Soils

chapter 2

UNIVERSITY OF WISCONSIN–MADISON • DIVISION OF EXTENSION
FOUNDATIONS IN HORTICULTURE

In a nutshell...

- Healthy soil makes for healthy plants.
- It is easier to adjust your plantings to fit the soil than adjust the soil to fit your plants. Understand your soil and learn how to get the most from it.
- Many common soil problems result from too much rototilling (ruining soil structure) or planting species that are poorly adapted to the soil's pH.
- Adding organic matter, like compost, is a good way to improve the chemical, physical, and biological properties of your soil.
- Check the resources at **hort.extension.wisc.edu** for issues not covered in this chapter.

MASTER GARDENER
UNIVERSITY OF WISCONSIN–MADISON
DIVISION OF EXTENSION

Introduction

Plants have the unique ability to make everything they need from water, light, air, and an adequate supply of 14 mineral nutrients. Soil is the primary source of most of these mineral nutrients. The soil in which a plant grows is a complex and fascinating ecosystem. Understanding how this living ecosystem works is vital for understanding how to get the most out of your garden.

Plants evolved to prefer certain soil conditions. For example, blueberries prefer strongly acidic soils, tomatoes prefer soils with relatively high levels of calcium, and willows thrive in wet soils.

There are many ways to manage and improve the soil for a specific type of plant. Some soil problems, however, require unreasonable costs or labor to solve. Understanding soils will allow you to know when it is best to change the soil to suit a plant or when choosing a different plant is the best option.

This chapter provides basic information about soils and the chemical, physical, and biological processes that affect plant growth. An understanding of soil and how it affects nutrient supply will help you select plants your soil can best support.

Learning objectives

1. Understand the chemical, physical, and biological properties of healthy soil.
2. Understand and explain a soil test report.
3. Describe how soils are formed, their composition, and how difficult it is to modify them.
4. Define pH, its significance to plants, and how it can be modified higher or lower for specific plant growth requirements.
5. Calculate fertilizer application rates to achieve the desired amount of nutrients for a given area.
6. List organic materials recommended as soil amendments.
7. Know how to improve heavy clay soils or dry sandy soils.

What is soil?

Soil is a complex system composed of mineral and organic material. The mineral material is better known as sand, silt, and clay, which are derived from rocks after millennia of physical, chemical, and biological weathering or breaking down.

Soil is much more than sand, silt, and clay, though. Organic matter usually makes up no more than 5% of the soils, but this material has a strong influence on the water and nutrient availability to plants. Organic matter is made of plant remains in various stages of decomposition, microorganisms and their waste products, and very highly decayed, stable organic material called **humus**.

Soil is teeming with microorganisms and provides optimum conditions for many chemical reactions important for plant growth to take place. Most soils are about 50% solid material (including sand, silt, clay, and organic matter) and 50% pore space. The arrangement of solids in soil determines how efficiently the pore spaces maintain a balance between air and water for successful plant growth. The pore spaces must be the right size and have a varied size distribution to allow water and air to flow through. Soils with plentiful populations of earthworms are often considered healthy because their burrows create large pores and allow air and water to rapidly enter the soil.

Soil formation

Soil is formed initially from the disintegration and decomposition of rocks by physical and chemical processes. The combination of freezing and thawing, wetting and drying, and soil organism activity accelerates the breakdown process. As organisms die, their residue becomes soil organic matter. Rain percolates downward, carrying dissolved substances and depositing them at different depths. These processes create distinct physical and chemical differences with soil depth.

Why is it important for a gardener to know about soil formation? Developing a picture of how the soil formed over thousands of years will help you understand why it has certain characteristics, how you can make improvements, and why soil resources need to be protected. There are five factors that work together to give the soil its characteristics.

1. **Parent material:** Yes, soil has a parent! Across most of the state, glaciers provided the original sediments that became our soil. Most areas adjacent to Lakes Superior and Michigan are dominated by heavy clay soils called *lacustrine* parent material. These clay soils were the result of large glacial lakes where the clay and fine sediments were the last particles to settle out of the water. The sandy soils in central Wisconsin were deposited by moving melt water called *outwash*. Most Wisconsin soils were deposited by the moving ice of glaciers and are called *ground moraines*. These soils can have a variety of sediments and often contain rocks of various sizes. Soils dominated by silts were most likely deposited by wind after the glacier retreated. Wind-deposited parent material is called *loess*. The various glaciers that moved through Wisconsin missed the southwest corner of Wisconsin, often called the driftless area. The parent material in these areas is called *residum* and is formed from weathered rock and sediment from before the glaciers.
2. **Geologic time:** Even though time itself doesn't affect soil, it's important to remember that soils develop over time—on a geologic scale, where time is measured in thousands of years. Many minerals migrate and change over time and may cause a soil's characteristics to change drastically.
3. **Climate:** Weathering occurs when soil is exposed to various climatic processes. Rainfall moving downward through soil leaches (or washes) minerals deeper within the soil. The expansion and contraction caused by freezing and thawing helps soil structure develop. Climate influences the amount of biological activity, which also impacts soil development. For example, desert or arctic soils develop very slowly because they occur in extreme climates.
4. **Biological activity:** Soil characteristics can be greatly influenced by the flora and fauna that live in and on the soil. The rich black color of topsoil comes from the organic matter (dead vegetation) that decomposes in the soil. In order for organic material to decompose, a healthy population of microbes—such as bacteria and fungi—must exist. The roots of plants also help the soil to develop by allowing

minerals to flow down the root channels into lower portions of the soil profile. Anyone who has seen tree roots growing through rock can see that roots help break the rock down to smaller-sized particles. Earthworms, gophers, voles, and various macro soil fauna are also great for mixing the upper part of the soil.

5. **Relief or topography:** Many gardeners know that a garden facing north is cooler and grows more slowly. Soil also develops differently on a north-facing slope. Soils on steep hillsides are usually thinner and less developed because of erosion. Conversely, soils in depressions have sediments deposited in them. The depth to groundwater can also impact the development of the soil by encouraging a different plant community.

All of these processes work together to help build a particular soil's characteristics. Since it takes thousands of years for the soil to develop, conserving the soil is critical. Allowing topsoil to erode and run off contributes to water pollution and washes away the nutrient-rich sediment necessary for plant growth and health. You'll find more information about soil conservation in the management section of this chapter.

Physical properties and characteristics of soil

There are more than 700 classifications of soils found in Wisconsin. Soils can vary locally in your town, village, or city. Even within your property boundaries the soil can vary greatly. In this section we will explore the various physical properties of the soil.

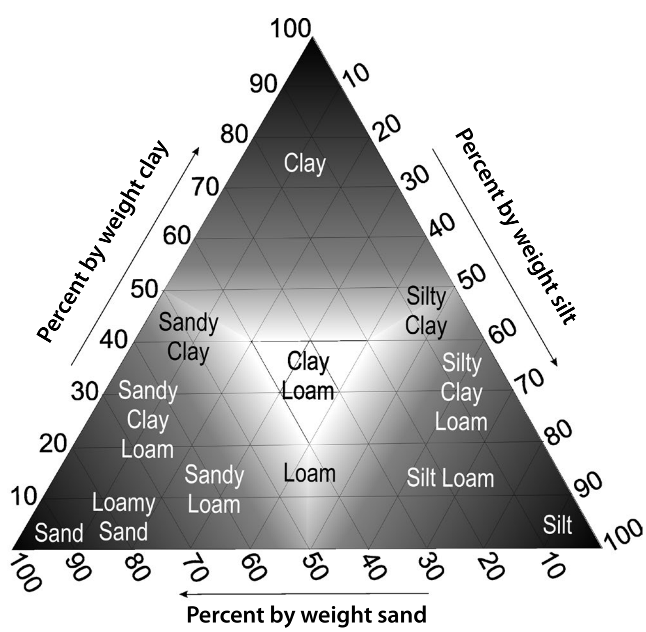
Texture

Soil texture refers to the predominant size or size range of particles and how the soil feels—coarse and gritty, or fine and smooth. Soil particles are usually divided into three classes: sand, silt, and clay. The proportion of these three size classes dictates the soil's texture. Soil texture greatly influences the ability to grow certain plants and also retain nutrients for plant growth.

Particle surface area determines the amount of available water and nutrients soil can hold. Smaller clay-sized particles have a large surface area. Sand and silt-sized particles have relatively small surface areas and substantially less ability to hold water and nutrients. While you may think you have a sense of your soil's general texture, many silty soils are mistaken for clays, and many clay-loam soils are mischaracterized as heavy clay.

The textural triangle (figure 1) shows all the major textural classifications. The texture of the soil can be determined by a laboratory test or field analysis. The laboratory test involves passing the soil through a series of sieves into three particle sizes. Field classification or analysis involves a visual examination and manipulation of the soil by hand to determine the soil's textural classification.

FIGURE 1. The textural triangle



Describing all the textural classifications is beyond the scope of this manual; however, the following provides a sense of the feel of the various soil particles. When feeling a soil's texture, start by wetting the soil and rubbing it between your thumb and forefinger.

- **Sand** is the largest soil particle and has a distinct gritty feel. You can also see the individual sand particles, which can be square and angular, or smooth and round.
- **Silt** is smaller than a sand particle and generally cannot be seen with the naked eye. It feels slippery or velvety when wet. Some people have described it as feeling like flour when rubbed between their fingers.
- **Clay** is the smallest of all the particles. It holds together well and feels stickier than the slippery feel of silt. Clays can be molded into various shapes that hold their shape. You can produce a ribbon when you rub a molded piece of clay between your forefinger and thumb.
- **Organic soils** are found in low areas where the groundwater table is high. Under saturated soil conditions, organic material degrades very slowly because of the lack of oxygen. This causes an accumulation of organic material as plants grow and die over the seasons. Peat and muck are the two types of organic soils. Peat soils will have recognizable plant materials, while muck soils are degraded to the point where you cannot identify the plant material. (Note: Organic material is found in most topsoil. To be classified as an organic soil, the soil must be dominated by organic material.)

The best way to learn how to determine the texture of soils in the field is to work with a mentor. You can also use a soil survey to locate soils with a known texture and learn by trial and error.

Soil structure

Soil structure is the arrangement or organization of particles in soil. Soil texture and surface area are relatively constant in a soil, but structure is highly dynamic. Structure provides space for air, which is essential for plant (root) respiration. Structure can change in response to natural conditions, management, and biological activity. Soil structure can in many ways determine how productive soil can be. In soils that have been compacted, air and water cannot reach the plant and this inhibits plant growth and health.

Typical soils have individual particles organized into small clods called **aggregates**. These aggregates can be described by shape and, like texture, can be divided into different categories. The more common categories are:

- **Granular** structure indicates a lot of organic matter in the soil and most often occurs in the uppermost horizon of the soil. It is characterized by pea-sized or smaller aggregates that have a granular shape.
- **Blocky aggregates** are larger and more angular than granular structure. They are more typically found lower in the soil horizon. The surfaces of blocky aggregates are often coated with clay minerals.
- **Prismatic** structures are elongated blocks oriented vertically in the soil profile. They are normally found below the topsoil.
- **Platey aggregates** are characterized by flat soil aggregates arranged horizontally in the soil profile. It is an indication that clay minerals, which are flat to begin with, have been deposited by water. A platey soil structure can impede water movement and cause a soil to be poorly drained.

In general, the finer spherical aggregates are typically found in topsoil and the larger, more massive blocky or prismatic aggregates are found in subsoil. The formation and stability of aggregates depend upon the type of clay and the presence of organic matter/microorganisms and iron/aluminum compounds, which form coatings around the particles and "cement" them into characteristic aggregate shapes.

Maintain good soil structure by avoiding soil loss and compaction. Heavy equipment, vehicles, or foot traffic can all cause significant compaction. The soil is particularly vulnerable to compaction when it is saturated, which is why you should never till when the soil is wet. Poor soil structure can cause a dense, impervious surface layer—or **hardpan** (a compact layer that occurs at the depth of the tilled layer)—to form. Such compact layers can be impenetrable to water, air, and plant roots, contributing to poor plant growth.

For most gardening situations, it is best to have well-drained soil. If you know a soil drains poorly, choose plants, such as cardinal flower, that are adapted to those conditions.

Soil color

The rainbow of colors found in soil can tell you many things about it. Black often indicates an accumulation of organic material. Black surface layers generally have at least 5% organic matter and lighter soil layers generally indicate progressively less organic material.

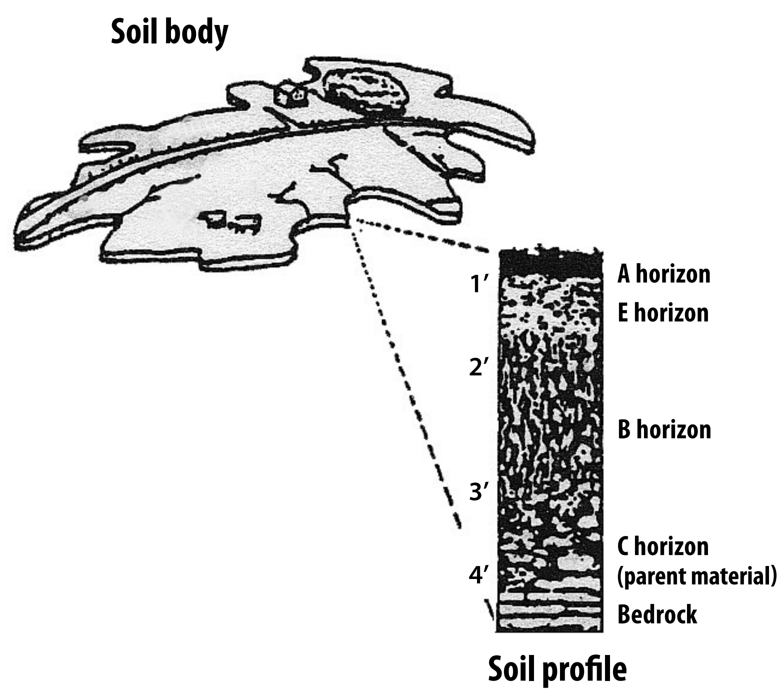
- Soil color can somewhat depend on the parent material. The minerals deposited by glaciers often dictate the soil's base color. For example, sandy outwash is often a characteristically tan color.
- Drainage conditions will change soil colors, as well. Iron minerals found in most soils will reflect periods of saturation in the soil by changing color. Mottles are blotches of color found on the surface of soil aggregates caused by poor drainage. Mottles are generally about the size of a dime, although they can be larger or smaller. Red mottling indicates that the soil containing the mineral is saturated for at least part of the year. Gray mottling is an indication that the iron-containing minerals are saturated for most of the year.
- A black color does not always indicate organic matter. Some soils contain "black sand" and are really a mineral soil with extremely poor fertility. Also, the color of clay soil is less affected by organic matter content than loamy soil.

Soil profile

Soil is three-dimensional, so it is important to explore more than the top few inches. A description of a soil profile is a compilation of all the physical characteristics of the soil. The soil is divided into distinct **horizons** that have distinctly different characteristics (see figure 2).

Soils in temperate areas, such as Wisconsin, are generally no more than five feet in depth. Below five feet, the soil becomes geologic material that has not developed structure and has not been influenced by the soil-forming factors. It may not be necessary to dig down five feet in your garden to learn more about the soil, but it might be a good idea to explore a few feet into the soil profile.

FIGURE 2. Relationship of soil horizons and profile to soil body



The following are some names and descriptions of common soil horizons:

1. The **O horizon** is dominated by degrading organic material in the top few inches of the soil. Earthworms and microorganisms are often found in this layer, mixing the soil and aiding in decomposition. Incorporate this horizon into lower horizons by tilling or plowing.
2. The **A horizon** also has a predominance of humus (decomposed organic matter) and, under optimal conditions, has a good granular structure. The parent material dictates the texture. The A horizon is generally no deeper than a foot.
3. The **E horizon** does not occur in all soils and only develops under certain circumstances. It is a zone of intense **leaching** and almost always occurs below a horizon with an accumulation of organic matter. As a result, these soils can have poor fertility. The color of an E horizon is light gray or even white. In most cases it will only be a few inches thick. This horizon is somewhat rare and only found in the sandy, forested soils of northern Wisconsin.
4. The **B horizon**, commonly called the subsoil by many gardeners, is generally located below the top soil (O, A, and E horizons). Don't ignore this zone of the soil—it contains many of the minerals needed for plant growth, which often accumulate from the upper layers through leaching. Many prairie plants are specialized with deep root systems to gain access to the minerals stored in the B horizon. If there are drainage problems, you may find gray or red mottling in this horizon.
5. The **C horizon** generally is unaltered parent material and contains little or no structure. It is extremely helpful in determining the origins of the soil. It is generally not important to plant growth because it is beyond the rooting depth of most species of plants. Bedrock, a type of parent material, is sometimes encountered in this horizon.

This is a summary of the physical characteristics of the soil. It is important to remember that the soil is a living ecosystem consisting of a variety of flora and fauna. Both microscopic and larger macro organisms—bacteria, fungi, molds, earthworms, centipedes, tree roots, gophers, and grubs—inhabit the soil and help influence its physical characteristics. While a few of these organisms are considered "pests," a healthy soil ecosystem includes a diversity of organisms.

Chemical properties and characteristics of soil

Essential plant nutrients

All plants require 17 chemical elements for life. These nutrients are literally vitamins for your plants. Table 1 lists all the essential nutrients necessary for plant growth. Carbon, oxygen, and hydrogen are the essential nutrients required in the largest quantity by plants. These three are obtained from the air and water (see chapter 1, Botany). The remaining 14 are provided mainly by the soil, and are called the essential mineral nutrients.

Primary mineral nutrients—nitrogen, phosphorus, and potassium—make up about 0.5 to 3% of the plant's weight and are most commonly in the shortest supply in the soil for optimum plant growth.

Nitrogen (N) is a necessary part of all proteins, enzymes, and metabolic processes in plants and, as part of chlorophyll, N is essential for photosynthesis. Nitrogen promotes vegetative growth.

- The primary source of nitrogen in the soil is the soil organic matter. Soils high in organic matter will require lower nitrogen fertilization.
- Nitrogen fertilizer is often very soluble in the soil and readily leaches downward and out of the root zone. As a result, it needs to be replenished more often than the other nutrients, especially in situations where more frequent watering is required, such as plants growing in containers, in sandy soil, or in very rainy weather.

TABLE 1. Essential plant nutrients

Type of nutrient/name	Chemical symbol	Primary sources
Structural nutrients		
Carbon	C	Air
Oxygen	O	Air and water
Hydrogen	H	Water
Primary nutrients		
Nitrogen	N	Organic matter, air
Phosphorus	P	Soil minerals, organic matter
Potassium	K	Soil minerals
Secondary nutrients		
Calcium	Ca	Soil minerals, limestone
Magnesium	Mg	Soil minerals, limestone
Sulfur	S	Organic matter, air
Micronutrients		
Boron	B	Organic matter, soil minerals
Chlorine	Cl	Rainwater, manure, fertilizer
Cobalt	Co	Soil minerals
Copper	Cu	Soil minerals, organic matter
Iron	Fe	Soil minerals
Manganese	Mn	Soil minerals
Molybdenum	Mo	Soil minerals, organic matter
Zinc	Zn	Soil minerals, organic matter

- Plants don't take up nitrogen as readily when soils are cool—around 55˚F or less—so early spring fertilization may be a waste because it will leach away from the roots before the plants can use it.
- Nitrogen is also very mobile in plants; when supplies are short, the nitrogen in older leaves will move to the younger, more actively growing leaves, where it is needed most. The older leaves will be paler in color as a result, which can tip you off to a nitrogen deficiency.
- Certain plants in the legume or Fabaceae family (peas and beans) are able to get nitrogen from the air with the help of special nitrogen-fixing bacteria in the soil. The bacteria, called *rhizobia*, fix the nitrogen from the air and the plant then absorbs the nitrogen from the bacteria. This is called a **symbiotic relationship**.

Phosphorus (P) is also necessary for photosynthesis and is involved in the formation of oils, sugars, and starches. It encourages flowering and root formation.

- Fertilizers with more phosphorus than nitrogen or potassium are used as so-called "blossom boosters." The same fertilizer can be used as a starter fertilizer when transplanting young herbaceous flowers and vegetables and on lawns to stimulate root production.
- It is very important to only apply phosphorus to your garden when a soil test indicates it is needed. Excess phosphorus that escapes from your garden may stimulate algae growth in lakes and rivers.

Potassium (K) is required in many processes, including photosynthesis and building proteins. It is absorbed by plants in larger amounts than any other mineral element except nitrogen.

In Wisconsin, soils are generally rich in phosphorus and potassium; most often nitrogen is the only primary nutrient that needs to be added. Test your soil to be sure!

Secondary nutrients—calcium, magnesium, and sulfur—are frequently found in sufficient amounts in the soil (or from the air for sulfur), so fertilization is not always needed for these elements.

Micronutrients are elements essential for plant growth that are needed in only very small (micro) quantities. These elements are sometimes called minor or trace elements, but the American Society of Agronomy and the Soil Science Society of America encourage the use of the term micronutrient. Similar to the secondary nutrients, soils almost always have sufficient supplies of micronutrients for plant growth. The lone exception is iron, which may be required when growing certain plants in high pH soils.

Soil fertility

Soil fertility is the quality that enables a soil to provide nutrients for plant growth. Although there may be sufficient quantities of nutrients in soil, they may not always be readily available for plant growth for a variety of reasons. The next few sections discuss how nutrients behave in the soils and their availability for plant growth.

Cation exchange capacity

Clay minerals and humus have negative electrical charges that can hold positively charged **cations**—nutrients plants depend on for optimal growth. Cations can be thought of as tiny storehouses where nutrients not used during one season can be saved until the next.

Negative charges attract and hold positively charged ions much like a magnet attracts and holds metal. Highly attracted cations such as calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), and ammonium (NH_4^{+}) do not leach easily from the soil, yet they are readily available to plants because they can be displaced or exchanged by other cations from the soil solution. For example, if potash is added to soils, the potassium ion will exchange places with calcium, hydrogen (H^{+}), or some other cation held on the clay surface. This process is identical to what takes place in a water softener. Hardness cations—Ca^{++}, Mg^{++}, Fe^{++} (iron)—are exchanged for Na^{+} (sodium). When the exchange resin in the softener becomes saturated with hardness ions, it is regenerated by displacement of those cations with Na^{+} from salt brine. This process is reversible.

The number of negative charge sites in a soil—and thus its ability to hold cations—is known as the soil's **cation exchange capacity** (CEC). The CEC of a soil can be used as an index of potential soil fertility. The higher the CEC, the more exchange sites—and the better able the soil is to hold and retain nutrients. A clay soil will generally be more fertile (with more available nutrients) than sandy soils. Sandy soils generally have a lower CEC because they contain very little clay or organic matter. It is not practical to build high levels of exchangeable potassium in such soils—the excess will eventually leach and be lost.

Negatively-charged nutrients, called **anions**, such as nitrate-nitrogen (NO_3-N) and sulfate-sulfur (SO_4-S), are not held on cation exchange sites and tend to remain dissolved in the soil solution. They are subject to leaching beyond the root zone to where they are no longer available to the plant root. Phosphorus, though negatively charged, reacts very strongly with iron and aluminum compounds in acid soils and with calcium compounds in neutral and alkaline soils. Over time very insoluble iron, aluminum, or calcium phosphates are formed. Phosphorus thus tends to become "fixed," which explains why it does not leach or move far from the point of application.

Nutrient availability

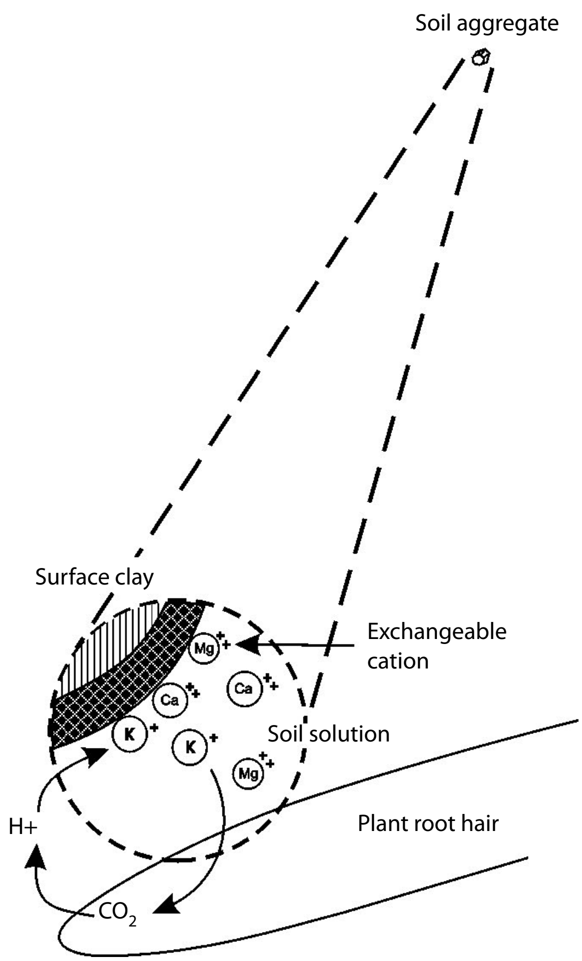
Root hairs formed at the tips of plant roots absorb nutrients from water surrounding the soil particles. All nutrients must be water-soluble in order for the root hairs to absorb them. The concentration of nutrients in soil solution is very low. If soil solution were the plant's only source of nutrients, most of the nutrient supply would be exhausted in a few days during the root hairs' active growth period. Fortunately, the nutrient supply in soil solution is rapidly replenished by cation exchange. In addition, decomposing organic matter also releases nutrients—especially nitrogen, phosphorus, sulfur, and micronutrients. New segments of root hairs take up nutrients in unexploited soil volume as plant roots grow and elongate.

Nutrients in the soil solution, soil minerals, and soil organic matter are in dynamic equilibrium, as illustrated in figure 3. A fertile soil can maintain an adequate concentration of all the essential elements in the soil's solution. Managing soil fertility for optimum plant growth should include determining what nutrients are needed and supplying them in adequate amounts. Taking soil samples for fertility testing is the only practical way to identify nutrient needs.

Organic matter

The average agricultural soil contains only 1 to 5% organic matter. However, this small fraction has a tremendous influence on the physical and chemical properties of the soil. Physically, organic matter helps to bind the individual soil particles into aggregates to give the soil structure. It does this directly by the action of root hairs and fungal mycelia (thread-like cellular projections), which proliferate in fertile soil. Indirectly, microorganisms feeding on soil organic matter secrete gums that also act as cementing agents. A soil with a crumb-like structure has good **tilth**, which permits rapid water infiltration, good aeration, and easy root penetration.

FIGURE 3. Uptake of nutrients from the soil solution by a plant root hair



Organic matter consists of plant and animal residues in various stages of decay, living microbial cells and the residues of dead ones, and decomposition products of plants and animal residues. After organic matter has undergone considerable alteration and decomposition, there remains a complex, dark-colored, semi-stable product known as humus. Humus, which is chemically very reactive, is dark colored in soils high in organic matter.

Adding organic residue improves both the physical conditions and physical characteristics of soils. Soil organisms such as bacteria and fungi secrete sticky, glue-like substances that bind individual microscopic soil particles into aggregates.

- In heavier or finer-textured soils this means that these "crumbs" are better able to resist compaction and don't break down easily when wet. Because of crumb stability, the larger pore spaces between them are better able to drain excess water and provide better aeration to roots.
- In coarser-textured or sandy soils, the effects of added organic residues result in greater water holding capacity because the organic matter tends to act like a sponge.

Chemically, organic matter serves as a storehouse and plant nutrient source. As fresh organic matter decays, the nutrients contained are released in an inorganic form for plant use. Because of the decay process, new surfaces are created that attract and hold inorganic nutrients such as potassium, calcium, magnesium, and several trace elements.

Acidity

Soil acidity influences many of the chemical and biological processes taking place in the soil and, thereby, affects the availability of most of the essential nutrients. Soil acidity is measured in pH units on a scale of 1 to 14, with 7 being neutral (pure water has a pH of 7).

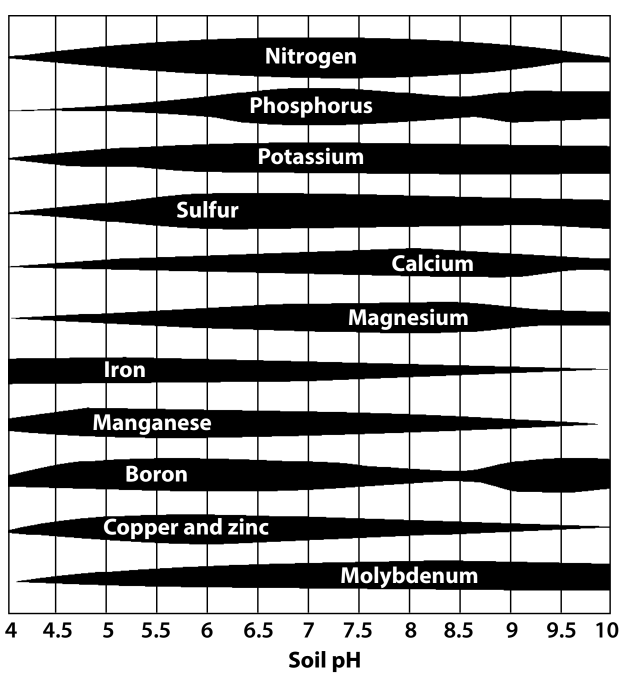
- Acidic soils have pH values less than 7.
- Alkaline soils have pH values more than 7.

Each unit change in soil pH represents a tenfold change in acid concentration. For example, a soil at pH 5 is ten times as acidic as one with a pH of 6. Changing soil pH can have dramatic effects on the availability of nutrients for plant use (figure 4). Change in nutrient availability with pH is related to the chemical form of the nutrient and its ability to "fix" to soil surfaces.

Most flowers, vegetables, and ornamental plants grow best in slightly acidic soil (pH 6 to 7). Controlling soil acidity creates a better environment for soil microorganisms, which are responsible for decomposing plant residue and more active in slightly acidic to neutral soil. Liming acid soils can result in faster release of nutrients in crop residue and better soil structure. It also reduces the possibility of aluminum and manganese toxicity in acid soils. Over-liming, however, can induce deficiencies of iron, manganese, boron, and zinc in soils already low in these nutrients, or in plants sensitive to high pH.

FIGURE 4. The relationship between soil pH and nutrient availability

Note: Bar width represents relative nutrient availability

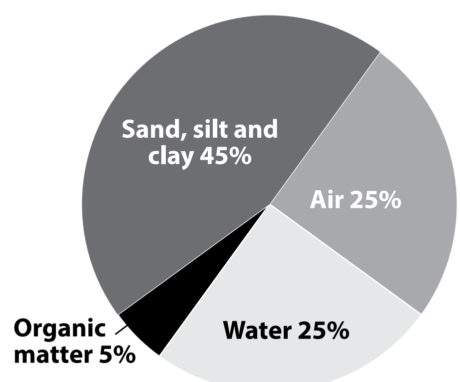


Soil management

Every gardener wants the ideal **loam** soil with roughly equal parts sand, silt, and clay. We also want the perfect proportions of air, water, organic matter, and minerals (figure 5). However, nature rarely provides us with these ideal conditions. You CANNOT change some of the basic soil characteristics—like texture—but you can wisely manage and improve any soil.

Exploring and characterizing the soil is the first step in managing any soil. Hopefully, this chapter has provided you with information and curiosity to explore and characterize the soil in your garden. The next step is to develop a management scheme that will optimize growth and maintain healthy plants.

FIGURE 5. The ideal soil



Before you do anything, think about which plant or types of plants you want to grow. Many plants will thrive in multiple soil conditions; a few, however, have very specific requirements.

- Some plants are heavy feeders, while other plants will not do well if provided with excess nutrients.
- Some plants prefer acidic soils, while others prefer a higher pH or basic soil.
- Some plants like poorly drained soils, while others thrive in dry sandy soil.

Whenever possible, try to match a plant to its preferred soil conditions. For example, blueberries—which are best adapted to grow in sandy, acidic soils—are not recommended for clay soils with a pH of 8 or more because you simply cannot adjust and maintain the necessary pH of 5 on these soils.

Soil lead contamination

Sometimes soils are contaminated with substances that can cause harm. For example, many urban soils contain hazardous levels of lead. Lead was an ingredient in paint and additive to gasoline in the 20th century, and therefore soils near roadways and houses constructed prior to 1980 often contain elevated levels of lead. Lead is one of the top environmental hazards to children, and even small amounts can cause problems. Inhaling dust in the air or ingesting soil from hands or food is the primary source of exposure. Soils with over 200 ppm total lead should not be used for gardening. Soils with elevated lead levels should be covered with sod or mulch to prevent exposure. It is a good practice to always have the soil tested for lead before beginning a garden in an urban setting. For more information on soil lead and other contaminants of soils, consult *Soil Contaminants in Community Gardens* (Extension publication A3905-03).

Soil sampling

The only way to know your garden's fertility is with a **soil test**. A soil test is a rapid chemical analysis to determine relative nutrient availability to plants. Results of the test indicate where potential deficiencies of specific nutrients may occur and also which are in excess. Once you've made some preliminary decisions about what you want to grow, you can proceed to sample your soil.

Generally, you should sample your soil every 3 to 4 years or whenever your plants are showing signs of nutrient deficiency. It is especially important to take a sample before you plant a new bed because pH adjustments are easier to achieve when you can incorporate the lime or acidifier into the soil. County Extension offices provide soil sampling materials. You can find specialty soil-sampling tools for home gardeners online and in stores, but they aren't necessary.

Sampling Lawn and Garden Soils for Soil Testing contains directions for sampling the soil (Extension publication A2166). It is important to sample each garden area separately because the fertilizer recommendation differs depending on the type of plants being grown. Lawns require substantially more nitrogen than a perennial border garden or vegetable garden, for example. Specialty plants like blueberries or azaleas will most likely require a much different pH adjustment. The recommendations based on soil analysis can be no better than the sample taken, so be sure your sample represents the average fertility of the area.

Collect a composite soil sample from any individual garden to compensate for variations within the garden. You can use a shovel or trowel to collect the sample in the root zone at a depth of 4 to 6 inches. Use a bucket and mix the soil from at least five different locations within the garden thoroughly in the bucket. Fill a sample bag with the mixture from the bucket.

FIGURE 6. Sample soil test report

Samples Analyzed By:
UW Soil & Plant Analysis Lab
8452 Mineral Point Road
Verona, WI 53593
(608) 262-4364

SOIL TEST REPORT
LAWN & GARDEN

Lab Number: 12345 **Date received:** 3/12/2004 **Account:** 556996 **Client:** B. A. Gardener
123 Crabgrass Lane
Anytown, WI 53700

County: Dane **Date processed:** 3/24/2004

Send to:

B. A. Gardener
123 Crabgrass Lane
Anytown, WI 53700

Area Type
Garden/Vegetable

Area Designation
Front

RECOMMENDATIONS

Lime to Apply

Apply 13.6 lbs/100 sq-ft (13.6 cups) of finely ground limestone. Broadcast and incorporate into the upper 6 to 8 inches of soil. It is impractical to adjust soil pH when permanent plantings are already established. If lime has been applied in the last 2 years, more lime may not be needed due to incomplete reaction.

Fertilizer to Apply

The following summary specifies the actual amount of nutrients needed based on the results of your soil analysis. Most plants require at least an annual nitrogen application, but recommended potash should be split over two years and soils retested in 2-3 years to determine if more is needed.

Actual Nutrient Need (lbs/100 ft^2)

Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)
0.30	0.0	1.0

These nutrients can be applied using many different products including commonly available turf fertilizer materials. The following suggestions are provided for your reference. Avoid 'weed and feed' or crabgrass inhibitor fertilizer types.

Nitrogen: Needed nitrogen will be supplied with the phosphate and/or potash recommendations below.

Phosphate: No phosphate fertilizer needed. Excessive phosphorus is not detrimental to plant growth but may contribute to surface water pollution.

Potash: Apply 2.5 lbs of winterizer turf fertilizer per 100 sq-ft annually for 2 years to meet plant potash needs.

Use of winterizer turf fertilizer will increase available potassium to a level optimum for plant growth and supply some needed nitrogen. For a description of fertilizer grades please see http://uwlab.soils.wisc.edu/pubs/grades.pdf

Cultural and Management Tips

Soil tests indicate that potash fertilizer is needed. Broadcast and incorporate recommended materials into the upper 6-8 inches prior to planting or topdress to previously established areas and water in thoroughly.

Leafy vegetables, sweet corn, tomatoes, and vine crops may require additional nitrogen at flowering. Place about 1 oz (2 Tbl) urea or 4 Tbl of a high nitrogen turf fertilizer in a band at least 3 inches from the plant. Use 1.5 lbs (3 cups) urea or 3 lbs (6 cups high nitrogen turf fertilizer) for every 100 ft or row.

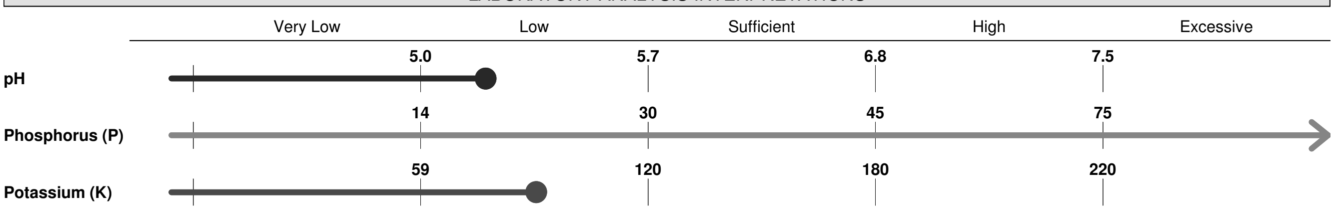
If growing a scab susceptible variety of potato a lower pH is desired. For additional information contact your County Extension Office.

References and Resources

For additional information on garden fertilization please see http://uwlab.soils.wisc.edu/gardens.htm

For further explanation please contact your County Extension Office.

LABORATORY ANALYSIS INTERPRETATIONS



LABORATORY ANALYSIS

Sample	pH	Phosphorus [P] (ppm)	Potassium [K] (ppm)	Organic Matter %
1	5.2	182	90	2.1

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The soil sample(s) should be mailed to a state-approved soil analysis laboratory. The University of Wisconsin Soil and Plant Analysis Lab routinely tests soils for pH, "buffered" pH, organic matter content, available phosphorus, and potassium. The report includes the results and interpretations for these tests and recommendations for additional lime, nitrogen, phosphate, and/or potash, if needed. Once you have received the test results (figure 6) you can finalize your planting plans, adjust your pH and nutrients, and select your plants.

You can also sample plant materials showing signs of nutrient deficiencies. Nutrient deficiency causes a variety of symptoms in plants, including stunting, poor yields, curling leaves, and discoloration. Plant tissue sampling is the only way you can analyze most micronutrients.

Make sure you are not confusing the symptoms of a nutrient deficiency with disease, insect, or cultural problem. **Chlorosis**, for example, is a common symptom that manifests as a yellow discoloration of the leaves or other plant parts, but many fungal diseases also cause a similar discoloration.

If you suspect your plants are suffering from a nutrient deficiency, take a soil sample, adjust the soil pH if needed, and add the necessary primary nutrients. Adjusting the pH will address most secondary and micronutrient deficiencies. If the symptoms persist, it is time to work closely with your local Extension office to diagnose and manage the problem.

pH adjustments

Once you have a soil test report in hand you can follow the directions and make the necessary adjustments. Adjusting the pH of the soil will maximize the availability of the nutrients. Whether you need to increase (through liming) or decrease (through sulfur amendments) your soil's pH depends on the plants and initial water pH reading.

If soils have a pH less than optimum for the identified plants, the soil test report will recommend an application of lime.

- The most common liming material in Wisconsin is crushed dolomite limestone. The finer the lime particle, the faster it will react.
- In Wisconsin, the particle size is indicated by the neutralizing index (NI). Select the 70-79 or 80-89 NI grade for maximum efficiency.

It is very important to plan ahead—preferably at least a year in advance—when adjusting soil pH as it takes time for the lime to react with the soil and accomplish the desired change.

The sample soil test report indicates that 13.6 pounds of lime per 100 square feet should be incorporated into the soil. Use finely ground 80-89 dolomitic limestone for the best results. One pound is equal to 1 cup of limestone. One hundred square feet is equal to a 10 x 10-foot garden area (see box).

The sample report calls for 13.6 pounds of lime per 100 square feet; with a 300 square-foot garden you should multiply by 3 to find the amount you need: 3 x 13.6 = 40.8 pounds of lime.

To effectively apply lime, it needs to be evenly spread and incorporated—or tilled—into the top 6 to 8 inches.

- It is not practical to change the pH of a soil by **topdressing** lime on the surface of the soil. The lime must come in contact with the soil particles in order to change the soil pH.
- If it is absolutely necessary to change the pH of a soil in an established perennial bed or lawn, the best solution is to remove the plants, mix the lime and soil, and replant.

Many garden plants are somewhat tolerant of alkaline soil conditions. However, you may need to acidify your soil, particularly if you are growing acid-loving plants like azaleas, blueberries, or roses. The same principles apply to acidification as applying lime: Your goal, however, is to lower the soil pH.

Calculate your garden's size

Calculate the number of square feet in an area by multiplying the width by the length of your garden.

For example, for a vegetable garden measuring 15 feet by 20 feet:

15 x 20 feet = 300 square feet

There are several types of acidifying materials that can be used.

- Elemental sulfur is the most effective at changing the soil pH. However, elemental sulfur takes 3 to 4 months to react with the soil to change the pH and can also cause damage or burning to nearby plants and foliage. Elemental sulfur can also be difficult to find. If using elemental sulfur, you should plan a year in advance so that the sulfur will have time to react with the soil.
- Aluminum or iron sulfate will react more quickly, but you must apply six times more than the amount of elemental sulfur you would need. Two cups of aluminum or iron sulfate equals one pound: use the same procedure as for lime to calculate the amount of aluminum or iron sulfate to apply.
- Liquid acidifiers will provide some immediately available nutrients to acid-loving plants, but are not practical for changing soil pH and should not be used for these purposes.

The heavy clay soils of eastern Wisconsin are not easily acidified, because they are buffered by the minerals found in the clay. It may not be practical to grow acid-loving plants in those areas.

Nutrient management

Your soil report will include any recommendations for nutrient additions. Because adjusting the soil pH will solve most secondary and micronutrient deficiencies, the report only addresses the primary nutrients of nitrogen (N), phosphorus (P), and potassium (K).

The soil report will always recommend that nitrogen be added to the soil, because nitrogen is continually depleted through decomposition, plant uptake, and leaching. The other nutrients will be held by the cation exchange sites and should only be added if they have been depleted or are reported as low or very low.

Most Wisconsin soils already contain enough phosphorus for plant growth, particularly if any organic material has been added. Phosphorus can be depleted, however, so don't guess—soil test!

The soil test report uses the most common soil fertilizers available at most garden centers. Fertilizers recommended are based on "turf blends" and may include maintenance or regular (high nitrogen), starter (high phosphate), and/or winterizer (high potassium), depending on the plants being grown and available phosphorus and potassium soil test levels. The sample soil report shows that the soil is deficient in potassium, and the recommendations are listed by category of fertilizer.

You can determine the amount of any of the nutrients in a fertilizer by looking at the label. By law all fertilizers list the amount of nutrients by giving three numbers separated by hyphens: 10-5-5. The first number contains the percent nitrogen (N)—our example contains 10% nitrogen. The second and third numbers indicate the percent phosphorous (P) and potassium (K), respectively. Thus, 10 pounds of a 10-5-5 fertilizer would contain 1 pound of nitrogen, ½ pound of phosphorus (phosphate), and ½ pound of potassium (potash). The remaining ingredients are inert materials that make the fertilizer easy to apply.

Different plants have differing nutrient needs, and it is extremely important that you indicate the types of plant you are growing on the sample information page. NEVER apply more nutrients than are called for by the test report. This can cause plants to become stressed or even die.

- Many gardeners have learned the hard way and applied too much lawn fertilizer or fresh manure, which burned or killed their plants.
- Too much fertilizer can cause excessive vegetative growth and poor flower or vegetable production.

Excessive nutrients, particularly nitrogen and phosphorus, are also bad for the environment and water quality.

- Phosphorus should be used judiciously because it causes excessive algae and weed growth. In Wisconsin, phosphorus fertilization of lawns is prohibited unless a soil test indicates a need for the nutrient. While phosphorus has not been restricted for gardens, the same principle should be followed.

- Excessive additions of nitrogen, particularly in sandy soils, can leach into groundwater and contaminate the aquifer.

Organic fertilizers

Some people prefer to use only organic sources of fertilizer. From a scientific standpoint, the nitrogen found in a commercial grade of fertilizer is no different from the nitrogen found in manure. There are, however, benefits of using strictly organic sources of nutrients:

- Organic sources are inherently slow release. Many of the nutrients are locked in the decaying organic material and are released over the course of the season as the material decomposes (some commercial brands of fertilizer also have slow release properties).
- Organic sources of primary nutrients (N-P-K) also contain many of the micronutrients that may be lacking in the soil (particularly coarse-textured, sandy soils).
- Organic sources of nutrients also improve soil structure and water-holding capacity. Organic matter will also improve the drainage in a heavy clay soil and a sandy soil's ability to hold water. The ideal soil contains 5% organic matter, which helps keep the amount of air and water in the proper balance. Since organic matter is constantly degrading, it also needs to be replenished in order to maximize this benefit.
- Organic sources of nutrients degrade slowly into humus. Humus helps improve the cation exchange capacity by adding more negatively charged sites. This will improve the ability of the soil to retain nutrients for plant growth.

The major disadvantage of organic sources of nutrients is that it generally requires large quantities of materials to provide the optimum amount of nutrients. Table 2 lists the amount of nutrient from various organic sources. As an example, it takes approximately 15 times the amount of horse manure to provide the same amount of nutrients as a 10-10-10 fertilizer. For quicker uptake, many gardeners get good results by applying organic nutrients throughout the growing season in the form of manure or compost teas (see chapter 3, Composting).

Another concern about adding too much organic matter with a lot of carbon is causing an imbalance between carbon and nitrogen (see chapter 3, Composting). Excessive carbon will cause the nitrogen to be tied up in the soil and not available for plant growth. To avoid this problem, make sure that any organic material is sufficiently degraded (composted) before you apply it to plants. Also, do not apply anything to the soil that is difficult to degrade, like wood chips or sawdust. Deciding to use strictly organic, strictly synthetic, or a combination is a personal decision that each gardener must make. There is no right or wrong answer. For more information on organic gardening approaches, see chapter 17, Organic Gardening.

TABLE 2. Nutrient content (%) of organic fertilizers

Fertilizer	N	P_2O_5	K_2O
Blood meal	13	1.5	0.6
Bone meal	2.2	27	0
Leaf mold	0.7	0.1	0.8
Cow manure	0.6	0.6	0.5
Pig manure	0.5	0.4	0.5
Horse manure	0.7	0.3	0.5
Poultry manure	1.0	0.9	0.5
Rabbit manure	2.4	1.4	0.6
Compost	1.8	1.3	1.1
Lawn clippings	1.2	0.3	2.0
Wood ash	0.0	2.0	6.0

A water-soluble balanced blend fertilizer is best used for annual beds and containers.

Ornamental annuals require lots of nutrients to achieve optimal bloom in a short amount of time. A water-soluble fertilizer can provide the necessary nutrients immediately. A balanced blend, such as a 10-10-10, would provide the levels of N-P-K to promote blooms with the annuals.

Woody plants and turf are perennials with cyclic growth periods. Having a constant, low level concentration of nutrients (mostly N) in the form of slow-release or organic fertilizer is optimal for their needs and minimizes the negative environmental impacts with leaching and runoff.

Other management considerations

Compaction

For healthy plants, avoid compacting your soil. Compaction inhibits root growth, eliminates vital air spaces, and can impede proper drainage. The best way to avoid compacting your soil is to avoid equipment or foot traffic when the soil is saturated. Once compacted, you should allow your soil to thoroughly dry and then re-till the soil. Adding additional organic matter will also improve the structure and rebuild the soil's tilth.

Drainage

Most plants require good drainage for optimal growth. This is particularly important for root crops like potatoes. Farmers often use drain tiles to remove excess water from fields, which is generally not practical for the small gardener or homeowner.

There are two strategies to address drainage problems.

- You can use plants that are adapted to poorly drained soils, such as cardinal flower or willows.
- You can use raised beds (see chapter 9, General Gardening Practices).

When using raised beds, avoid drastic changes in soil texture at the base of the raised bed—where it meets the native soil—as this can cause problems with water movement from one zone to another. Simply till or otherwise incorporate the raised bed soil into the native soil surface to avoid this.

Growing on shallow bedrock

Shallow soil on bedrock is another common problem in parts of Wisconsin, particularly in Door County. Bedrock can limit the growing space or rooting zone for many vegetables and flowers.

There are two strategies to address this problem.

- Use raised bed techniques to deepen the amount of soil in the root zone.
- Grow plants that are adapted to shallow bedrock conditions. There are many fascinating alpine plants that are adapted to growing in such conditions. Some gardeners even go to great lengths to artificially create alpine conditions in their gardens.

Conclusion

Understanding and managing your soil resources is an important part of any successful horticultural endeavor. The soil is the foundation for what you grow. Being a good steward of your soil resources is also better for the environment and water quality.

Knowing your plant's needs by taking a soil test and applying only those necessary nutrients is a good step toward being a successful gardener. Another important step is providing everything necessary to have a healthy soil ecosystem. Adding organic matter will encourage this living ecosystem by providing the fuel for its growth and health. In turn, you will have healthier and more productive plants.

Resources

Wisconsin Horticulture publications are available at hort.extension.wisc.edu.

FAQs

Why should I bother doing a soil test?
Doing a soil test provides a picture of where the soil is currently at in terms of basic nutrients. This allows you to use the right amount of fertilizer. Excess fertilizer is a waste of money and can run off to pollute waterways.

Should I add lime (epsom salts, wood ash, compost, grass clippings, oak leaves, leaf mold, fertilizer, etc.) to my garden?
Addition of lime (or any soil amendment) should be based on the results of your soil test.

I never did a soil test and my garden does just fine…why start now?
Perhaps you could do better. Perhaps you are spending more on fertilizers than necessary. Perhaps you could have a more productive garden. Perhaps your garden is decreasing in fertility or micronutrients and you don't know it. Perhaps you are contributing to nitrogen and phosphorus runoff. Knowledge is power!

Soils, practice exam questions

(Answers below)

1. **Which of the following is a true statement regarding soils:**
   a. Soils form quickly
   b. Soils do not change
   c. Soils form over a long time and are influenced by many factors
   d. None of the above
2. **A soil's texture is primarily determined by:**
   a. The amount of organic matter in the soil
   b. The soil's pH
   c. The ratio of sand, silt, and clay making the soil
   d. Soil aggregates
3. **An ideal, healthy soil is:**
   a. Approximately 50% pore space
   b. Approximately 45% mineral component
   c. Roughly equal ratios of water and air
   d. All of the above
4. **Properties of a compacted soil include:**
   a. Reduced pore space
   b. Poor ventilation
   c. Difficult for roots to grow
   d. All of the above
5. **A general soil test will determine:**
   a. The amount of N present in your soil
   b. The amount of P and K present in your soil
   c. Diseases in your garden
   d. All of the above
6. **Soil particles can be divided into three size classes which include all of the following except:**
   a. Clay
   b. Organic matter
   c. Sand
   d. Silt
7. **Incorporating organic matter into the soil:**
   a. Can improve soil structure
   b. Add micronutrients
   c. Improve water holding capacity in sandy soils
   d. All of the above
8. **A water soluble balanced blend fertilizer is best used:**
   a. To fertilize established trees and shrubs
   b. For fertilizing lawns at major holidays
   c. For ornamental annual beds and containers
   d. All of the above
9. **Which of the following statements is false regarding a routine soil test?**
   a. Lawn should be a separate test from vegetable garden
   b. Multiple cores need to be taken from an area and combined for a single sample
   c. Test will determine pathogens in the soil
   d. Compacted soils are not determined
10. **Which of the following statements is false?**
    a. Nitrogen promotes leafy growth in plants
    b. Phosphorous will lower soil pH
    c. A balanced fertilizer is equal parts NPK
    d. Nutrient leaching can be problematic on sandy soils
11. **Primary plant nutrients include:**
    a. Nitrogen, Phosphorus, Potassium
    b. Calcium, Magnesium, Sulfur
    c. Boron, Chlorine, Copper
    d. Sand, silt, clay
12. **When compared to a 5lb bag of 28-2-15 slow release lawn fertilizer, a 5lb bucket of cow manure most likely:**
    a. Has more nitrogen
    b. Has less nitrogen
    c. Is a source of organic matter
    d. B+C
13. **For most garden plants, the ideal soil pH is:**
    a. Around pH 5.5
    b. Around pH 6.8
    c. Around pH 8.5
    d. Around pH 9.0

Answer key: Soils

1. (c) 2. (c) 3. (d) 4. (d) 5. (b) 6. (b) 7. (d) 8. (c) See sidebar, page 43 9. (c) Pathogens must be tested for through the Disease Diagnostic Clinic and may be difficult to culture from soil 10. (b) Aluminum and sulfur type products can be used as acidifiers to lower soil pH 11. (a) 12. (d) B+C (Has less nitrogen and is a source of organic matter) 13. (b)