the plant. This method is used if:

1. insufficient fertilizer was applied before planting
2. you want a quick growth response
3. when micronutrients (e.g., iron or zinc) are unavailable from the soil
4. soil is too cold for plants to extract or use nutrients from the soil

Foliar-applied nutrients are water soluble and absorbed and used by plants quite rapidly. Absorption begins within minutes after application and, for most nutrients, is completed within 1 to 2 days, but is not a substitute. At transplanting time, a foliar application of a balanced fertilizer will help establish young plants in cold soils. Be sure to use label-recommended dilutions.

**Applying Fertilizers**

The amount of fertilizer you need to apply depends upon the analysis of the fertilizer, the area to be covered, and the plants to be fertilized. It is extremely important to accurately calculate the area to be fertilized. No additional benefit will come from adding more nutrients to the soil than are needed by the plant. Further the excess fertilizer can have negative environmental consequences in your garden as well as nearby water bodies.
Avoid these potential environmental pollution problems by taking the time to determine the area and apply fertilizer at the recommended rate only.

Granular fertilizers:

\[
\begin{array}{c}
\text{Nutrients needed} = \text{amount of fertilizer to apply} \\
\text{Fertilizer analysis} (\%) \\
\end{array}
\]

The # symbol is used for indicating pounds.

In the below calculations notice the fertilizer analysis (of 21%) is written as .21.

\[
\frac{21\%}{100} = \frac{21}{100} = .21
\]

this saves one step

How much ammonium sulfate, with an analysis of 21-0-0, would you need to apply at the rate of 1 lb. of N per 1000 sq. ft. to a lawn that is 3000 sq. ft. in area

**Step 1:** note the recommended amount of nutrient to apply (1# of nitrogen for each 1000 sq ft), then note the analysis of the nitrogen source (in this case 21%)

\[
\begin{array}{c}
1\# (\text{recommended rate}) = 4.46\# \text{ or about 4.5\# of ammonium sulfate} \\
.21 (\text{analysis of fertilizer}) \quad \text{will be needed for each 1000 sq ft} \\
\end{array}
\]

**Step 2:** note how much area is to be treated (here the lawn is 3000 sq ft)

So will need to apply 13.1# of ammonium sulfate to fertilize the total lawn area to deliver nitrogen at the 1# rate.

Would you need more or less product to do the job if you used urea (46-0-0)?

\[
\begin{array}{c}
1\# = 2.2 \# \text{ for each 1000 sq ft or 4.4\# for the whole lawn area} \\
.46 \quad \text{(urea is a much more concentrated nitrogen source)} \\
\end{array}
\]

**Liquid Fertilizers**

With liquid fertilizers, the amount of fertilizer in a package is expressed on a volume basis, while the analysis is expressed on a percentage basis.

To begin any calculation, you must first determine the weight of a given volume of fertilizer and then calculate the weight of N, P, and K in that volume of fertilizer.
Problem:
How much 20-40-10 liquid fertilizer would you apply to obtain a fertilization rate of 2 lbs. of N per 1000 sq. ft. when you have a 2000 sq. ft. area?
Given that: 1 gal of 20-40-10 liquid fertilizer weighs 11.5 lbs. 
calculate the amount of nitrogen contained in each gallon.

11.5 lbs. (weight of gallon) x .20 (the nitrogen analysis) = 2.3 lbs. of nitrogen in each gallon of 20-40-10

Using the formula:

\[
\frac{2 \text{ lbs. N is the recommended rate}}{2.3 \text{ lbs. (nitrogen content/gallon)}} = \frac{.87 \text{ gallon of 20-40-10 is needed per 1000 sq. ft}}{}
\]

Your area is 2000 sq. ft in size so .87 gallons x 2 = 1.7 gallons are needed to do the entire area.

A number of excellent resources were used to provide critical information. Many thanks to the following individuals for developing such helpful resources:

Fred Magdoff and Harold van ES for Building Soils for Better Crops

David Wolfe for Biological Indicators of Soil Health and Out of the Thin Air.

Harold van Es, Stu Klausner and Shaw Reid for Nitrogen and the Environment.

Nina Bassuk for Trees in the Urban Landscape.

You may also be interested in reviewing the Organic Gardening section of the NYS Master Gardener Manual and locating resources like Soils of New York Landscapes on the following web site:

http://www.gardening.cornell.edu/factsheets/soil/soilsnylandscapes.pdf
Review Questions:

1. What are the 4 major components of soil?

2. Name 2 reasons why organic matter is added to soils?

3. Name 3 soil particles that make up mineral soils. How would you describe their size and shape?

4. How would you describe macropores and micropores and why are they so important in the soil?

5. Define soil texture and soil structure.

6. Can soil structure change? Name three ways.

7. What can you tell about the soil by looking at its color?

8. What kind of information would be helpful to know when buying bulk topsoil?

9. Are micronutrients important for plant growth?

10. What is leaching?

11. What does a mottled-colored soil indicate?

12. Why should we avoid walking or moving equipment over fine-textured wet soil?

13. What do the three fertilizer analysis numbers on the package stand for?

14. Name three forms of fertilizer. (hint: one of them is granular form)

15. Organic fertilizers come from __________.

16. What are the advantages and disadvantages of organic fertilizers?

17. What kinds of information do soil tests provide?

18. What three plant nutrients are needed by plants in large quantities?

19. Is it possible to fertilize a plant through its leaves? What is this method called?

20. Calculate how much 5-10-5 fertilizer you would need to apply 1 pound of nitrogen per hundred square feet. Assume a garden space of 200 sq. feet.
21. Is there a difference between the nutrient content of dried cow manure and fresh cow manure? Explain.

22. Which soils have higher cation exchange capacity – sandy or clayey?

23. Give an example of how the pH affects the availability of a nutrient to plants.

24. What is nitrogen fixation in the soil and why is it important to life?

25. True or false: A side dress fertilizer application can be done anytime during the growing season. Explain your answer.
FERTILIZING ANNUALS, HERBS AND PERENNIALS
GENERAL FERTILIZER GUIDELINES
when soil test results are not available

Flowering Annuals and Herbs

at time of planting apply per 100 sq. ft.
2# of 5-10-5 or 5-10-10
mix into upper 4-6" of soil

maintenance fertilizer* apply per 100 sq.ft.
These plants may benefit from an application of a water soluble fertilizer
4-6 weeks after planting. For continued good growth make the applications
every 4-6 weeks throughout the growing season.

Perennials

at time of planting apply per 100 sq. ft.
2# of 5-10-5 or 5-10-10
mix into upper 4-6" of soil

maintenance fertilizer* apply per 100 sq.ft.
1# of 5-10-5 or 5-10-10 in mid-July

established perennial beds* per 100 sq. ft.

2# of 5-10-5 or 5-10-10 in early spring
1 # of 5-10-5 or 5-10-10 in early June
½ # of 5-10-5 or 5-10-10 in mid-July

* Apply fertilizer to soil surface. Avoid fertilizer contact with plant foliage.
Carefully scratch fertilizer into the upper ½ - 1" of soil to avoid damaging plant roots.

J. Gruttadaurio and T. C. Weiler
FERTILIZING SPRING AND SUMMER FLOWERING BULBS
GENERAL FERTILIZER GUIDELINES
when soil test results are not available

Spring Flowering Bulbs

crocus, hyacinth, narcissus, tulips, snowdrops, squill, grape hyacinth, winter aconite, snowflake, bulbous iris

at time of planting apply per 100 sq. ft.
1# of 5-10-5 or 5-10-10
mix into upper 4-6" of soil

when plants flower* apply per 100 sq.ft.
2# of 5-10-5 or 5-10-10

Summer Flowering Bulbs

amaryllis, canna, dahlia, glads, German, Japanese or Siberian iris, lily

at time of planting apply per 100 sq. ft.
2# of 5-10-5 or 5-10-10
mix into upper 4-6" of soil

when plants flower* apply per 100 sq.ft.
1# of 5-10-5 or 5-10-10

established perennial bulbs* per 100 sq. ft.
1# of 5-10-5 or 5-10-10 in early spring
½ # of 5-10-5 or 5-10-10 in early June
¼ # of 5-10-5 or 5-10-10 in mid-July

* Apply fertilizer to soil surface. Avoid fertilizer contact with plant foliage.
  Carefully scratch fertilizer into the upper ½ - 1" of soil to avoid damaging plant roots.

T.C. Weiler and J. Gruttadaurio

Soils-MG/NYS 12.04
FERTILIZING TREES AND SHRUBS
GENERAL FERTILIZER GUIDELINES
when soil test results are not available

Fertilizer at Time of Planting

Trees and Shrubs

- avoid heavy use of inorganic fertilizer at this time
- after plants are established for one year broadcast:
  2# of 5-10-5/100 sq. ft or 1# of 10-10-10 sq. ft. on the soil surface over
  the root zone.

Maintenance Fertilizer

Rates

Roses

- apply 2# of 5-10-5/100 sq. ft. when new spring growth is established and the
  danger of freezing is past. A second application of 1# of 5-10-5/100 sq.ft.
  can be applied in June if plants show evidence of deficiency.

Small trees and shrubs after establishment

- apply 2# of 5-10-5/100 sq. ft or 1# of 10-10-10 per 100 sq. ft. over the root
  zones of plants.

Trees

- up to 4" in diameter*: broadcast 2# of 5-10-5 or 1# 10-6-4 per 100 sq ft. over
  root zone.

- 4" in diameter*: broadcast 2# of 5-10-5 or 1# 10-6-4 per inch of trunk diameter
  as subsurface application (see method of application information on next page).

  * measure tree diameter at 4 ½ ' tree height.

Ericaceae: Rhododendron, azalea, mountain laurel

- apply to soil surface 1# of ammonium sulfate per 100 sq. ft. at first signs of
  shoot growth. Split application if possible: ½ # at 1st sign of shoot growth and ½
  # in late May or early June.
Ericaceae: Rhododendron, azalea, mountain laurel – continued

- use commercial evergreen fertilizer if at least 1/3 of the nitrogen is in the ammonium form. Follow manufacturer's directions.

- if soil is very acid, at or below pH 5.0, conventional garden fertilizer can be used, i.e. 2# of 5-10-5 or 1# or 10-10-10 per 100 sq. ft.

Application Time

- If split applications are possible apply ½ the fertilizer in the spring when shoots become active and ½ in late May or early June.

- Do not fertilizer after July 1st.

- Fall fertilizer applications to small, shallow rooted trees and shrubs should be avoided, particularly on well drained soils.

- A fall application (late October, early November) can be made to large, more deeply rooted trees and shrubs when plants are dormant.

Application Methods

- Broadcast application: (scattering fertilizer over soil surface above the root zone) is beneficial to young trees, up to 4" in trunk diameter*. Apply water to move fertilizer off turf and into soil.

- Subsurface application: start 2½ ' from trunk, make holes at 18" intervals to a depth of 8-18". This is a useful application method for larger trees, above 4" in trunk diameter* when surface applications of fertilizer are in excess of what turfgrass can tolerate.

* measure tree diameter at 4½ ' tree height

G.L. Good and J. Gruttadaurio
FERTILIZER AND pH RECOMMENDATIONS FOR TREE FRUIT

<table>
<thead>
<tr>
<th>Time of Planting:</th>
<th>spring</th>
<th>Desirable pH*: 6.0 – 6.5</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>FERTILIZER AT PLANTING</th>
<th>MAINTENANCE FERTILIZER</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inorganic Fertilizer</strong></td>
<td><strong>Organic Fertilizer</strong></td>
<td><strong>Comments</strong></td>
</tr>
<tr>
<td>Tree Fruits</td>
<td>2 gallons starter solution: i.e. 20-20-20</td>
<td>Mix: 1/3 top soil 1/3 peat moss 1/3 well-rotted manure</td>
</tr>
<tr>
<td>Apple</td>
<td>2 gallons starter solution: i.e. 20-20-20</td>
<td>Mix: 1/3 top soil 1/3 peat moss 1/3 well-rotted manure</td>
</tr>
<tr>
<td>Plum</td>
<td>2 gallons starter solution: i.e. 20-20-20</td>
<td>Mix: 1/3 top soil 1/3 peat moss 1/3 well-rotted manure</td>
</tr>
<tr>
<td>Cherry</td>
<td>2 gallons starter solution: i.e. 20-20-20</td>
<td>Mix: 1/3 top soil 1/3 peat moss 1/3 well-rotted manure</td>
</tr>
</tbody>
</table>

*Liming material should contain 10% dolomitic lime. Use ammonium sulfate as the nitrogen source if pH is over 7.0.

^After leaf out apply ¼ " of calcium nitrate per tree. Apply 6" away from the tree.

**Broadcast fertilizer beneath the outer spread of the branches and somewhat beyond.  

Technical input provided by Warren Stiles
VEGETABLE GARDEN
DIAGNOSTIC INFORMATION SHEET

<table>
<thead>
<tr>
<th>Plants and Varieties</th>
<th>Crops</th>
<th>Site Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>□ not planted</td>
<td>size ___ sq. ft.</td>
</tr>
<tr>
<td></td>
<td>□ newly planted</td>
<td>□ mostly sunny</td>
</tr>
<tr>
<td></td>
<td>□ established</td>
<td>□ mostly shady</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ often wet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ often dry</td>
</tr>
</tbody>
</table>

Soil type: ______________________

<table>
<thead>
<tr>
<th>Last Application</th>
<th>Analysis/Kind</th>
<th>Rate/100 sq. ft.</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>lime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sulfur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fertilizer (list analysis)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>manure (fresh or aged) cow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>horse</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chicken</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>compost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>organic matter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wood ashes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Check: □ site and soil problems □ improper fertilizing practices
       □ varieties grown □ spacing
       □ pest problems: insects, diseases, weeds

Soils-MG/NYS 12.04
**HOME LAWN**
**DIAGNOSTIC INFORMATION SHEET**

<table>
<thead>
<tr>
<th>Turfgrass Use</th>
<th>Type of Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>□ general lawn mixture</td>
</tr>
<tr>
<td></td>
<td>□ Kentucky bluegrass mixture</td>
</tr>
<tr>
<td></td>
<td>□ Shady site mixture</td>
</tr>
<tr>
<td></td>
<td>□ Tall Fescue □ other: __________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plant Information:</th>
<th>Site Description:</th>
<th>Size: ______ sq. ft.</th>
<th>Soil Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ for establishment</td>
<td>□ mostly sunny</td>
<td>□ good drainage</td>
<td>□ sandy</td>
</tr>
<tr>
<td>□ for maintenance</td>
<td>□ mostly shady</td>
<td>□ poorly drained</td>
<td>□ loamy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age of Lawn:</th>
<th>Irrigation:</th>
<th>Clippings:</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ planted last year</td>
<td>□ none (only rainfall)</td>
<td>□ returned</td>
</tr>
<tr>
<td>□ 2-3 year old planting</td>
<td>□ occasionally</td>
<td>□ removed</td>
</tr>
<tr>
<td>□ more than 4 years</td>
<td>□ on schedule: ___ inches/week</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time of Seeding/Sodding:</th>
<th>Mowing Height:</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ early spring</td>
<td>□ 1/2&quot;</td>
</tr>
<tr>
<td>□ spring</td>
<td>□ 1-2&quot;</td>
</tr>
<tr>
<td>□ summer</td>
<td>□ 3&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Last Application</th>
<th>Analysis/Kind</th>
<th>Rate/100 sq. ft.</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>lime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ground limestone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pelletized lime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>other:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sulfur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>other:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fertilizer (list analysis)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note specific pests:**

<table>
<thead>
<tr>
<th>Occurrence: low, medium, high</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ insects:</td>
</tr>
<tr>
<td>□ diseases:</td>
</tr>
<tr>
<td>□ weeds:</td>
</tr>
</tbody>
</table>

Soils-MG/NYS 12.04 45
SUGGESTED LAWN FERTILIZER TREATMENTS
When soil test results are not available

Fertilizer for Starting a Lawn

The fertilizer used should have nutrients in 3:4:1 ratio or as recommended on soil test result sheets. For example: 18-24.6.

1. Apply the recommended fertilizer at a rate of 1# of nitrogen per 1000 sq. ft. This should be tilled into the seed bed. Early fall is the best time to seed a new lawn.

   AND

   Apply 1# of nitrogen/1000 sq. ft. 3-4 weeks after turfgrass germinates. Choose a fertilizer with a high percentage of nitrogen yet low in phosphorus, such as a: 4:1:2 or 6:1:3 ratio.

Fertilizer for Maintaining a Lawn

The fertilizer used should have nutrients in a 2:1:1 or 4:1:2 ratio or close to these ratios. For ex., 20-10-10, 10-6-4 (2:1:1 ratio) or 16-4-8, 20-5-10 (4:1:2 ratio).

2. Low maintenance lawn - usually fine fescue and shady sites.
   1# nitrogen/1000 sq. ft. Usually applied in early September.

3. Medium maintenance lawn - usually improved Kentucky bluegrass and turf-type perennial ryegrass.
   Apply per 1000 sq ft:
   - 1# of nitrogen in May
   - 1# of nitrogen in early September
   - 1# of nitrogen in late November after last mowing*

4. High maintenance lawn - usually improved Kentucky bluegrass.
   Apply per 1000 sq ft:
   - 1# of nitrogen in May
   - ½ - 1# of nitrogen in June
   - 1# of nitrogen in early fall
   - 1# of nitrogen in late November after last mowing*

Summer fertilizer should be in the slow release forms of nitrogen.

* For Long Island use slow release forms of nitrogen to minimize nitrate leaching.

J. Gruttadaurio and N. Hummel

Soils-MG/NYS 12.04
# Related Resources

## Soils and Fertilizers

<table>
<thead>
<tr>
<th>Title</th>
<th>Item Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Soil for Better Crops</td>
<td>125BSBC</td>
</tr>
<tr>
<td>Home Composting</td>
<td>123HCB</td>
</tr>
<tr>
<td>Composting to Reduce the Waste Stream: A Guide to Small Scale Food and Yard Waste Composting</td>
<td>123NRAES43</td>
</tr>
<tr>
<td>Cornell Field Crops and Soils Handbook</td>
<td>125CUFCHNBK</td>
</tr>
</tbody>
</table>

These titles are available for review and sale at The Resource Center's online bookstore: [www.cce.cornell.edu/store](http://www.cce.cornell.edu/store)

You may also order titles or a catalog by:
Phone: 607-255-2080
Fax: 607-255-9946
E-Mail: rescrt@cornell.edu

Or write:
The Resource Center
Cornell University
PO Box 3884
Ithaca, NY 14852-3884

These titles are also usually available through your local Cooperative Extension association office.
Cornell Website information on **Soils and Fertilizers**

All Cornell website information on gardening is accessible through the Cornell Gardening Resources Website [www.gardening.cornell.edu](http://www.gardening.cornell.edu)

The following are specific sections of the Cornell Gardening Resources Website as of Dec.15, 2004. New web pages are added regularly. Please check [www.gardening.cornell.edu](http://www.gardening.cornell.edu) periodically for updates and new information.

[http://www.gardening.cornell.edu/soils/index.html](http://www.gardening.cornell.edu/soils/index.html)

[http://mulch.mannlib.cornell.edu/](http://mulch.mannlib.cornell.edu/) (on soil health)

[http://www.hort.cornell.edu/soilhealth/](http://www.hort.cornell.edu/soilhealth/)

[http://www.hort.cornell.edu/uhi/outreach/csc/article.html](http://www.hort.cornell.edu/uhi/outreach/csc/article.html)

**Cornell Visual Presentation Resources in Soils and Fertilizers**

Master Gardeners may borrow resources from the Department of Horticulture’s Home Grounds and Community Horticulture Resource Library in Ithaca, NY. MG’s should discuss it with their county MG Coordinator and reserve a resource through that staff person. Resources in this library are slides, powerpoint CD-ROM’s and videos. They are generally used by Master Gardeners to make presentations to community groups as part of the county CCE’s educational mission. The ⚖ symbol means that it is appropriate for the Core Qualifying Course for Master Gardeners. The number preceding each resource is its library code number in Ithaca.

**SOILS**

76. **Soil Testing** Slide Set (39 slides & script) K. Brown, CCE/Erie Co.
145. **Soil Structure** Slide Set (from Soil Modification Module) (54 text and picture slides, with instructor’s outline) Urban Horticulture Institute, Cornell University
146. **Soil Texture** Slide Set (from Soil Modification Module) (28 text and picture slides, with instructor’s outline) Urban Horticulture Institute, Cornell University
147. **Drainage and Aeration** Slide Set (from Soil Modification Module) (32 text and picture slides, with instructor’s outline) Urban Horticulture Institute, Cornell University
148. **Soil pH** Slide Set (from Soil Modification Module) (11 text slides, with instructor’s outline) Urban Horticulture Institute, Cornell University
150. **Soil Contaminants** Slide Set (from Soil Modification Module) (30 text and picture slides, with instructor’s outline) Urban Horticulture Institute, Cornell University

V 25. ⚖ **Soil: Gardening at the Ground Level** Video, (120 min.) University of Wisconsin
V-26. **Support Your Local Tree – Cornell Structural Soil Mix** Video, (14 min.) Urban Horticulture Institute, Cornell University
V-33. **How Water Moves Through Soil** Video, (30 min.) University of Arizona

**FERTILIZING**

149. **Nutrient Management** Slide Set (In the Landscape) (from Soil Modification Module) (42 text and picture slides, with instructor’s outline) Urban Horticulture Institute, Cornell University
COMPOSTING


157. Organic Gardening Slide Set and CD-powerpoint (80 slides & script) Kelly Hennigan, Charles P. Mazza, Sally Jean Cunningham, Cornell University

CD-5 Organic Gardening CD-powerpoint -- 80 frames (images and/or text) & script – K. Hennigan, C. Mazza, S. Cunningham, Cornell University, 2001


V-29. It's Gotten Rotten Video & Teacher’s Guide, (20 min.) Waste Management Institute, Cornell University

V-30. Compost: Truth or Consequences Video, (15 min.) Waste Management Institute, Cornell University