MASTER GARDENER
COLORADO STATE UNIVERSITY
EXTENSION

CMG GardenNotes #210-251

Soils, Fertilizers, and Soil Amendments

Soil Horizons with Worms
Artwork by Melissa Schreiner © 2023

This Soils, Fertilizers, and Soil Amendments curriculum was developed by David Whiting, CSU Extension, retired; Carl Wilson, CSU Extension, retired; Catherine Moravec, former CSU Extension employee; and Jean Reeder, PhD, USDA-ARS, retired. Cover art by Melissa Schreiner. Used with permission.

Updated 2023

MASTER GARDENER
COLORADO STATE UNIVERSITY
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CMG GardenNotes #210

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References and Review Material

Reading/Reference Materials

CSU GardenNotes

- https://cmg.extension.colostate.edu/volunteer-information/cmg-gardennotes-class-handouts/.
- #211, *Introduction to Soils.*
- #212, *The Living Soil.*
- #213, *Managing Soil Tilth: Texture, Structure, and Pore Space.*
- #214, *Estimating Soil Texture: Sandy, Loamy, or Clayey.*
- #215, *Soil Compaction.*
- #218, *Earthworms.*
- #219, *Soil Drainage.*
- #221, *Soil Tests.*
- #222, *Soil pH.*
- #223, *Iron Chlorosis of Woody Plants.*
- #224, *Saline Soils.*
- #231, *Plant Nutrition.*
- #232, *Understanding Fertilizers.*
- #233, *Calculating Fertilizer Application Rates.*
- #234, *Organic Fertilizers.*
- #241, *Soil Amendments.*
- #242, *Using Manure in the Home Garden.*
- #243, *Using Compost in the Home Garden.*
- #244, *Cover Crops and Green Manure Crops.*
- #245, *Mulching.*
- #246, *Making Compost.*
- #251, *Asking Effective Questions About Soils.*

CSU Extension Fact Sheets

- https://extension.colostate.edu/topic-areas/yard-garden/.
- #0.501, *Soil Testing*.
- #0.503, *Managing Saline Soils.*
- #0.504, *Managing Sodic Soils*.
- #0.520, *Selecting an Analytical Laboratory.*
- #0.521, *Diagnosing Saline and Sodic Soil Problems.*

- **Recommendations for plants that tolerate high alkaline/high pH soils:**
    - #7.220, *Colorado Gardening: Challenge to Newcomers*.
    - #7.421, *Native Trees for Colorado Landscapes*.
    - #7.422, *Native Shrubs for Colorado Landscapes*.
    - #7.214, *Mulches for Home Grounds.*

Plant*talk* Colorado™

- https://planttalk.colostate.edu/.

Learning Objectives

At the end of this training, the student will be able to:

- Describe characteristics of a typical landscape soil and how it differs from native or agricultural soils.
- Describe how soil organisms directly and indirectly benefit the soil and plant growth.
- Describe management practices effective in nurturing soil organisms.
- Describe the relationship between soil texture, structure, pore space, and tilth.
- Describe effective management practices for sandy soils, clayey soils, and decomposed granite rocky soils.
- Describe effective management practices to prevent and reduce soil compaction.
- Describe considerations in selecting soil amendments.
- Describe considerations in selecting mulch.
- Describe considerations in selecting appropriate fertilizers.

Review Questions

Introduction To Soils

1. Explain how soils may vary horizontally and vertically. Describe characteristics of the A, B, and C soil horizons.
2. Describe how landscape soils differ from agricultural and native soils.
3. Describe the typical percentage of air, water, organic matter, and mineral solids for a native soil. How does this change for a compacted landscape soil?

The Living Soil

4. Describe how organisms directly benefit the soil and plant growth.
5. Describe how organisms indirectly benefit the soil and plant growth.
6. Should gardeners inoculate their soil with rhizobia, mycorrhizae, and decomposers?
7. What makes up the soil organic matter? Define humus.
8. How does a gardener enhance the living soil? How can a gardener damage soil life?

Managing Soil Tilth

9. Define the terms soil texture, soil structure, and soil profile. Explain how they are interrelated.
10. Describe characteristics of the following soil types:
    - Coarse-textured, sandy soil.
    - Fine-textured, clayey soil.
    - Gravelly and decomposed granite soils.
11. Explain what is significant about large pore spaces and small pore spaces.
12. Describe how water moves through small pore spaces and large pore spaces.

13. In relation to root growth, air infiltration, and water movement, what happens when the soil has a texture interface?
14. Explain management of fine-textured clayey soils, coarse-textured sandy soils, gravelly and decomposed granite soils.

Soil Compaction

15. Describe soil compaction in terms of pore space, water movement, and air infiltration.
16. List techniques to prevent soil compaction. List techniques to mitigate soil compaction.

Soil Drainage Problems

17. Describe drainage problems as related to pore space, surface runoff, and leaching.
18. Why is it important to identify the causes of a drainage problem before attempting corrections?
19. List common causes of surface drainage problems with possible corrective actions. List common causes of sub-surface drainage problems with possible corrective actions.

Soil Tests

20. List situations when a soil test would be helpful. List examples of plant growth problems for which a soil test would not be helpful. Which nutrient is typically not accurately measured on a single soil test?
21. Describe the steps to a soil test.
22. Where does one find a list of soil testing laboratories?

pH and Iron Chlorosis

23. What does soil pH measure? What is an acceptable range for most plants? What are the implications for gardening in Colorado?
24. Describe the function of the free lime vinegar test. Can the pH of an alkaline soil be effectively lowered?
25. Describe the symptoms of iron chlorosis. What other situations can be confused with iron chlorosis? How can you tell them apart?
26. List primary factors that contribute to iron chlorosis.
27. What simple method identifies soils prone to iron chlorosis problems?
28. Describe the limitations and application criteria for the following iron treatments:
    - Soil applications of sulfur.
    - Soil applications of iron sulfate plus sulfur.
    - Soil applications of iron chelates.
    - Foliar sprays.
    - Trunk injections.

Saline Soils

29. Describe plant problems associated with excess soil salt levels.
30. List sources/causes of high soil salts.
31. Describe the leaching process for salty soils. What about situations when excess salts cannot be leached out?
32. Describe other management strategies for salty soils.

Plant Nutrition

33. Define plant nutrient and fertilizer.
34. Will the addition of nitrogen fertilizer help plant growth when soil compaction is the limiting factor? Explain.
35. What are the typical symptoms of nitrogen deficiency? What are the problems associated with excessive nitrogen fertilization?

36. In Colorado soils, under what situations will phosphorus levels likely be adequate and likely be deficient? How does one determine the need for phosphate fertilizer?
37. In Colorado soils, under what situations will potassium levels likely be adequate and likely be deficient? How does one determine the need for potash fertilizers?

Fertilizers

38. Define the following terms: organic fertilizer, certified organic fertilizer, and soil amendment.
39. What does grade or analysis indicate about a fertilizer? What is the fertilizer ratio?
40. What is a fertilizer formulation? What is a complete fertilizer? When applying a complete fertilizer, what is the application rate always based on?
41. What is the routine application rate for nitrogen fertilizer? How does it change based on soil organic matter? What is the routine application rate when using these fertilizers?
    - Ammonium sulfate, 21-0-0.
    - Ammonium nitrate, 34-0-0.
    - Urea, 45-0-0.
42. Address your answers relative to phosphorus water pollution. What happens to phosphate fertilizers applied 1) to a lawn or garden area, and 2) over-spread onto the street, sidewalk, or driveway? What is the major source of phosphate water pollution from the landscape setting?

Soil Amendments

43. Explain the differences between soil amendments, mulch, and compost.
44. Explain how organic soil amendments improve a clayey soil and a sandy soil.
45. Describe considerations in selecting a soil amendment as it relates to the following:
    - Desired results.
    - Potential for routine application.
    - Longevity.
    - Salt.
46. What is the routine application rate for soil amendments? What is a precaution about adding additional amounts?
47. Explain the use and limitations of using manure as it relates to:
    - *E. coli.*
    - Nitrogen release rates.
    - Salt.
    - Weed seeds.
48. What are cover crops and green manure crops? List benefits of cover-cropping and green manuring.

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CMG GardenNotes #211

Introduction to Soils

Outline:

Soil Attributes

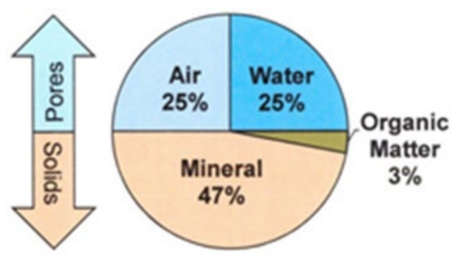
What is soil? Gardeners know that soil is more than simply broken up rocks. Rather than being an inert unchanging material, soil is a dynamic living substance in which complex chemical and biological reactions are constantly occurring.

According to the Soil Science Society of America, soil is defined as, "…the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants..." Unconsolidated materials are loose materials composed of multiple units (e.g., sand, gravel, etcetera.) unlike hard, massive materials like rock. Effective gardeners manage soils to produce healthy and resilient plants.

Soil contains a variety of substances. In a well-managed western soil, usually around 50% of the soil's volume is composed of solid particles, while the other 50% is empty space. Soil scientists refer to these empty spaces as "pores." [**Figure 1**]

Most of the solid particles are derived from mineral sources such as decomposed rocks or sediments. 1 - 5% of the soil's volume is organic matter - plant, animal, and microbial residues in various stages of decomposition. [**Figure 1**]

Figure 1.
A well-managed Western soil has 25% air, 25% water, 1-5% organic matter and 45-49% mineral solids.



The empty space between the solid particles can be occupied by water, air, or a combination of both. In a well-managed soil, about 25% of the soil's volume is air, while the remaining 25% is occupied by water. This combination of components provides a healthy environment for roots to grow.

Soil Forming Factors

Soils vary across the landscape. A Colorado gardener may have noticed substantial differences between the soil in his or her yard compared to their neighbor's soil. In Colorado, there are many diverse types of soils ranging from heavy clays to sands or decomposed granite.

The factors that cause variation in soils in different locations are referred to as soil forming factors. Soil scientists recognize five soil-forming factors, including:

- Parent material.
- Climate (precipitation, temperature, wind).
- Topography.
- Biological organisms.
- Time.

These factors differ in subtle and complex ways over the surface of the earth to create an infinite array of soils.

The term **parent material** refers to the starting material for a soil. It consists of specific minerals (or organic materials) from which a soil is formed. The mineralogy of the parent material has a significant effect on the mineralogy and properties of the soil.

Climatic factors influence soil formation in several ways. First, precipitation and temperature cause weathering of rocks. In dry climates like Colorado (unlike warm, moist climates), wind is often more important than water in weathering rocks and transporting parent materials. Second, climatic factors often transport parent materials over long distances. Sometimes the parent material for a soil is *residual*, meaning it disintegrated in place to form soil. In other cases, the parent material is *transported* by water (rivers and streams), wind, gravity, or glaciers. As with weathering, wind is the primary means of transport in Colorado. Once the parent materials land on a stable surface, the process of soil formation can begin. The presence or absence of biological organisms can determine how long it takes to create different soil horizons (see below). The characteristics of the resulting soil will depend on the interaction of the remaining four soil forming factors on the parent material. Together, these factors act over thousands of years to form soil.

Soil Variation

Soils are three-dimensional entities. Soil not only varies across the landscape, but also varies vertically with depth. Gardeners will notice changes in soil color, physical properties, and chemical properties as they dig deeper. Over time, the soil-forming factors change the undifferentiated parent material into a vertically differentiated soil. Soil scientists recognize **horizons**, or horizontal layers within a soil. Horizons are identified by letter codes. They may blend gradually or have abrupt borders between layers. [**Figure 2**]

A Horizon (also referred to as "topsoil")

The A horizon is usually the surface horizon. This is an area of high biological activity with the greatest organic matter content. It is also a zone of leaching. As precipitation enters the A horizon, it dissolves soluble soil organic compounds and minerals. These dissolved compounds are then moved downward through the soil profile. Most plant roots are found in the A horizon.

B Horizon (also referred to as “subsoil”)

The B horizon lies underneath the A horizon. This layer usually contains less organic matter than the surface layer, but accumulates the dissolved materials leached from the A horizon (clays, iron oxides, aluminum, and dissolved organic compounds). For this reason, the B horizon typically contains more clay than the surface layer. The accumulated products in the B horizon increase over time as the soil forms.

C Horizon

The C horizon contains unconsolidated material that has been minimally affected by the soil forming factors. It lies beneath the B horizon and may or may not be the same as the parent material from which the soil formed.

Figure 2. Soil Profile

A Horizon
- High biological activity.
- Greatest organic matter.
- Leaching zone.
- Largest concentration of roots.

B Horizon
- Lower biological activity.
- Accumulated dissolved materials.
- More clay than A Horizon.

C Horizon
- Unconsolidated material.
- Not impacted by soil-forming factors.
- May or may not be the parent material form which the soil is formed.

Landscape Soils

Landscape soils differ significantly from agricultural or native soils. **Landscape soils** are soils that are found in a typical neighborhood community around homes, parks, schools, offices, parking lots, and buildings. Soil scientists often refer to landscape soils as “urban” soils.

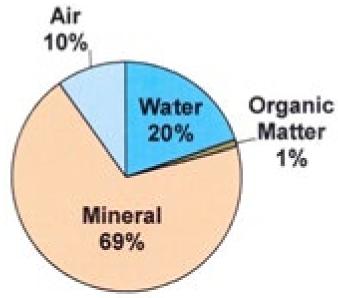
During the construction process, soils in communities are often graded by moving large volumes of soil. This process often removes the A horizon, taking with it most of the organic matter. Furthermore, when construction workers drive large pieces of equipment over soil it becomes compacted. Thousands of years of soil development can be destroyed in minutes with a bulldozer and other soil moving equipment in a construction site.

Sometimes construction debris, such as wood, trash, drywall, bricks, asphalt, or concrete, is buried in the soil during construction. Other possible landscape soil changes include increased variability, increased surface crusting, increased pH, decreased drainage, decreased soil microbial activity, and increased soil temperature. All these factors can cause problems when managing soils around buildings.

Native, undisturbed soils typically have well defined A, B, and C horizons. In compacted landscape soils, the horizons are scrambled and not defined, organic content is low, and air and water movement are reduced.

In comparison, the compacted unamended landscape soil typically has 10% air, 20% water, 1% organic matter and 69% mineral solids. The most significant aspect of the compacted landscape soil is the reduction in air. Low soil oxygen is the most common limiting factor of plant (root) growth. [**Figure 3**]

Figure 3.
A typical compacted, unamended landscape soil has 10% air, 20% water, 1% organic matter, and 69% mineral solids.



Soil conditions contribute to many plant problems. What can the gardener do?

1. Understand soils as a living ecosystem. Nurture soil organisms by providing their food source (organic matter) and improving aeration and drainage (oxygen and water). For additional information, refer to CMG GardenNotes #212, *The Living Soil*.

2. Understand the soil physical properties of texture, structure, and pore space as they relate to soil tilth. Compaction is a reduction in total pore space, but more importantly, compaction is a major reduction in large pore space where the air is located. Gardeners will be more successful in soil management by understanding what properties can be changed and what properties cannot be changed. For additional information, refer to CMG GardenNotes #213, *Managing Soil Tilth*: *Texture, Structure, and Pore Space*.

In summary, soils are important to gardeners because it strongly influences plant growth. In Colorado, soils vary horizontally across the landscape and vertically with depth. In addition, landscape soils may vary considerably from agricultural and native soils. Landscapers and gardeners must take these changes into account when developing a soil management plan.

Authors: Catherine Moravec, former CSU Extension Employee; David Whiting, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised October 2015 by Dan Goldhamer, CSU Extension. Reviewed August 2022 by Dan Goldhamer, CSU Extension, and Cassey Anderson, CSU Extension.

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CMG GardenNotes #212

The Living Soil

Outline:

Soil Organisms Improve Garden Tilth

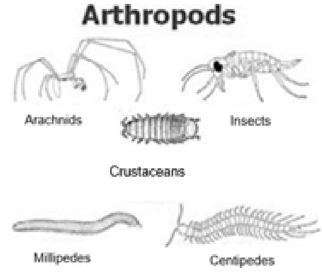
Rather than being an inert material, soil contains a dynamic living ecosystem. The 1-5% **organic matter found in soils includes living organisms**. Soil is thought to have the most biodiverse ecosystems, with only about 1% of the organisms being identified. Although most soil organisms are invisible to the naked eye, they help gardeners in multiple ways. One major benefit to gardeners is their ability of soil organisms to improve soil tilth. Soil **tilth** is the suitability of a soil to support plant growth, especially as it relates to ease of tillage, fitness for a seedbed, impedance to seedling emergence and root penetration. Soil organisms also play a significant role in making nutrients available to plants. The community of soil organisms is varied, versatile, and adaptable to changing conditions and food supplies.

Types of Soil Organisms

Soil contains an enormous number of living organisms. One cup of undisturbed native soil may contain:

Organism	Number
Bacteria	200 billion
Protozoa	20 million
Fungi	100,000 meters
Nematodes	100,000
Arthropods	50,000

Arthropods



Insects by Bob Hammon

Other organisms that can be found in the soil include earthworms and algae. Soil organisms are naturally active during certain times of the year. Most are active when the soil is warm and moist, like during late spring and early summer. If the soil dries out during the summer months, soil organism activity naturally declines. During fall, if there is rain or snow that moistens the soil while it is still warm, soil organisms may resume partial activity. As the soil cools in the fall, many soil organisms go dormant. Gardeners should note that fertilizers that require processing by soil organisms will be more available to plants when the soil is warm and moist and less available when the soil is cool or dry.

Despite their small size, soil organism activities have a large influence on plant growth. Soil organisms can be grouped into three categories:

1. Organisms that are **beneficial** to plants - directly or indirectly.
2. **Neutral** organisms - those whose activities have no effect on plants.
3. Organisms that are **harmful** to plants. Harmful organisms are often described as **pathogens**, such as the soil fungi that cause wilt diseases, or **plant pests**, such as white grubs that feed on plant roots.

Directly Beneficial Soil Organisms

Some soil organisms have a close, mutually beneficial (**symbiotic**) relationship with plants. Two examples include rhizobia and mycorrhizae. **Rhizobia** are bacteria that form symbiotic associations with legumes such as beans and peas. The bacteria form nodules on the roots of the host plant in which they fix nitrogen gas from the air. Rhizobia supply the plant with nitrogen and in turn the plant supplies the bacteria with essential minerals and sugars. It may be helpful to add Rhizobia in the first planting of beans and peas in a soil area. Afterwards they will be present.

Mycorrhizae are formed by symbiotic relationships of specific fungi with plant roots. Found in most soils, mycorrhizal fungi are very host specific (i.e., each plant species has specific species of mycorrhizal fungi associated with it).

The Latin word *mycor* means fungus and *rhiza* means root. The terms “mycorrhiza” (singular) or “mycorrhizae” (plural) refer to the tissue that forms when fungi and roots develop a mutually beneficial relationship. Enlarging the surface-absorbing area of the roots by 100 to 1,000 times, mycorrhizae create filaments or threads that act like an extension of the root system. This makes the roots of the plant much more effective in the uptake of water and nutrients such as phosphorus and zinc. In exchange, the fungus receives essential sugars and compounds from the roots to fuel its own growth. Some types of mycorrhizae can be seen on roots, while most are invisible to the naked eye.

Mycorrhizae improve plant health. They enhance the plant’s ability to tolerate environmental stress (like drought and dry winter weather) and reduce transplant shock. Plants with mycorrhizae may need less fertilizer and may have fewer soil borne diseases.

A by-product of mycorrhizal activity is the production of **glomalin**, a primary compound that improves soil tilth. In simple terms, glomalin glues the tiny clay particles together into larger aggregates, thereby increasing the amount of large pore space, which in turn creates an ideal environment for roots. For additional details, refer to the U.S. Department of Agriculture web site at https://agresearchmag.ars.usda.gov/2002/sep/soil.

Mycorrhizal cocktails are sometimes incorporated in planting or post-planting care of trees and landscape plants. However, results have been mixed from studies that *add* mycorrhizae to the soils to benefit plants (as opposed to naturally occurring mycorrhizae). Over time, additional research will help clarify what procedures result in improved plant health and vigor.

Indirectly Beneficial Soil Organisms

In addition to directly beneficial organisms such as rhizobia and mycorrhizae, there is a large portion of soil organisms whose activities indirectly help plants. Soil organisms collectively decompose organic matter, resulting in two principal benefits.

First, as soil organisms decompose organic matter, they transform nutrients into mineral forms that plants can use; thus, this process is called **mineralization**. Without soil microorganisms, insects, and worms feeding on organic matter, the nutrients in organic matter would remain bound in complex organic molecules that plants cannot utilize.

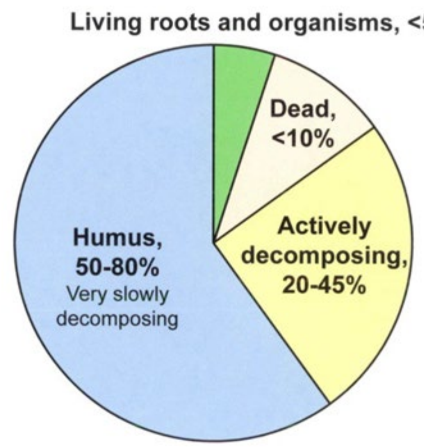
Second, as soil organisms break down organic matter, their activities help improve soil structure. Improved soil structure provides a better environment for roots, with less soil compaction and better water and air movement. Many gardeners know that organic matter improves soil, but it is important to note that its beneficial properties are only released *after* being processed by soil organisms.

Soils naturally contain these decomposers. Adding decomposers to the soil or compost pile is not necessary. Rather, the gardener should nurture them with food (organic matter) and good aeration and drainage (air and water).

Soil Organic Matter

Soil organic matter is composed of a wide variety of organic substances. Derived from plants, animals, and soil organisms, the soil organic matter "pool" can be divided into four categories. [**Figure 1**]

Figure 1. Make-Up of Soil Organic Material



First are the living organisms and roots, making up less than 5% of the total pool.

Second are the residues from dead plants, animals and soil organisms that have not yet begun to decompose (<10%).

Third is the portion undergoing rapid decomposition (20-45%).

Humus is the fourth. It is the stabilized organic matter remaining after further decomposition by soil microorganisms (50-80%).

The stabilized organic matter, or humus, is the pool of soil organic matter that has the longest lasting benefits for gardeners. After rapid decomposition occurs, a mix of stable, complex organic compounds remains, which decomposes slowly over time (about 3% per year). Humus is a mix of tiny solid particles and soluble compounds. While it is too chemically complex to be used by most organisms, it has great benefits for soil properties and thus plants. Humus contains a potpourri of sugars, gums, resins, proteins, fats, waxes, and lignin. This mixture plays a significant role in improving the physical and chemical properties of soil.

Humus improves the physical and chemical attributes of soil in several ways, including the following:

- Humus improves soil structure by binding or "gluing" small mineral particles together into larger aggregates creating large soil pores for improved air and water infiltration and movement.

- Humus improves water retention and releases it to plants.
- Humus slowly releases nitrogen, phosphorus, and sulfur over time, which plants then use for growth and development.
- Because of its positive surface charge, humus improves soil fertility by retaining nutrients.
- Humus buffers the soil pH, so it remains stable for plant roots.
- Humus can chelate or bind metals in soil, preventing metal toxicities.

As a point of clarification, garden stores sometime carry soil amendments labeled as “humus.” These are generally compost and do not meet the soil scientist definition of humus as given here.

Soil Inoculation

Gardeners can purchase products at garden centers that are intended to introduce soil organisms to an existing soil. Adding decomposing bacteria from a purchased product is not necessary because decomposing soil organisms are already present in the soil. Even if their populations are low due to unfavorable conditions, as soon as organic matter and water become available, their populations rapidly increase. Thus, soil biologists encourage gardeners to nurture existing communities rather than introducing external organisms through purchased products.

In addition, inoculating with rhizobia is generally not needed, unless a vegetable gardener is planting a leguminous crop for the first time. In this case, the gardener should purchase the appropriate inoculant (bacteria) for the leguminous vegetable being planted. Inoculation in future years is not needed, because rhizobia produce survival structures to over-winter.

Mycorrhizal products are not recommended by CSU Extension for general use. While there is ongoing research into mycorrhizal amendments for very specific objectives (e.g. native soil restoration, or nursery production of native plants), studies show mycorrhizal inoculation is unnecessary and ineffective in most landscapes.

Soil Food Web

Within the soil, organisms’ function within an ecological food web (the smaller becoming the food for the larger) cycling nutrients through the soil biomass. This soil food web is the basis of healthy, living soil. Significant soil organisms involved in the soil food web include bacteria, fungi, protozoa, nematodes, arthropods, and earthworms.

Bacteria – are simple, single-celled microorganisms. Bacteria inhabit a wide variety of habitats, including soil. In fact, a teaspoon of productive soil can contain from one hundred million to one billion bacteria. Soil-inhabiting bacteria can be grouped as decomposers, mutualists, pathogens, or chemoautotrophs. Bacteria that improve soil quality feed on soil organisms, decompose organic matter, help keep nutrients in the root zone, enhance soil structure, compete with disease-causing organisms, and filter and degrade pollutants in soil.

Fungi – are a diverse group of multi-cellular organisms. The most known fungi are mushrooms, molds, and yeast, but there are many others that go unnoticed, particularly those living in soil. Fungi grow as long strands called hyphae (up to several yards long), pushing their way between soil particles, rocks, and roots. Fungi can be grouped as decomposers, mutualists, or pathogens. Fungi that improve soil quality decompose complex carbon compounds; improve accumulation of organic matter; retain nutrients in soil; bind soil particles into aggregates; compete with plant pathogens; and decompose certain types of pollution.

Protozoa – are microscopic, single-celled microbes that primarily eat bacteria. The bacteria contain more nitrogen than the protozoa can utilize, and some ammonium (NH_4) is beneficially released to plants. Protozoa also prevent some pathogens from establishing on plants and function as a food source for nematodes in the soil food web.

Nematodes – are small, unsegmented round worms. Nematodes live in water films in the large pore spaces in soil. Most species are beneficial, feeding on bacteria, fungi, and other nematodes, but some cause harm by feeding on plant roots. Nematodes distribute bacteria and fungi through the soil as they move about. Predatory nematodes can consume root-feeding nematodes or prevent their access to roots.

Arthropods – in the soil are small animals such as insects, spiders, and mites. They range in size from microscopic to several inches in length. Most live near the soil surface or in the upper three inches. Arthropods improve soil quality by creating structure through burrowing; depositing fecal pellets; controlling disease-causing organisms; stimulating microbial activity; enhancing decomposition via shredding organic matter and mixing soil; and regulating healthy soil food web populations.

Soil arthropods can be *shredders* (millipedes, sowbugs, etc.), *predators* (spiders, scorpions, pseudoscorpions, centipedes, and predatory mites, ants, and beetles), *herbivores* (symphylans, root-maggots, etc.), or *fungal-feeders* (springtails and turtle mites). Most soil-dwelling arthropods eat fungi, worms, or other arthropods.

Earthworms – come in three types, two of which live in Colorado soils. Earthworms digest micro-organisms and organic matter. Refer to CMG GardenNotes #218, *Earthworms* for more information.

Ways to Encourage Beneficial Soil Organisms

Creating a favorable environment for soil organisms improves plant growth and reduces garden maintenance. Encouraging their efforts is central to building healthy fertile soil supportive to optimum plant growth. Suggestions for aiding soil organisms include:

- **Add organic matter to the soil.** Soil organisms require a food source from soil amendments (compost, crop residues) and/or mulch.
- **Use organic mulch.** It stabilizes soil moisture and temperature and adds organic matter. Mulches may help prevent soil compaction and protect soil oxygen levels needed by soil organisms and roots. **NOTE:** The term ***mulch*** refers to material placed on the soil surface. A mulch controls weeds, conserves water, moderates soil temperature and has a direct impact on soil microorganism activity. ***Soil amendment*** refers to materials mixed into the soil.
- **Water effectively.** Soil organisms require an environment that is damp, like a wrung-out sponge, but not soggy, between 50°F to 90°F. Soil organism activity may be reduced due to dry soil conditions that are common in the fall and winter. Avoid over-irrigation because water-logged soils will be harmful to beneficial soil organisms.
- **Avoid unnecessary rototilling**, as it will destroy the mycorrhizae and soil structure. Instead of tilling, mulch for weed control.
- **Avoid unwarranted pesticide applications.** Some fungicides, insecticides and herbicides are harmful to various types of soil organisms.
- **Avoid plastic sheets under rock mulch.** This practice discourages microorganism activity by reducing water and air movement and preventing the incorporation of organic matter.

Authors: Catherine Moravec, former CSU Extension employee; David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised October 2015 by Susan Carter, CSU Extension. Reviewed October 2022 by Sarah Schweig, CSU Extension.

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MASTER GARDENER
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CMG GardenNotes #213

Managing Soil Tilth:
Texture, Structure, and Pore Space

Outline:

Soil Tilth

The term soil ***tilth*** refers to the soil's general suitability to support plant growth, or more specifically to support root growth. Tilth is technically defined as the physical condition of soil as related to its ease of tillage, fitness of seedbed, and impedance to seedling emergence and root penetration.

A soil with good tilth has large pore spaces for adequate air infiltration and water movement. (Roots only grow where the soil tilth allows for adequate levels of soil oxygen.) It also holds a reasonable supply of water and nutrients.

Soil tilth is a function of soil texture, structure, fertility, and the interplay with organic content and the living soil organisms that help the soil ecosystem.

Gardening in Colorado can be a challenge due to poor soil tilth. Sandy soils hold little water and nutrients. Along Colorado's Front Range, many soils are clayey and compact readily. These soils may have poor drainage, which may lead to salt problems. Due to low soil oxygen levels, root systems are typically shallow, reducing the crop's tolerance to drought and hot windy weather.

Special attention to soil management is the primary key to gardening success. While gardeners often focus their attention on insect and disease problems, a large number of plant problems begin with soil conditions that reduce the plant's vigor.

Gardeners often address the soil's nutrient content by applying fertilizers. However, fertilization is only one of the keys to a productive garden.

Managing Soil Tilth

Gardening on Coarse-Textured, Sandy Soils

The major limitation of sandy soil is its low capacity to hold water and nutrients. Plants growing on sandy soils do not use more water; they just need to be irrigated more frequently but with smaller quantities. Heavy irrigation wastes water because it readily leaches below the root zone. Water-soluble nutrients, such as nitrogen, also leach below the rooting zone with excessive irrigation or rain.

The best management practice for sandy soils is routine applications of organic matter. Organic matter holds ten times or more water and nutrients than sand. Sandy soils with high organic matter content (4-5%) make an ideal gardening soil.

Gardening on Fine-Textured, Clayey Soils

The limitations of clayey soils arise from a lack of large pores, thus restricting both water and air movement. Soils easily waterlog when water cannot move down through the soil profile. During irrigation or rain events, the limited large pore space in fine-textured soils quickly fills with water, reducing the roots' oxygen supply.

The best management practice for clayey soils is routine applications of organic matter and attention to fostering the activity of soil microorganisms and earthworms. As soil microorganisms decompose the organic matter, the tiny soil particles bind together into larger clumps or *aggregates*, increasing large pore space. This improvement takes place over a period of years. A single large application of organic matter does not do the trick.

A gardener may start seeing improvement in soil conditions in a couple of years as the organic content reaches 2-3%. As the organic content increases, earthworms and soil microorganisms become more active; this over time improves soil tilth. The ideal soil for most gardens has 4-5% organic matter. However, some native and xeric plants do not like this high organic content, having evolved for poor soils.

Take extra care to minimize soil compaction in soils. Soil compaction reduces the large pore space, restricting air and water movement through the soil, thus limiting root growth. <u>Soil compaction is the primary factor limiting plant growth in landscape soils.</u> Soils become compacted during home construction and need to have organic material added over several years to develop its tilth.

Gardening on Gravelly and Decomposed Granite Soils

Soils in Colorado foothills and mountains change with topography and precipitation. Soils may be well developed with organic matter on north and east facing slopes and in valley floors, but on dryer south and west facing slopes soils are often shallow and extremely low in organic matter.

Gardening in the gravelly and decomposed granite soils, common to many foothills and mountain areas, may be extremely challenging. Large rocks, erratic depths for bedrock, little organic matter, pockets of clayey soil and rapid drainage with poor water holding capacity characterize these coarse textured soils. They erode readily once disturbed.

If the soil has been disturbed with the surface layer removed, decomposed granite soils will benefit from organic matter. Add up to 25% by volume. For example, if tilling to a depth of eight inches, add two inches of compost or other organic materials. If only tillable to a depth of four inches, add one inch of compost. Use well decomposed materials. In some situations, mixing in the organic matter may be very labor intensive or impossible.

When Soil Amendment Is Not Practical Or Possible

In real world settings, the ideal approach of improving soils by adding soil amendments may not be practical or possible. For example:

- In existing landscapes, it is easy to add amendments to annual flower beds and vegetable gardens, but amendments cannot be worked into the soil in the rooting zone of trees, shrubs, perennials, and lawn.
- In working with new landscapes, the new homeowner may not have the financial resources to purchase the amendments desired.
- The gardener may not have the physical ability for this intense labor.
- On slopes, removing the plant cover predisposes the soil to erosion.
- On rocky soils, it may be physically impractical or impossible to work in amendments.

Where amending is not practical or possible, gardeners need to consider alternatives. Primarily, understand that without soil improvement the gardener may need to accept less than optimum plant growth and increased maintenance.

When amending is not practical or possible, consider the following options:

- Focus on selecting plants more tolerant of the soil conditions. This includes tolerance to low soil oxygen and reduced root spread (compaction issues), poor drainage (tolerance to wet soils), drought (tolerance to dry soils), and low fertility (fertilizer need). These are characteristics of some rock garden or alpine garden plants. However, be careful about assuming that these characteristics apply to native plants as it may or may not be the case.
- Space plants further apart to reduce competition for limited soil resources.
- Small transplants may adapt to poor soils better than either larger transplants or trying to grow plants from seed.
- Raised-bed gardening and container gardening may be a practical option when soils are poor.
- Pay attention to minimizing additional soil compaction with the use of organic mulches and management of foot traffic flow.
- Organic mulch (wood/bark chips) helps improve soil tilth over a period of time as the mulch decomposes and is worked into the soil, by soil organisms. To allow this process to occur, do not put a weed fabric under the mulch and add material periodically.
- Established lawns, which have been in place for more than twenty years, come to equilibrium between root dieback and soil organic content.

Soil Practices To Avoid

The following is a summary of common practices that should be avoided in Western soils to maximize soil tilth and plant growth potential.

- **Avoid working the soil when wet**. Water lubricates soil particles, making the soil easier to compact.
- **Avoid excessive fertilization**. This has the potential for surface and ground water pollution and adds salts to the soil that can become toxic to plants. Heavy fertilization will not compensate for poor soil preparation. Many gardeners have over applied phosphate and potash.
- **Avoid adding too much organic matter**. This leads to salt build-up, large release of nitrogen, the build-up of excessive phosphorus, and an imbalance in potassium, calcium, magnesium, and iron.

- **Avoid adding lime or wood ashes**. Being calcium sources, they are used to raise the soil pH. Most Colorado soils have a neutral to high pH. Lime or wood ashes would only be used on soils with a soil pH below 5.5.
- **Avoid adding gypsum (a calcium source)**. Gypsum is used to reclaim sodic soils by displacing the sodium with calcium.
- **Avoid creating texture interfaces**. For example, when making a raised bed, adding a different soil in the box creates an interface at the change line. Use similar soils and mix the soils.
- **Avoid trying to make dramatic changes in soil pH**. If the soil is high in *free lime* (calcium carbonate), lowering the pH is not effective.

Texture

Texture refers to the size of the particles that make up the soil. The terms sand, silt, and clay refer to relative sizes of the individual soil particles. [**Table 1, Figure 1,** and **2**]

Table 1. The Size of Sand, Silt, and Clay

Name	Particle Diameter
Clay	below 0.002 mm
Silt	0.002 to 0.05 mm
Very fine sand	0.05 to 0.10 mm
Fine sand	0.10 to 0.25 mm
Medium sand	0.25 to 0.5 mm
Coarse sand	0.5 to 1.0 mm
Very coarse sand	1.0 to 2.0 mm
Gravel	2.0 to 75.0 mm
Rock	greater than 75.0 mm (~2 inches)

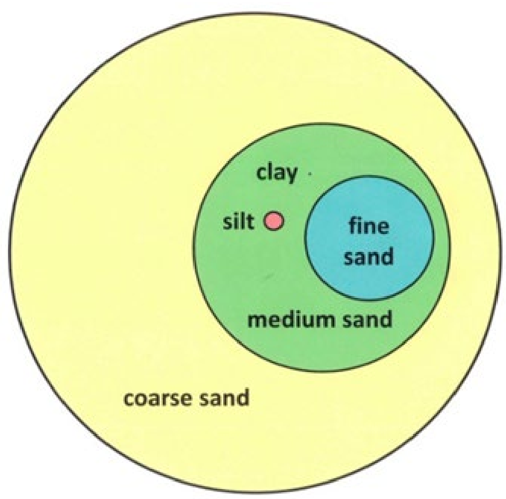
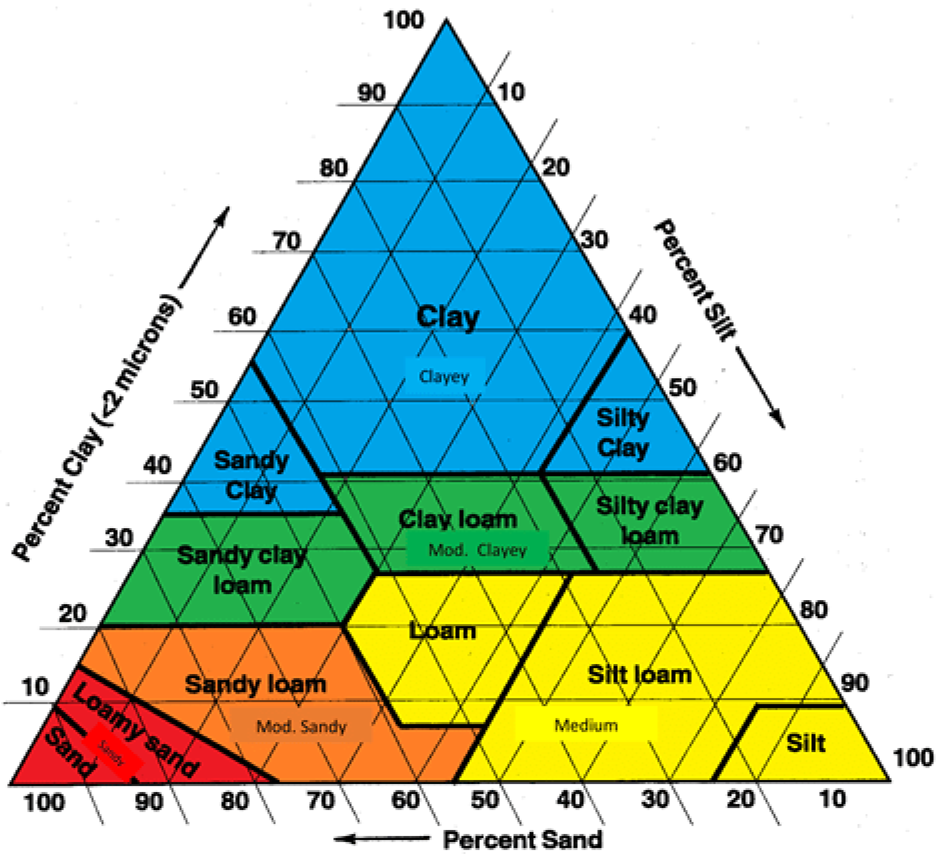


Figure 1.
Comparative size of clay to coarse sand. Clay is less than 0.002 mm (0.00008 inch) with coarse sand up to 1.0 mm (0.04 inch).

Based on the ***Soil Textural Class Triangle,*** [**Figure 2**]**,** the percentage of sand, silt and clay determine the texture class. (For example, a soil with 30% clay, 10% silt, and 60% sand is called a sandy clay loam. A soil with 20% clay, 40% silt and 40% sand is a loam.)
A ***fine-textured*** or ***clayey soil*** is one dominated by tiny clay particles. A ***coarse- textured*** or ***sandy soil*** is one comprised primarily of medium to large size sand particles. The term ***loamy soil*** refers to a soil with a combination of sand, silt, and clay sized particles.

Some types of clayey soils expand and contract with changes in soil moisture. These ***expansive*** soils create special issues around construction and landscaping. For homes on expansive clays, limit landscaping along the foundation to non-irrigated mulch areas and xeric plants that require little supplemental irrigation. Avoid planting trees next to the foundation and direct drainage from the roof away from the foundation.

Figure 2. Soil Texture Triangle. Source: USDA.



Clay

Clay particles are flat, plate-like, negatively charged particles. They are so tiny in size that it takes 12,000 clay particles in a line to make one inch. Clay feels sticky to the touch. <u>Soils with as little as 20% clay size particles behave like a sticky clayey soil</u>. Soils with high clay content have good water and nutrient holding capacity, but the lack of large pore space restricts water and air movement. Clayey soils are also prone to compaction issues. Clay particles are the source of most of the chemical properties of soil and retain many of the plant nutrients such as calcium, magnesium, potassium, trace elements, and some of the phosphorus. As organic matter breaks down, clay reacts with it to stabilize the humus in the soil. A soil without clay particles can be infertile.

Silt

Silt has a smooth or floury texture. Silt settles out in slow moving water and is common on the bottom of an irrigation ditch or lakeshore. Silt adds little to the characteristics of a soil. Its water holding capacity is similar to clay.

Sand

Sand, being the largest sized particles, feels gritty. There is a major difference in soil characteristics between fine sands and medium to coarse sands. Fine sands add little to the soil characteristics and do not significantly increase large pore space. An example of fine sand is the bagged sand sold for children's sandboxes.

True sandy soil requires greater than 50% medium to coarse sized sand. Sandy soils have good drainage and aeration, but low water and nutrient holding capacity.

Gravel and Rock

Some Colorado soils are dominated by gravel and rock, making them difficult for the gardener to work. Gravel and rock do not provide nutrients or water holding capacity. They often drain readily with low nutrient holding capacity.

Texture effects how water and nutrients move through a soil profile as shown in **Table 2**.

Table 2. Comparison of Fine-Textured (Clayey) Soil and Coarse-Textured (Sandy) Soil

	Clayey	**Sandy**
Water Holding Capacity	High	Low
Nutrient Holding Capacity	High	Low
Compaction Potential	High	Lower
Crusts	Yes	No/Sometimes
Drainage	Slow	Fast
Salinity Build-Up	Yes	Seldom
Warming in Spring	Slow	Fast

Structure

Structure refers to how the various particles of sand, silt and clay fit together, creating ***pore spaces*** of assorted sizes. Sand, silt, and clay particles are "glued" together by chemical and biological processes creating ***aggregates*** (clusters of particles). Mycorrhizae, earthworms, soil microorganisms and plant roots are responsible for creating aggregates. [**Figures 3** and **4**]

Figure 3.
The size of pore spaces between soil particles plays a key role in plant growth. Pore spaces are a function of soil texture and structure.

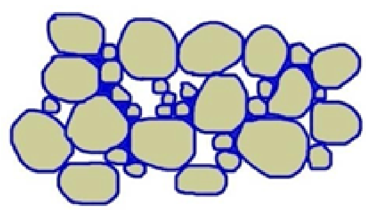
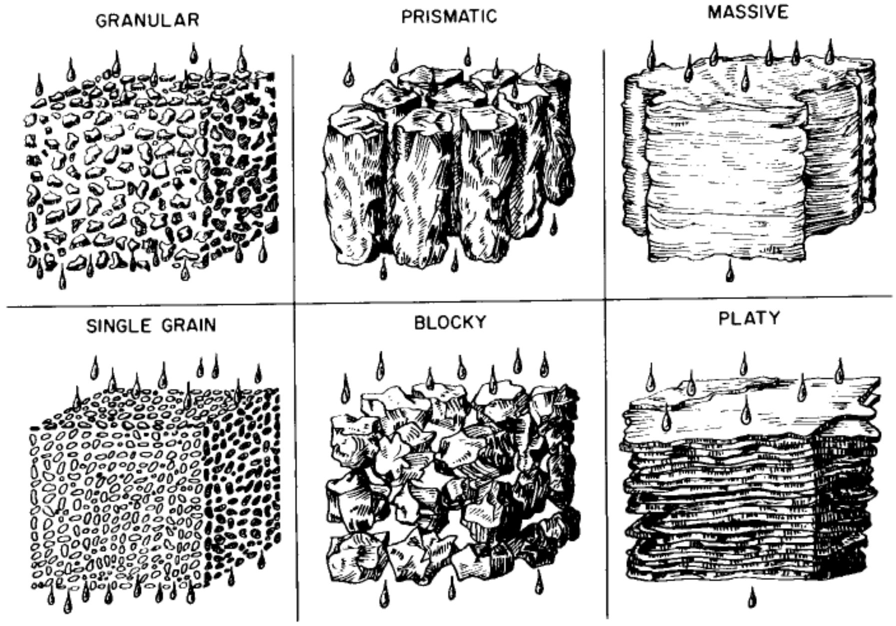


Figure 4 on next page.

Figure 4. Examples of soil structure types. Line drawing by USDA.



Undisturbed native soils often have a granular structure in the upper layer (with rapid drainage) and block structure (with rapid to moderate drainage) in the lower layers. A platy structure (with slow to no drainage) is common in soils high in clay.

Compacted, unamended landscape soils typically have a massive structure with no defined layers, little organic matter, low total pore space, and most significantly low large pore space.

The term ***peds*** describes the soil's individual aggregates or clods. Soils that create strong peds tolerate working and still maintain good structure. In some soils, the peds are extremely strong, making cultivation difficult except when the soil moisture is precisely right. Soils with soft peds may be easy to cultivate but may readily pulverize destroying the soil's natural structure.

Primary factors influencing structure include the following:

- Texture.
- Activity of soil mycorrhizae, earthworms, and other soil organisms.
- Organic matter content.
- Soil moisture (year-round).
- The freeze/thaw cycle.
- Cultivation – Tilling a soil has a direct impact on structure by breaking apart aggregates and collapsing pore spaces. Avoid tilling except to mix in organic matter, control weeds (limited use), or to prepare a seedbed.
- Soil compaction.

To maintain good structure avoid over-working the soil. Acceptable ped size depends on the gardening activity. For planting vegetable or flower seeds, large peds interfere with seeding. In contrast, when planting trees peds up to the size of a fist are acceptable and pulverizing the soil would be undesirable.

Pore Space

Pore space is a function of soil texture, structure, and the activity of beneficial soil organisms. Water coats the solid particles and fills the smaller pore spaces. Air fills the larger pore spaces. [**Figure 5**]

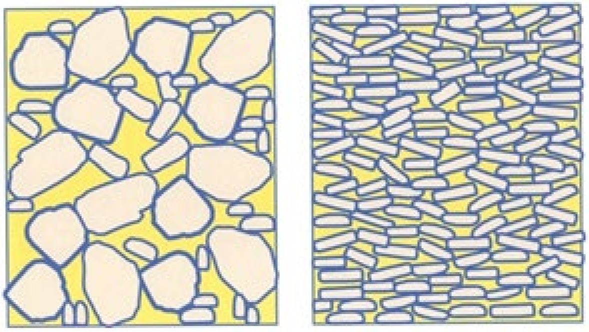
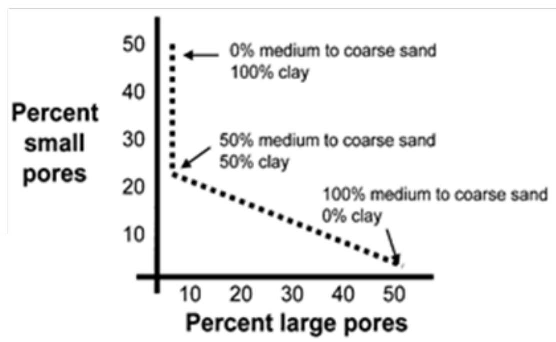


Figure 5.
Comparative pore space.
Left soil with large pore space.
Right soil lacking large pore space.

To help understand pore space, visualize a bottle of golf balls and a bottle of table salt. The pore space between golf balls is large compared to the pore space between the salt grains.

The relative percent of clay size particles versus the percent of medium to coarse sand size particles influences the pore space of a soil. Silt and fine sand particles contribute little to pore space attributes. Note in **Figure 6** how large pore space is minimal until the sand strongly dominates the soil profile. Organic matter also plays a key role in creating large pore space.

Figure 6.
Percent of small versus large pore space as a factor of soil texture.



The quantities of large and small pore spaces directly effect plant growth. On fine-texture, clayey, and/or compacted soils, a lack of large pore spaces restricts water and air infiltration and movement, thus limiting root growth and the activity of beneficial soil organisms. On sandy soils, the lack of small pore space limits the soil's ability to hold water and nutrients.

Water Movement

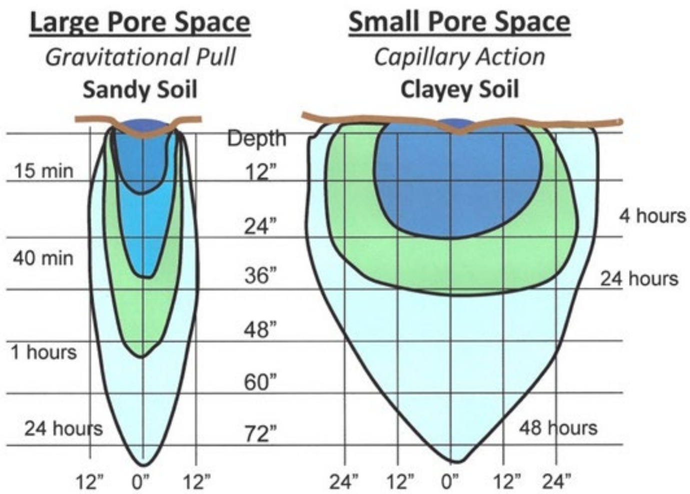
Characteristics of water molecules:

- **Cohesion Force** is where water molecules are attracted to one another. Cohesion causes water molecules to stick to one another and form water droplets.
- **Adhesion Force** is responsible for the attraction between water and solid surfaces. A drop of water can stick to a soil particle surface as the result of adhesion.
- **Surface tension**, from cohesion, causes water surfaces to behave in unusual ways. Water molecules are more attracted to other water molecules, as opposed to air particles, and water surfaces behave like expandable films.
- **Capillary action**, also referred to as capillary motion or capillarity, is a combination of cohesion/adhesion and surface tension forces. Capillarity is the primary force that enables the soil to retain water, as well as to regulate its movement. Water moves upwards (against

gravity) through soil pores, or the spaces between soil particles. The height to which the water rises is dependent upon pore size, with the smaller the soil pores, the higher the capillary rise.

The lack of large pore space leads to drainage problems and low soil oxygen levels. In sandy soils with large pores, water readily drains downwards by ***gravitational pull***. Excessive irrigation and/or precipitation can leach water-soluble nutrients, like nitrogen, out of the root zone and into ground water. [**Figure 7**]

Figure 7. Comparative Movement of Water in Sandy and Clayey Soils



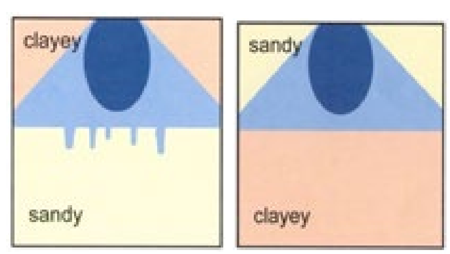
Texture Interface

Within the soil profile, a ***texture interface*** (abrupt change in actual pore space) creates a boundary line that affects the movement of water, air infiltration, and root growth. Water and air are very slow to cross a texture interface. [**Figure 8**]

When a clayey and/or compacted soil layer (primarily small pore space) is on top of a sandy soil layer (primarily large pore space) water accumulates just above the change. Water is slow to leave the small pore space of the clayey soil due to the water properties of cohesion.

Likewise, when water moving down through a sandy soil layer (primarily large pore space) hits a clayey and/or compacted soil layer (primarily small pore space) water accumulates in the soil just above the interface. This back up is due to the slow rate that water can move into the small pore space of the clayey soil. It is like a four-lane freeway suddenly changing into a country lane; traffic backs up on the freeway.

Figure 8.
Left image with clayey soil over sandy soil, water is slow to leave the small pore space of the clay.
Right image with sandy over clayey soil, water is slow to move into the small pore space of the clay.



Perched Water Table

This change in water movement creates a ***perched water table*** (overly wet layer of soil) six inches thick or greater just above the change line. When creating raised bed boxes, mix the added soil with the soil below to avoid creating a texture interface. In tree planting, to deal with the texture interface between the root ball soil and the backfill soil it is imperative that the root ball rises to the surface with no backfill soil over the root ball. In landscape soils that have a texture interface between soil layers, a perched water table may sit just above the interface line. In this situation, be cautious about frequent irrigation creating an oxygen deficiency in the roots below the perched water table. [**Figures 9** and **10**]

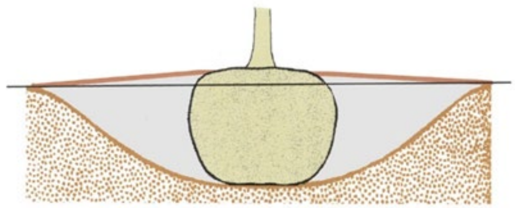


Figure 9.
In tree planting, to deal with the texture interface between the root ball soil and the backfill soil it is imperative that the root ball is above the surface with no backfill soil over top of the root ball.

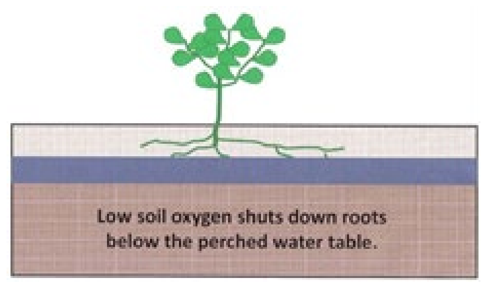


Figure 10.
On landscape soils with a texture interface in the soil profile, too frequent of irrigation creates a perched water table above the interface line. Roots below the perched water table have low soil oxygen levels.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; Catherine Moravec, former CSU Extension Employee; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting unless otherwise noted. Used with permission. Revised October 2015 by Eric Hammond, CSU Extension. Reviewed May 2023 by Mark Platten, CSU Extension.

Reviewed May 2023

MASTER GARDENER
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CMG GardenNotes #214

Estimating Soil Texture:
Sandy, Loamy, or Clayey

Sand, Silt, and Clay

Texture refers to the size of the particles that make up the soil. The terms ***sand***, ***silt***, and ***clay*** refer to relative sizes of the soil particles. Sand, being the larger size of particles, feels gritty. Silt, being moderate in size, has a smooth or floury texture. Clay, being the smaller size of particles, feels sticky. [**Table 1** and **Figure 1**]

Table 1. The Size of Sand, Silt, and Clay

Name	Particle Diameter
Clay	below 0.002 mm
Silt	0.002 to 0.05 mm
Very fine sand	0.05 to 0.10 mm
Fine sand	0.10 to 0.25 mm
Medium sand	0.25 to 0.5 mm
Coarse sand	0.5 to 1.0 mm
Very coarse sand	1.0 to 2.0 mm
Gravel	2.0 to 75.0 mm
Rock	greater than 75.0 mm (~2 inches)

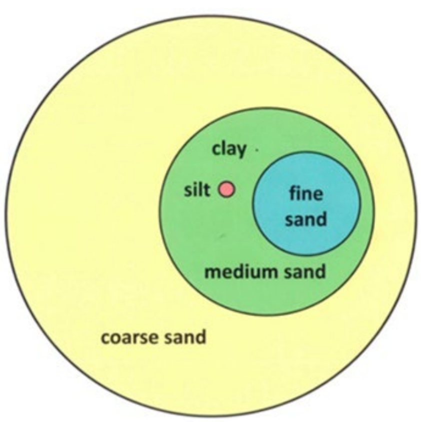
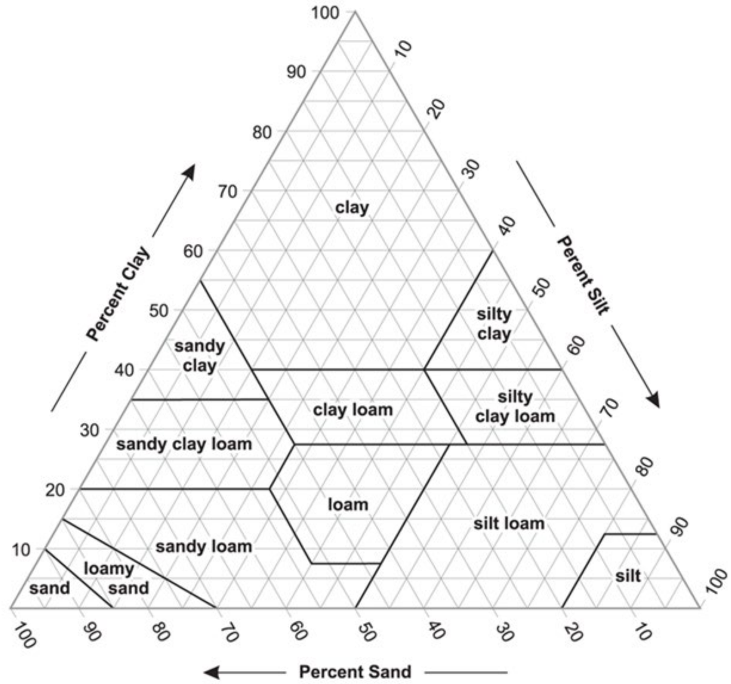


Figure 1.
Comparative size of sands, silt, and clay. If clay was the size of a dot on the page, silt and sands would be a comparative size.

Soil Texture Triangle

The ***soil texture triangle*** gives names associated with various combinations of sand, silt, and clay. A *coarse-textured* or *sandy* soil is one comprised primarily of medium to coarse size sand particles. A *fine-textured* or *clayey* soil is one dominated by tiny clay particles. Due to the strong physical properties of clay, a soil with only 20% clay particles behaves as sticky, gummy clayey soil. The term *loam* refers to a soil with a combination of sand, silt, and clay sized particles. For example, a soil with 30% clay, 50% sand, and 20% silt, is called a *sandy clay loam*. [**Figure 2**]

Figure 2. Soil Texture Triangle. Source: USDA



Identifying Soil Texture by Measurement [**Figure 3**]

1. Spread soil on a newspaper to dry. Remove all rocks, trash, roots, and such. Crush lumps and clods.
2. Finely pulverize the soil.
3. Fill a tall, slender jar (like a quart jar) one-quarter full of soil.
4. Add water until the jar is three-quarters full.
5. Add a teaspoon of powdered, non-foaming dishwasher detergent.
6. Put on a tight-fitting lid and shake hard for 10 to 15 minutes. Shaking breaks apart the soil aggregates and separates the soil into individual mineral particles.
7. Set the jar where it will not be disturbed for 2 to 3 days.
8. Soil particles will settle out according to size. **After 1 minute**, mark on the jar the depth of the sand.
9. **After 2 hours**, mark on the jar the depth of the silt.
10. **When the water clears,** mark on the jar the clay level. This typically takes 1 to 3 days; some soils may take weeks.
11. Measure the thickness of the sand, silt, and clay layers.
    - Thickness of sand deposit.
    - Thickness of silt deposit.
    - Thickness of clay deposit.
    - Thickness of total deposit.
12. Calculate the percentage of sand, silt, and clay.
    - Clay thickness, divided by total thickness, equals percentage of clay.
    - Silt thickness, divided by total thickness, equals percentage of silt.
    - Sand thickness, divided by total thickness, equals percentage of sand.
13. Turn to the soil texture triangle and look up the soil texture class. [**Figure 2**]

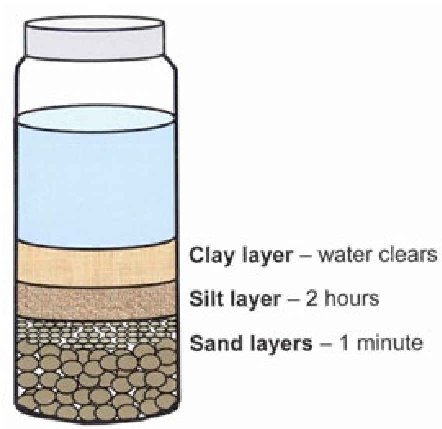


Figure 3. Measuring Soil Texture

Identifying Soil Texture by Feel

Place soil in palm of hand. Add a small amount of water and knead the soil into a smooth and plastic consistency, like moist putty.

Feel test – Rub moist soil between fingers.

- Sand feels gritty.
- Silt feels smooth.
- Clays feel sticky.

Ball squeeze test – Squeeze a moistened ball of soil in the hand.

- Coarse texture soils (sand or loamy sands) break with slight pressure.
- Medium texture soils (sandy loams and silt loams) stay together but change shape easily.
- Fine textured soils (clayey or clayey loam) resist breaking.

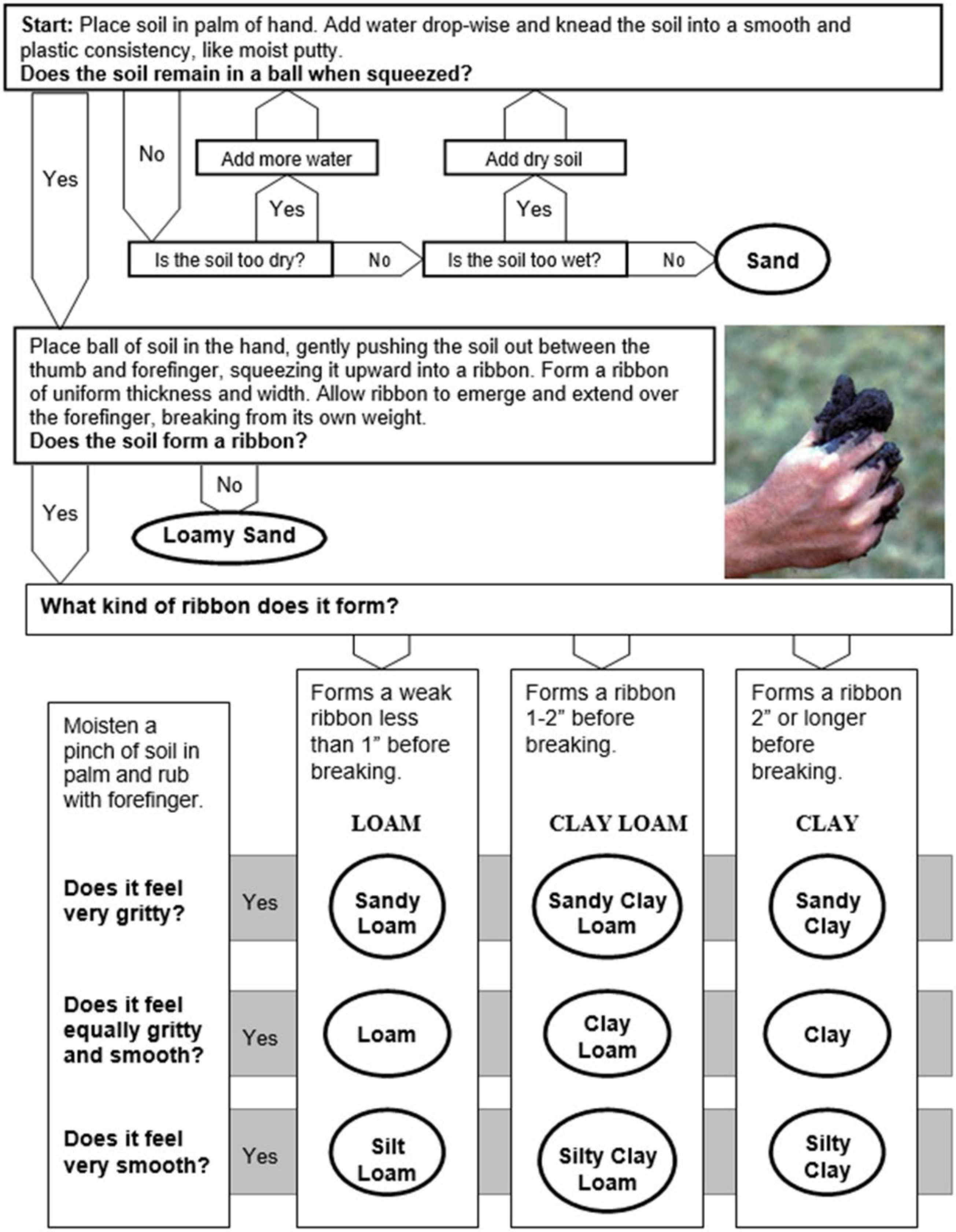
Ribbon test – Squeeze a moistened ball of soil out between thumb and fingers while squeezing upward. Form a ribbon of uniform thickness and width. Allow ribbon to emerge and extend over the forefinger, breaking from its own weight. [**Figure 4**]

- Ribbons less than 1 inch before breaking:
    - Feels gritty = coarse texture (sandy) soil.
    - Not gritty feeling = medium texture soil high in silt.
- Ribbons 1 to 2 inches before breaking.
    - Feels gritty = medium texture soil.
    - Not gritty feeling = fine texture soil.
- Ribbons greater than 2 inches = fine texture (clayey) soil.

Note: A soil with as little as 20% clay will behave as a clayey soil.
A soil needs 45% to over 60% medium to coarse sand to behave as a sandy soil. In a soil with 20% clay and 80% sand, the soil will behave as a clayey soil.

Figure 4, next page.

Figure 4. Soil Texture by Feel



Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Reviewed December 2015 and September 2022 by Eric Hammond, CSU Extension.

Reviewed September 2022

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CMG GardenNotes #215

Soil Compaction

Outline:

What Is Soil Compaction?

Soil compaction is the compression of soil particles. Compaction reduces total pore space of a soil. More importantly it significantly reduces the amount of large pore space, restricting air and water movement into and through the soil. *Low soil oxygen levels caused by soil compaction are a primary factor limiting plant growth in landscape soils*. Soil conditions, primarily soil compaction, contribute to a large portion of plant problems in the landscape setting. **Figure 1** illustrates comparison of large pore spaces in a non-compacted versus a compacted soil. Soil compaction can change a block or aggregate structure with good infiltration and drainage into a massive structure with poor infiltration and drainage. [**Figure 2**]

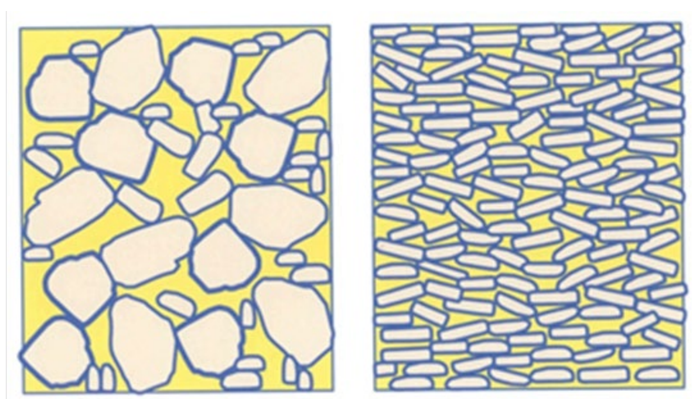

Figure 1. Comparison of large pore space in non-compacted soil (left) and compacted soil (right).

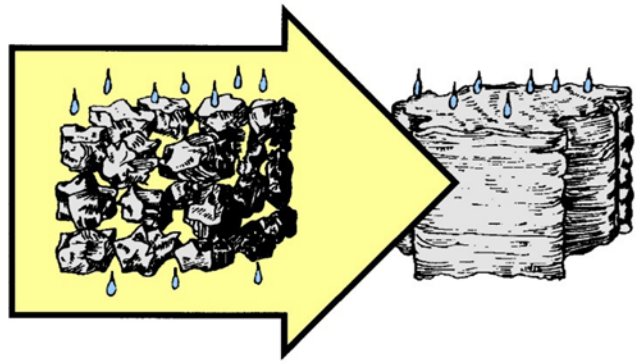

Figure 2.
Soil compaction can change a blocky or granular soil structure with good air infiltration and drainage into a massive structure with poor air infiltration and drainage. Line drawing by USDA.

Soil compaction is difficult to correct, thus efforts should be directed at preventing compaction. Soil generally becomes compacted during home construction or other heavy traffic. Foot traffic on moist soils can also contribute to compaction in the home landscape. The impact of falling raindrops and sprinkler irrigation also compacts the surface of fine-textured clayey soils. [**Figure 3**]

Figure 3.
Foot traffic in the garden bed is a major source of compaction. The impact of raindrops and sprinkler irrigation also compacts fine-textured soils.

Techniques to Minimize Soil Compaction

Adding Organic Matter

To reduce soil compaction, cultivate organic soil amendments into the top six to eight inches of the soil. In compacted/clayey soils, anything less can lead to a shallow rooting system with reduced plant growth, lower vigor, and lower stress tolerance.

General application rates for organic soil amendments are based on the type of product and the salt content. **Table 1** gives standard application rates for compost products. Compost made solely from plant residues (leaves and other yard wastes) is basically free of salt problems, so higher application rates are safe.

Compost that includes manure or biosolids as a component has a potential for high salts. Excessive salt levels are common in many commercially available products sold in Colorado. For compost made with manure or biosolids, the application rate is limited unless a soil test on that batch of product shows a low salt level. An amendment with up to 10 dS/m (10 mmhos/cm) total salt is acceptable if incorporated six to eight inches deep in a low-salt garden soil (less than 1 dS/m or 1 mmhos/cm). Any amendment with a salt level above 10 dS/m (10 mmhos/cm) is questionable.

> **Note:** dS/m or mmhos/cm is the unit used to measure salt content. It measures the electrical conductivity of the soil.

Do not leave compost in chunks as this will interfere with root growth and soil water movement. As the soil organic content builds in a garden soil, the application rate should be reduced to prevent ground water contamination issues.

Table 1. Routine Application Rate for Compost			
Site	**Incorporation Depth**[2]	**Depth of Compost Before Incorporation**[1]	
		Plant Based Compost and other compost known to be low in salts[3]	**Compost Made with Manure or Biosolids** for which the salt content is unknown[4]
One-time application – such as lawn area	6-8"	2-3"	1"
Annual application to vegetable and flower gardens – **first three years**	6-8"	2-3"	1"
Annual application to vegetable and flower gardens – **fourth year and beyond**	6-8"	1-2"	1"

1. Three cubic yards (67 bushels) covers 1,000 square feet approximately 1 inch deep.
2. Cultivate compost into the top 6-8 inches of the soil. On compacted/clayey soils, anything less may result in a shallow rooting depth predisposing plant to reduced growth, low vigor, and low stress tolerance. When depth of incorporation is different than 6-8 inches, adjust the application rate accordingly.
3. Plant based composts are derived solely from plant materials such as leaves, grass clippings, wood chips and other yards wastes. Use this application rate also for other compost known, by soil test, to be low in salts.
4. Use this application rate for any compost made with manure or biosolids unless the salt content is known, by soil test, to be low. Excessive salts are common in many commercially available products sold in Colorado.

Manage Traffic Flow

Traffic over the soil is the major contributor to soil compaction. For example, a moist soil could reach 75% maximum compaction the first time it is stepped on, and 90% by the fourth time it is stepped on.

Raised bed gardening techniques, with established walkways, eliminate compaction in the growing bed. In fine-textured clayey soils, limit routine traffic flow to selected paths.

Soils are more prone to compaction when wet. Soil water acts as a lubricant allowing the soil particles to readily slide together reducing large pore spaces.

Using Mulches

Some types of mulch effectively reduce the compaction forces of traffic. For example, three to four inches of wood or bark chips will minimize the effect of foot traffic.

Mulch minimizes the compaction forces of rainfall and sprinkler irrigation. In fine-textured clayey soil, keep garden beds mulched year-round to minimize the compaction forces of summer and winter storms. Organic mulches create an ideal home for beneficial earthworms and soil microorganisms, which play a key role in improving soil tilth.

Aerate Lawns and Around Trees

In a lawn or tree's rooting area, where organic matter cannot be cultivated into the soil, reduce compaction with soil aeration. Make enough passes with the aerator to have plugs at two-inch intervals. Aim to aerate at least 1-2 times a year, and water well before aerating to achieve plugs that are at least 3" long. Plugs can be left to decompose on the soil surface or removed depending on preference. [**Figure 4**]

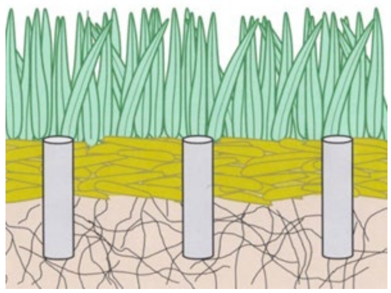

Figure 4.
Lawn aeration helps manage the impact of soil compaction if enough passes are made with the aerator to have plugs at two-inch intervals.

Avoid Excessive Cultivation

Avoid cultivating fine-textured clayey soils except to incorporate organic matter and fertilizer, and to prepare a seedbed. Use mulches to help manage weeds. Cultivation with a garden fork, broad fork, or shovel will disturb the soil less than using a rototiller.

Avoid Cultivating Overly Wet or Dry Soils

Never cultivate clayey soil when wet, as this will destroy soil structure; the clods created by tilling wet clay may last for years. To check dryness, take a handful of soil and gently squeeze it into a ball. If the soil is dry enough to crumble, it may be cultivated. If the ball only reshapes with pressure, it is too wet for cultivation. On some clayey soils, there may be only a few days (or even hours) between the time when the soil is too wet and too dry (too hard) to cultivate. In years when frequent spring rains prevent the soil from drying, planting will be significantly delayed.

Avoid Fill Over Compacted Soil

Adding a thin layer of topsoil over compacted soil is a common practice that leads to future landscape management problems. It is often justified as "a way to get plants established." However, root growth into the compacted layer will be restricted or even minimal.

Do not create a layer with added topsoil that is of a different texture than the soil below. This change in texture, actually, pore space, interferes with water movement and root spread. It is called a soil texture interface, and the upper layer must saturate completely before water can move into the different soil texture. Where additional fill is desirable, lightly mix the fill with the soil beneath.

Long-term landscape management will be much easier by breaking up surface compaction with tilling and organic matter amendments. Before planting a yard, enhance soil organic content to the extent feasible. A minimum of 3 to 4 cubic yards of organic matter per 1,000 square feet is recommended.

What About Adding Sand?

Some gardeners try to improve fine-textured soils by adding sand. The practice may help the gardeners feel that they have done something, but it will have a limited or even negative impact on the soil. Adding sand to clayey soil may reduce large pore space until enough medium-to–coarse-size sand is added to reduce the clay content well below 20%. In clayey soils, this becomes a process of soil replacement rather than soil amendment. In some situations, adding sand to clayey soil can create concrete-like soil properties. To improve the soil, put efforts into adding organic matter, not sand.

What About Adding Gypsum?

Gypsum is a salt also known as calcium sulfate. When added to calcareous clayey soils (typical of Colorado), it simply increases the already high calcium content. Gypsum will not break up compacted soil but can increase the soil's salt levels.

Gypsum is useful when a soil has a high sodium problem. Sodium has a unique physical characteristic that brings soil particles closer together, reducing large pore space and "sealing" soils to water penetration. The calcium in gypsum replaces the sodium on the soil cation exchange site and the freed sodium is then leached out by heavy irrigation. Good quality (low salt) irrigation water must be available to successfully reclaim a high sodium soil.

The use of sulfur has also been incorrectly acclaimed to break up compacted soils. Over time, sulfur may have an acidifying effect on a soil, if the soil is not high in lime. Adding sulfur to a calcareous soil only creates gypsum (calcium sulfate).

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Reviewed December 2015 by Eric Hammond, CSU Extension. Reviewed September 2022 by Cassey Anderson, CSU Extension.

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MASTER GARDENER
COLORADO STATE UNIVERSITY
EXTENSION

CMG GardenNotes #218

Earthworms

Regarded by Aristotle as the "intestines of the earth," earthworms aid in soil fertility and structure and contribute to overall plant health.

Earthworm Types

There are three types of earthworms: [**Figure 1**]

Anecic – Greek for "up from the earth" or "out of the earth."

- Capable of burrowing to depths of six feet.
- Builds permanent burrows into the deep mineral layers of the soil.
- Drags organic matter from the soil surface into their burrows for food.
- Includes the familiar bait worm, the nightcrawler or dew worm (Lumbricus terrestris).

Endogeic – Greek for "within the earth."

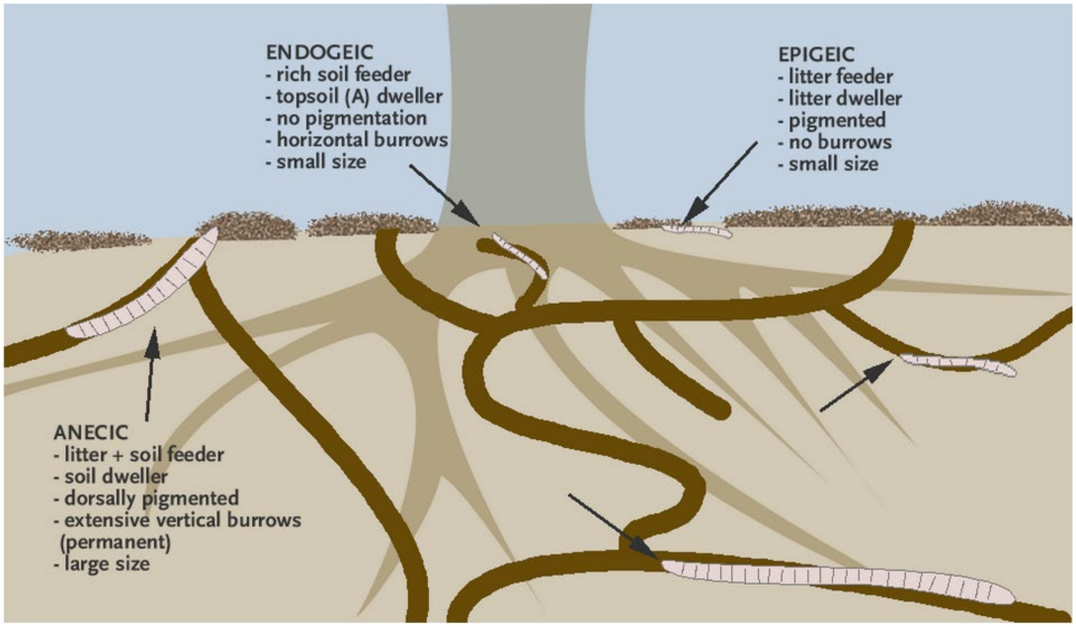
- Builds extensive non-permanent burrows in the upper mineral layer of soil.
- Feeds on the organic matter in the soil.
- Lives exclusively in soil and usually are not noticed, except after a heavy rain when they come to the surface.

Epigeic – Greek for "upon the earth."

- Lives on the soil surface.
- Forms no permanent burrows.
- Feeds on decaying organic matter.
- Common names: red worm, manure worm, brandling worm, red wiggler, and compost worm.

The anecic and endogeic are the types most often noticed in Colorado soils. Because the upper foot of soil freezes here during the winter, the epigeic worms are usually killed. In addition, the low organic matter content of Colorado soils will likely not support the food needs of epigeic earthworms. Anecic are larger than the endogeic.

Figure 1. Three Types of Earthworms. Image from UNM, Natural Resources Research Institute



Biology of Earthworms

Earthworms breathe through their skin and must be in an environment that has at least 40% moisture (at least as damp as a wrung-out sponge). If their skin dries out, they cannot breathe and will die.

Earthworms prefer a near-neutral soil pH.

Instead of teeth, earthworms have a gizzard like a chicken that grinds the soil and organic matter that they consume. They eat the soil microorganisms that live in and on the soil and organic matter.

Worm excrement is commonly called worm casts or castings. These soil clusters are glued together when excreted by the earthworm and are quite resistant to erosive forces. Their castings contain many more microorganisms than their food sources because their intestines inoculate the casts with microorganisms.

Earthworms become sexually mature when the familiar band (the clitellum) appears around their body, closer to their mouth. Each worm with a clitellum is capable of mating with other worms and producing cocoons that contain baby worms. Cocoons are lemon shaped and slightly and slightly smaller than a pencil eraser.

Benefits of Earthworms

Charles Darwin, known for his work with evolution of species wrote a paper on earthworms during his final years. In it he surmised that most all the fertile soil on earth must have passed through the gut of an earthworm. While not entirely accurate, earthworms do play an important role in soil and plant health.

Soil Fertility

Earthworms are part of a host of organisms that decompose organic matter in the soil. As earthworms digest the microorganisms and organic matter in soil, the form of nutrients is changed as materials pass through the earthworm's gut. Thus, worm casts are richer than the surrounding soil, containing nutrients changed into forms that are more available to plants. For example, one study found that in a sample of soil with 4% organic matter, worm casts contained 246 pounds of nitrogen per 1000 square feet while the surrounding soil contained 161 pounds of nitrogen per 1000 square feet (Source: ATTRA, Sustainable Soil Systems).

Soil Structure

The deep burrows of anecic earthworms create passages for air, water, and roots. Burrows provide easy avenues for the exchange of soil gases with the atmosphere. Clay soils with extensive earthworm burrows will allow water to infiltrate and percolate more readily than those without. Plants have the capacity to root deeper and the lower layers of soil can recharge with air more quickly. Air is an essential component of root development.

Anecic worms mix the soil as they create their burrows and build soil organic matter and humus as they drag litter into their burrows and excrete castings in the soil.

Endogeic worm burrows contribute to soil tilth, tying together many of the large pore spaces in the soil and increasing soil porosity.

The mucus from the skin of earthworm's aids in the formation of soil aggregates, which are integral components of the crumb of soil structure. Aggregates are also formed in castings.

Water-Holding Capacity

By increasing the organic matter content, soil porosity and aggregation, earthworms can greatly increase the water-holding capacity of soils.

How to Encourage Earthworm Activity

Earthworms will not go where it is too hot/cold or too dry/wet. Soil temperatures above 70ºF or below 40ºF will discourage earthworm activity. While soil temperature is hard to alter, moisture can be managed. When soil becomes waterlogged, oxygen is driven out of the large pore spaces. Without this free oxygen, earthworms cannot breathe. Conversely, when soil dries beyond half of field capacity, earthworm skin dries in the soil. Maintaining moisture levels that are ideal for optimum plant growth in a landscape or garden will also be ideal for earthworm activity.

Providing a food source in the form of organic matter is also important. Mulching grass clippings into the lawn, putting down a layer of organic mulch in beds, amending the soil with compost, and turning under a green manure are all excellent ways to feed earthworm populations.

Detrimental Practices to Earthworm Activity

- High rates of ammonium nitrate are harmful to earthworms.
- Tillage destroys permanent burrows and can cut and kill worms. Fall tillage can be especially destructive to earthworm populations. Deep and frequent tillage can reduce earthworm populations by as much as 90%.

- Earthworms are also hindered by salty conditions in the soil.
- Some chemicals have toxic effects on earthworm populations. [**Table 1**]

Table 1. Earthworm Population Reduction by Pesticides

Pesticide	Toxicity to Earthworms	Reduction
Sevin (carbaryl) insecticide	Severe	76-100%
Diazinon insecticide	Moderate	26-50%
2,4-D herbicide	Low	0-25%

Study from University of Kentucky Department of Entomology.

Transplanting Earthworms

To create worm populations in a soil without worms simply dig a large spade-full of soil from an area with visible worm numbers and bury this soil in the area where worms are needed.

Asian Jumping Worm

The Asian Jumping Worm, in the genus *Amynthas*, is an invasive worm making its way through the United States. These jumping worms are currently not in Colorado, but in nearby states and are very invasive. The Asian Jumping Worm is typically found in moist areas, like mud along a creek or river, and have been found in Eastern and Northwest states.

If you visit areas where Asian Jumping Worms are found, please note that they and can be transferred on footwear. The current recommendation is to wash footwear. Do not purchase Asian jumping worms for vermiculture, fishing or gardening. As with all purchases, make sure you know what you are purchasing and that you are not bringing a new issue into your garden and community.

Learn more from University of Nebraska Extension: https://lancaster.unl.edu/pest/resources/asianworms.shtml.

Authors: Adrian Card, CSU Extension. Revised October 2015 by Susan Carter, CSU Extension. Reviewed September 2022 by Adrian Card, CSU Extension and Susan Carter, CSU Extension.

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CMG GardenNotes #219

Soil Drainage

Outline:

Pore Space Controls Soil Drainage Characteristics

Pore space controls soil drainage characteristics. In other words, drainage problems often arise from lack of large-sized pores in the soil substrate.

In soils dominated by large pores (i.e., sandy soils), water moves rapidly. Soils that allow rapid leaching (water movement down through the soil profile) also pose environmental hazards because rain or irrigation water moving through the soil profile can transport water-soluble pollutants with it. Ground water pollution is a sensitive issue in coarse-textured sandy soils.

In comparison, soils dominated by small-sized pores (i.e., compacted soils and soils with greater than 20% clay content), water is slow to move or may not move at all. Soils easily saturate or become waterlogged.

Roots must have oxygen to survive and root activity shuts down in waterlogged soils. Plants growing in wet soils are typically shallow rooted. Many plants are prone to root rot in wet soils. Prolonged periods of waterlogged soil conditions lead to the decline or even death of most plants.

When water does not leach through the soil profile, salts left behind by surface evaporation can accumulate and create a white crust on the soil. This is frequently observed as a white deposit on low spots of pastures and fields. High soil salt content limits plant growth in some areas of Colorado.

Poor drainage is a common problem in many Colorado soils. In some areas, the upper layers of soil allow water infiltration only to have the water stopped as it reaches a less permeable subsurface soil layer.

A simple test to evaluate soil drainage is to dig a hole twelve inches deep and fill it with water. If the water fails to drain in thirty minutes, the soil has a drainage problem. If the hole fails to drain in twenty-four hours, waterlogged soils may affect plant growth.

Correcting Drainage Problems

Managing Soil Tilth

The term soil tilth refers to the soil's general suitability to support plant growth, or more specifically to support plant root growth. A soil with good tilth has large pore spaces for adequate air infiltration and water movement.

Attention to managing soil tilth plays a key role in soil drainage. On coarse-textured sandy soils, routine applications of organic matter increase the water holding capacity. On compacted and fine-textured clayey soils, application of organic matter forms aggregates of the fine textured clay particles, which create larger pore space, improving drainage.

French Drains

In some situations, a French drain facilitates water drainage. A French drain is a lined ditch-like trench that is filled with rock or gravel, typically with a pipe in the bottom. It catches water runoff and directs it away from structures that can be damaged. The rock should meet grade to prevent soil from covering the drain. The trench must slope at least 1-3% and flow to an outlet. [**Figure 1**]

Figure 1. A French drain is a ditch-like trench filled with rock. Water must flow downhill to an outlet.

Surface Drainage and Runoff

To minimize surface runoff and soil erosion, sloping areas should be planted with perennial ground covers or turf. Mowed lawns or un-mowed naturalized grass areas make the best ground cover for slowing runoff. Some landscapes may be terraced to control runoff.

To improve surface drainage problems, first identify, and then correct, the contributing factors.

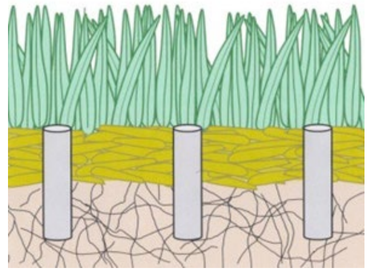
Irrigation – Many surface drainage problems arise from over-irrigation (too much and/or too often).

Compaction – Compaction is difficult to deal with; so, prevention is the key. Soils around new homes is typically compacted from construction traffic. Break up compacted layers by tilling, adding organic matter and planting ground cover. Adding organic matter and organic cover encourages earthworms and beneficial soil organisms, which creates larger pore spaces, improving drainage.

Organic mulches, like wood/bark chips, help manage compaction around trees and shrubs, perennials, small fruits, and garden paths.

Thatch in lawn – A heavy thatch layer in a lawn slows water infiltration. Improve by aerating the lawn, making enough passes so that plugs are at two-inch intervals. See lawn care information for additional details. [**Figure 2**]

Figure 2.
A heavy thatch layer slows water infiltration. Routine aeration may be needed on compacted clayey soil to help reduce thatch and open the soil to air and water.



Grading – Sometimes the grade may be deceiving. Make sure areas are properly graded so there are not low spots and all drainage heads in the right direction.

Standing water – It is common to find standing water in low spots. Fill in the low spot or install a French or underground drain with a gravity-flow outlet. Look at the irrigation schedule; is the area being over-watered? If so, or if irrigation is running off instead of soaking in, aerate and use multiple shorter irrigation cycles.

High water table – Some areas of Colorado have high water tables. The only solution may be to raise the soil level such as raised beds or berm gardening.

Impervious subsoil – In Colorado, we find many soil profiles with an impervious soil layer under the surface. This can be caused by many years of tillage at the same depth, also known as hardpan. Refer to the subsequent discussion on subsurface drainage.

Subsurface Drainage

Subsurface drainage problems are generally correctable only to the extent that large soil pore spaces can be increased to allow for better water movement. Use of soil drainage tiles are only effective to the extent that the soil will allow water to flow through it to the drain tile, and water in the drain tile can flow downhill to an outlet. It is more important to prevent poor drainage and compaction. This can be achieved through reducing traffic, managing soil load, and choosing appropriate equipment when working on soil.

To improve subsurface drainage problems, due to compaction, first identify, and then correct, the contributing factors.

Impervious/Compacted Subsoil Layer Underlain With Permeable Soil

- If less than two feet thick, rip or double dig when soil is dry enough to work.
- Irrigate to settle and do final grade when soil re-dries.
- If greater than two feet thick, bore holes through layer.
- Holes are typically four to six inches in diameter, at six-foot intervals.
- Fill with coarse sand or fine gravel.

Compacted/Impermeable Subsoil

- Increase soil depth through processes such as cultivation, ripping, double digging, or core aeration.
- Use of deep-rooted cover crops depending on depth of compaction layer.
- Select shallow-rooted and water-tolerant plants.

- These soils may have a salt problem.

Change in Soil Texture
A change in soil texture creates water movement problems called a soil textural interface. Even if the pores on the lower layer (such as large rocks in the bottom of a pot) are larger, the upper layer must saturate completely before water can move into the lower layer. This is a common problem when soils are added to a raised-bed box or applied as a top dressing. Cultivate to mix layers.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised October 2015 by Susan Carter, CSU Extension. Reviewed September 2022 by Yvette Henson, CSU Extension and Cassey Anderson, CSU Extension.

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MASTER GARDENER
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CMG GardenNotes #221

Soil Tests

Outline:

Value of a Soil Test

In the fields of agronomic crops, greenhouse crops, and turf, soil testing is a key tool in crop management for commercial producers.

In the home garden or landscape setting, soil testing is valuable in establishing a baseline, or in tracking changes, in soil limitations related to pH, salt levels, and the need for fertilizers. A special lead test would be of interest to homeowners with lead-based paints on older homes.

In some cases, soil testing may not paint the full picture. For example, soil test results for nitrogen can have limited use for the home gardener because the nitrogen level constantly changes in response to soil organic matter additions, soil microorganism activity, temperature, moisture levels, leaching, and nitrogen consumption by plants and other soil life.

Interpreting soil tests for landscape plants is difficult, as research to obtain general standards for those plants is lacking. A soil test for a maple tree, a native plant, or a gardener's favorite peony, would be difficult to interpret based on standards used for general agronomic crops.

While a soil test provides information about a variety of characteristics important for plant health/growth, a standard soil test will not identify common garden problems related to over-watering, under-watering, poor soil drainage, soil compaction, diseases, insects, weed competition, environmental disorders, too much shade, poor varieties, or simple neglect.

Typical Test

A standard soil test typically includes the following:

- Texture (estimated by the hand – feel method).
- Organic matter (reported as a percent of the total dry soil weight).
    - An estimated half a pound of nitrogen per 1,000 square feet will be released (mineralized to nitrate) during the growing season for each one percent organic matter present. This is dependent on various characteristics, such as climatic and soil conditions.

- pH.
- Lime ($CaCO_3$).
  - In soils with “free lime,” sulfur will not effectively lower the pH.
- Soluble salts (reported in mmhos/cm or dS/m).
- Nutrients (reported in parts per million), not limited to:
  - Nitrate nitrogen.
  - Phosphorus.
  - Potassium.
  - Micronutrients such as copper, iron, manganese, and zinc.

Additional tests could be run for special needs like lead content, heavy metals, or sodium problems. For additional details on soil testing, refer to CSU Extension Fact Sheet #0.502, Soil Test Explanation.

Frequency

For a gardener, a soil test gives a useful baseline on soil salts, phosphorus, potassium, pH, and free lime content (or buffer index if acid).

In the neutral and alkaline soils of Colorado, repeat the test when changes are made to the crop being planted or to the soil (such as addition of larger quantities of manure, biosolids, or compost that may be high in salts), or approximately every one to three years to reestablish the baseline.

In other parts of the country where lime is routinely added to raise the pH on acid soils, a soil test may be needed annually.

Taking a Soil Sample

A soil sample may be taken at any time of year, although spring or fall sampling is usually the most convenient.

The results of a test are no better than the quality of the sample sent to the laboratory. The sample must be representative of the yard or garden being considered. Gardeners who try to shortcut the sampling procedure will not receive a reliable result.

Submit a sample for each area that receives different fertilizer and soil management treatments. For example, if the front and back lawn are fertilized and managed the same, the sample should include subsamples taken from both lawns and mixed together. Because garden areas are managed differently from lawns, the garden should be sampled separate from the lawn. Garden beds that receive differing amounts of fertilizers and soil amendments should be sampled separately from each other as well.

Samples are most easily collected using a soil tube or soil auger. A garden trowel, spade, bulb planter, or large knife also works. Discard any sod, surface vegetation or litter before sampling. Sampling depth is critical and varies for the type of test taken and for various labs. Follow sampling depth directions given by the laboratory. [**Table 1**]

Table 1. Example of Sampling Depth Requirements for Soil Tests

Crop	Sampling Depth
Garden (vegetable & flower)	0 through 6-8 inches
Lawns, new (prior to planting)	0 through 6-8 inches
Lawns, established	0 through 6-8 inches

Based on the CSU Soil Testing Laboratory.

Each sample should be a composite of sub-samples collected from randomly selected spots within the chosen area. Take five or more subsamples from a relatively small area in the home lawn, flower border, or vegetable garden. Take ten to fifteen subsamples for larger areas. [**Figure 1**]

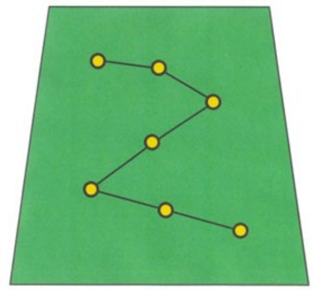

Figure 1.
A proper soil sample is a composite of five to fifteen sub samples.

Collect the subsamples in a clean plastic bucket, thoroughly mixing the subsamples together until you have a homogeneous sample. Do not oven-dry the sample.

Place about two cups of the soil mix into the sample bag or box. Label the sample container with an identifier (e.g., front lawn, vegetable garden, or flowerbed), your name, and sample depth. Keep a record of the area represented by each sample taken. Send the samples to a soil-testing laboratory, along with any forms required by that laboratory.

Climate and soil vary considerably in different parts of the country, so it is important to select a local laboratory that processes the alkaline calcareous soils of the mountain west. Future testing should be done with the same laboratory to make comparisons.

Soil tests are available from many local providers. For a list of laboratories, refer to CSU Extension Fact Sheet #0.520, Selecting an Analytical Laboratory available online at https://cmg.extension.colostate.edu/.

Soil Test Recommendations

In production agriculture, it is common for a grower or fertilizer dealer to split a sample and send it to different laboratories. Because individual laboratories do not necessarily use the same soil test procedures, their **availability indexes** (the reported available nutrients) can, and frequently do, differ.

Laboratories can also differ in the objectives behind their recommendations. For example, are maximum yields the primary objective? In this scenario, the recommendations will likely be for increased fertilizer application, which can mean increased costs, and higher potential for leaching of fertilizers into ground water. In another example, the crop's net return may be the primary objective, involve reducing production costs, (for instance, by reducing fertilizer use).

Plant needs and fertilizer practices may also impact recommendations. For example, before laying new sod add a single dose of fertilizer that is high in phosphorus, since phosphorous is important for the development of new roots. After establishment, the sod is maintained through annual additions of nitrogen fertilizer. Thus, context is critical in determining the appropriate recommendations (e.g., is a single or annual phosphorous application recommended?).

The recommendations resulting from a soil test need to be made by the laboratory doing the work, based on cropping information provided by the grower/gardener.

Home Soil Test Kits

Home soil test kits have questionable value. The accuracy of some tests is based on the pH of the soil being tested (e.g., a common phosphorous test is accurate only for soils with a pH less than 7.3). They may have questionable accuracy when testing the alkaline soils of the west. They also typically do not provide very precise metrics or any recommendations, so making decisions, such as determining fertilizer rates, based on home soil tests can be difficult.

The accuracy in home soil test procedures may, at best, give a ballpark reading but not precise accuracy. For example, the calibration on a home soil pH kit will tell the gardener that the soil has a pH level between 7 and 8. How close to 7 or 8 makes a huge difference for the growth of some plants. More precise measurement requires more expensive equipment.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised October 2015 by Eric Hammond. Reviewed September 2022 by Hania Oleszak, CSU Extension.

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CMG GardenNotes #222

Soil pH

Soil pH

Soil pH is a measurement of the acidity or alkalinity of a soil. On the pH scale, 7.0 is neutral, below 7.0 is acidic, and above 7.0 is basic (otherwise known as alkaline). A pH range of 6.8 to 7.2 is termed **near neutral**.

A soil's pH is a product of the factors which formed it. Primarily, it is a result of the parent material of the soil and of the climate. In Colorado, many of our soils are alkaline with a pH of 7.0 to 8.3. This is largely due to the high calcium carbonate content, known as **free lime**, that has accumulated in our soils through rock weathering and limited rainfall. In contrast, areas of the world with higher rainfall typically have acidic soils because the water leaches ions that contribute to alkalinity out of the soil profile. When soils contain an abundance of free lime, it is often impractical to lower the soil's pH by adding neutralizing acids because the excess free lime will buffer the effects of the acids. Soils with a pH of 8.3 or higher are typically also sodic soils, meaning that they have a very high sodium content.

The quality of irrigation water used can also influence soil pH. In some cases, irrigation water contains high levels of calcium carbonate which will further increase the soil pH. In other cases, irrigation water can promote a near neutral soil pH by leaching out ions that contribute to soil alkalinity. For example, some mountain soils and older gardens that have been irrigated and cultivated for many years have attained near neutral pH.

Soil pH is important to gardeners because it can affect the availability of plant nutrients and the soil ecology. In very acid or alkaline soils, some plant nutrients convert to forms that are more difficult for plants to absorb, which can result in nutrient deficiencies. Plants that have evolved under such soil conditions often develop mechanisms to deal with this issue. As a result, it's important to select plants that are adapted to your soil pH when possible.

Many gardening books list the preferred pH for common plants as 6.0 to 7.2. **Most common landscape plants can tolerate a wider range.** [**Table 1**] The exception is acid-loving plants, like blueberries, azaleas, and rhododendrons. Blue hydrangeas also require a pH lower than 5.0 to induce the blue flower color.

Table 1. Soil pH and Plant Growth

Soil Reaction	pH	Plant Growth
	>8.3	Too alkaline and sodic for most plants
	7.5	Iron availability becomes a problem in alkaline soils
Alkaline Soil	**7.2**	**6.8 to 7.2 is near neutral**
Neutral Soil	**7.0**	**6.0 to 7.5 is acceptable for most plants**
Acid Soil	6.8	
	6.0	
	5.5	Reduced soil microbial activity, especially bacteria
	<4.6	Too acid for most plants

Managing Alkaline Soils

To manage Colorado soils with moderate to high alkalinity (pH above 7.5), increase soil organic matter content by using organic amendments and mulches. Additionally, use proper irrigation to manage soil moisture. Overly wet or dry soils may amplify the issues created by high soil alkalinity.

In Colorado, a major problem with high pH is iron chlorosis. Our soils typically have an adequate supply of iron but, under alkaline conditions, the iron is present in a form that some plants are not able to access, leading to iron deficiencies.

Soils with a pH above 7.3 and/or with free lime cannot be adequately amended for acid-loving plants like blueberries, azaleas, and rhododendrons.

Gardeners may find a slight decrease in soil pH over many decades. This occurs as irrigation leaches out ions (calcium and magnesium) which contribute to higher pH. Many fertilizers also add acidity to soil and plant roots secrete weak acids into the soil which may contribute to a gradual pH change. The presence of free lime in a soil slows this gradual acidification.

Lowering the pH

Applications of elemental sulfur are often recommended to lower a soil's pH. This is effective in many parts of the country. **However, it is not effective in many Colorado soils due to their high levels of free lime.** In alkaline soils which contain free lime, drastically modifying the pH of the soil is impractical.

To test for free lime, place a heaping tablespoon of crumbled dry soil in a cup. Moisten it with vinegar. If the soil-vinegar mix bubbles, the soil has free lime. **In soils with free lime, a gardener will not be able to effectively lower the pH.**

In soils without free lime, the following products may help lower the pH.

> **Elemental sulfur** is one chemical that can be used to lower soil pH. The soil type, existing pH, and the desired pH are used to determine the amount of elemental sulfur needed. [**Table 2**] Incorporate sulfur to a depth of six inches. It may take several months to over a year for the sulfur to react with the soil, lowering the pH. Test soil pH again three to four months after initial application. If the soil pH is not in the desired range, reapply.

Table 2. Pounds of Sulfur Needed to Lower Soil pH[1]

Material	pH Change	Pounds per 100 Square Feet[2]
Sulfur	7.5 to 6.5	1.5
	8.0 to 6.5	3.5
	8.3 to 6.5	4.0

1. Effective only on soils without free lime - do the vinegar test.
2. Higher rates will be required in fine-textured, clayey soils and soils with a pH 7.3 and above.

Aluminum sulfate will lower pH, but it is not recommended as a soil acidifying amendment because of the potential of aluminum toxicity to plant roots.

Fertilizers – Use of **ammonium sulfate, ammonium nitrate or urea as nitrogen** fertilizer sources will also have a small effect on lowering soil pH in soils without free lime. For example, ammonium sulfate fertilizer, 21-0-0, at ten pounds per one thousand square feet (maximum rate for crop application) may lower the pH from 7.3 to 7.2. However, do not use these fertilizers at rates greater than those required to meet the nitrogen needs of the plants.

Raising the pH

In acidic soils, the pH can be raised by adding lime (calcium carbonate). The amount to add depends on the cation exchange capacity (nutrient-holding capacity) of the soil, which is based on the soil's clay content. Soil higher in clay will have a higher cation exchange capacity and will require more lime to raise the pH.

Lime is commonly sold as ground agricultural limestone. It varies in how finely it has been ground. The finer the grind, the more rapidly it will raise the pH. **Calcitic lime** mostly contains calcium carbonate (CaC03). **Dolomitic lime** contains both calcium carbonate and magnesium carbonate [MgCa(CO3)2]. On most soils, both are satisfactory. However, on sandy soils low in organic matter, dolomitic lime may supplement low magnesium levels. Low soil magnesium levels should be verified with a soil test prior to applying dolomitic lime as excess levels of magnesium can lead to calcium deficiencies in some vegetables.

A laboratory test called a **buffer index** measures the responsiveness of the soil to lime applications. The soil test will give recommendations on application rates based on the buffer index rather than just the pH. **Table 3** gives an estimated amount of lime to apply to raise a soil's pH.

Table 3. Limestone Application Rates to Raise Soil pH to Approximately 7.0 for Turf
Lime Application Rate (pound per 1,000 square feet)

Existing Soil pH	Sandy	Loamy	Clayey
5.5 to 6.0	20	25	35
5.0 to 5.5	30	40	50
3.4 to 5.0	40	55	80
3.5 to 4.5	50	70	80

- Lime application rates shown in this table are for dolomite, ground, and pelletized limestone and assume a soil organic matter level of approximately 2% or less. In soils with 4 to 5% organic matter, increase limestone application rates by 20%.
- Individual applications to turf should not exceed 50 pounds of limestone per 1,000 square feet.
- Avoid the use of hydrated or burned lime because it is hazardous to both humans and turf (can seriously burn skin and leaves). If hydrated lime is used, decrease application rates in the above table by 50% and apply no more than 10 pounds of hydrated or burned lime per 1000 square feet of turf.

Home pH Test Kits

In alkaline soils, home pH kits have questionable value. Inexpensive kits cannot be calibrated accurately enough to be meaningful when used on alkaline soils. Small changes in techniques, such as how much water is used and the pH of the water used in the sample, can change results. Most home soil test kits are designed for acid soils.

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MASTER GARDENER
COLORADO STATE UNIVERSITY
EXTENSION

CMG GardenNotes #223

Iron Chlorosis of Woody Plants

Symptoms

The term **chlorosis** means a general yellowing of leaves. Many factors contribute to chlorosis.

Iron chlorosis refers to a yellowing caused by an iron deficiency in the leaf tissues. The primary symptoms of iron deficiency are **interveinal chlorosis**, a general yellowing of leaves with veins remaining green. In severe cases, leaves may become pale yellow or whitish, but veins retain a greenish cast. Angular shaped brown spots may develop between veins, and leaf margins may scorch (become brown along the edge). [**Figure 1**]

Figure 1. Symptoms of iron chlorosis include yellowing of the leaf with veins remaining green.

Iron is necessary for the formation of chlorophyll, which is responsible for the green color in plants and necessary for photosynthesis (sugar production in plants). Any reduction in chlorophyll during the growing season reduces plant growth, vigor, and stress tolerance. Plants with reduced vigor from iron chlorosis are more prone to winter injury, and winter injury may aggravate an iron chlorosis problem. Weakened plants are also more susceptible to other diseases and insect infestations.

Iron is not very mobile within plants. Plants use their stores of iron in new leaves as they create them, so iron chlorosis shows first and more severely on the newer growth at branch tips. Leaves may be smaller than normal and may eventually curl, dry up, and fall. Fruits may be small with a bitter flavor. Mildly affected plants become unsightly and grow poorly. In severe cases individual limbs or the entire plant may die.

It is common for iron chlorosis to show on a single branch or on one side of a tree. This is particularly common for plant species with marginal winter hardiness following winter injury. Plant species and varieties vary in their susceptibility to iron deficiency.

On junipers, pines, and other evergreens, chlorosis usually develops as an overall yellowing of needles.

Similar Symptoms

Iron chlorosis symptoms can be confused with other problems. In the high pH soils of Colorado, a suspected iron chlorosis problem may be a combination of iron and manganese deficiencies. It is common for chlorotic trees to show a response to both iron and manganese treatments.

Zinc and manganese deficiencies result in similar leaf symptoms, but typically appear first on older, interior leaves. Iron chlorosis appears first on the younger or terminal leaves but may progress into older and lower leaves under severe conditions.

Nitrogen deficiency shows as a uniform yellowing of the entire leaf including the veins. It appears first in the older leaves, while iron chlorosis appears first in the newer growth.

Damage from soil sterilants (e.g., Pramitol, Atrazine, Simazine, Ureabor, and Diuron) used to prevent weeds results in similar symptoms. With these weed killers, the leaf tissue along the vein remains green. With iron chlorosis, just the vein itself remains green.

Natural aging of tissues may create similar symptoms in some plants. Root and trunk damage, some viruses, phytoplasmas, and vascular wilt diseases may cause similar leaf symptoms.

Causes and Complicating Factors

The factors leading to iron chlorosis are complex and not fully understood. Several chemical reactions govern iron availability and contribute to the complexity of iron chemistry in soils.

Many environmental factors also create or contribute to iron deficiency which need to be evaluated and alleviated to the extent possible. In many situations, attention to watering and soil conditions will satisfactorily correct minor iron chlorosis problems.

Calcareous Soils

Many Colorado soils are naturally high in lime (calcium carbonate and other calcium compounds) which raises the soil pH above 7.5. In these calcareous soils, iron chlorosis is common on susceptible plants.

Colorado soils are abundant in iron, as evidenced by the common “red rock” formations. In alkaline soils (pH above 7.0), iron is rapidly fixed through a chemical reaction into insoluble, solid forms that cannot be absorbed by plant roots. Such iron will be tied up indefinitely unless soil pH changes. Soil applications of iron alone are ineffective, as the applied iron will quickly be converted to these unavailable solid forms.

Over-Watering

Iron chlorosis is a common generic symptom of overwatering. Overly wet or dry soils predispose plants to iron chlorosis. It is more prevalent following wet springs, or when gardeners overwater in the spring. In western calcareous soils, iron chlorosis can be moderated by eliminating springtime overwatering.

Overly dry soils can also lead to nutrient deficiencies since many nutrients are absorbed in solution with water. Severe cases of iron chlorosis involving "acid-loving" plants may not be corrected through improved irrigation practices.

It is common for gardeners to allow sprinkler control settings to remain unchanged from the high summer water needs to the lower water needs of spring and fall. In this situation, the yard could receive as much as 40% more water than needed in the spring and fall. Such overwatering can contribute to iron chlorosis.

Soil Compaction

Soil compaction and other conditions that limit soil air infiltration (like surface crusting and use of plastic mulch) predispose plants to iron chlorosis by limiting effective rooting area and soil oxygen levels. Plants that have smaller root systems have less chance of "finding" available iron. These are key contributing factors in clayey soils. Using organic mulch (like wood or bark chips) helps prevent and reduce soil compaction. Avoid the use of plastic under rock mulch around landscape plants.

Trunk Girdling Roots

Iron chlorosis is a common early symptom of trunk girdling roots in trees. The primary cause of trunk girdling roots is planting trees too deep. Trunk girdling roots can lead to decline and death some twenty years after planting.

In tree planting standards, the top of the root ball should rise slightly above grade (e.g., one to two inches above grade) for newly planted trees. At least two structural roots should be in the top one to three inches of the root ball.

On established trees, the trunk-to-root flare should be noticeable. If the trunk goes straight into the ground, expect planting problems and possible development of trunk girdling roots over time. To check, perform a root collar excavation (carefully removing the soil around the base of tree) and examine the trunk/root flare.

Other Contributing Factors

Plant Competition – In susceptible plants, competition from adjacent lawns or flowers may aggravate iron chlorosis. Replace the grass under the tree canopy with wood/bark chip mulch.

Winter Injury – Trees with cankers and other winter injuries are prone to iron deficiency. (Winter bark injury on tree trunks is caused by winter drought.)

Soil Organic Matter – Organic matter is essential to successfully gardening in Colorado's soils. Ideally, the soil's organic content should be increased to 5%. However, excessive amounts may aggravate iron problems.

Excessive Salt Levels – High soil salt levels adversely affect uptake of water and nutrients, including iron. For details, refer to CMG GardenNotes #224*,* Saline Soils.

Soil Temperature and Light Intensity – Extreme soil temperatures and high light intensity may increase iron chlorosis problems. Use organic mulch to moderate soil temperature. Shading may help some crops.

Acid-Loving Plants – Acid loving plants are highly susceptible to iron chlorosis and not suited to Colorado's soil conditions. These include blueberries, azaleas, rhododendron, flowering dogwood, and heather.

Nutrients – Excessive levels (from over-application) of phosphate, manganese, copper, or zinc may aggravate iron chlorosis.

Plant Selection – Right Plant, Right Place

In Colorado's high pH soils, the best method to prevent iron chlorosis is to select plant species tolerant of high soil pH and less affected by low iron availability. Avoid planting the more susceptible species on soils prone to iron chlorosis problems [**Table 1**] (pH above 7.5, compacted, clayey, or wet soils).

Table 1. Examples of Plants with High Susceptibility to Iron Chlorosis

Amur maple	Dawn redwood	Northern red oak
Apple	Douglas fir	Peach
Arborvitae	Elm	Pear
Aspen	Flowering dogwoods	Pin oak
Azalea	Grape	Pine
Beech	Honeylocust	Raspberry
Birch	Horse chestnut	Red maple
Boxelder	Juniper	Rhododendron
Bumald spiraea	Linden	Silver maple
Cherry	London plane tree (sycamore)	Spruce
Cotoneaster	Magnolia	
Crabapple	Mountain ash	

Iron Additives

Unfortunately, there is no easy, inexpensive, or long-term correction for iron chlorosis. Treatments may be expensive and give disappointing results. Since plant and soil conditions vary, there is no single approach that is consistently best. Reducing springtime overwatering and soil compaction along with knowledge of other contributing factors can be effective in mitigating iron chlorosis in some situations.

The first step in using iron additives is to know the soil pH and free lime (calcium carbonate) content. These factors directly affect the success of any approach.

Determine soil pH by a soil test. When the pH is above 7.5, effective approaches are limited.

To check for free lime, place a rounded tablespoon of dry crumbled soil in a small cup and moisten the soil with vinegar. (The soil needs to be thoroughly moistened, but not swimming in vinegar.) If the soil-vinegar mix fizzes or bubbles, it has free lime. High lime content is typical of soils with a pH above 7.5. A standard approach in treating iron chlorosis is to lower the soil's pH, but **lowering the pH is impractical to impossible if the soil contains free lime.**

There are four general approaches to iron treatments: 1) lowering the soil's pH, 2) soil iron treatments, 3) foliar sprays, and 4) tree injections. Each has advantages, disadvantages, and gives variable results depending on plant species and soil conditions.

The two principal types of iron-containing products used for iron application include iron chelates and inorganic iron compounds (such as iron sulfate and ferrous sulfate). Several types of iron chelate are marketed under a variety of trade names. Soil pH dictates the type of chelate to use. Treatment with any iron product made mid-season may not produce satisfactory results.

Lowering Soil pH with Sulfur Products

A standard approach used in many products is to lower the soil pH. This approach merits consideration only if the soil does NOT have free lime (high calcium carbonate) and may show effectiveness over a period of years.

Due to the high pH and lime content of many Colorado soils, this approach seldom merits consideration. If irrigation water is hard, the calcium carbonate (lime) in the water will counter any acidifying effect. (As a side note, it has been observed that in some older gardens the pH has dropped below natural levels as the lime content is slowly leached out with decades of irrigation.)

The pH is lowered by soil applications of sulfur products. See the product labels for specific application rate. (Use of aluminum sulfate to lower soil pH is not recommended due to a potential for aluminum toxicity.) For details on lowering pH, refer to the CMG GardenNotes #222, Soil pH.

Soil Applications of Iron Sulfate Plus Sulfur

A simple approach is to apply a mixture of equal amounts of iron (ferrous) sulfate and sulfur to the soil. Examples of products include Copperas, Jirdon Super Iron Green, Hi-Yield Soil Acidifier Plus Micros, and Fertilome Soil Acidifier Plus Iron. Over a period of months to years, an improvement may be noticed. When it is effective, treatments may last up to three or four years, depending on soil conditions.

This approach merits consideration only on soils without free lime.

For trees, apply the mixture in holes around the dripline of the tree, as described for chelates (see below). Over time, the sulfur reacts to lower soil pH in a localized area. Broadcast applications, which dilute the material over a larger area, are less likely to give satisfactory results. Treat rows of berries or small shrubs by placing the mix in a furrow four inches deep and twelve to twenty-four inches away from the plant. See specific label directions for application rates. For the best results, treat the soil in spring.

Soil Applications of Iron Chelates

Soil application of iron chelates may give a rapid response if the correct chelate is used and other contributing factors are minimal. Applications after May 1st are less likely to show results. Treatments may last less than a season to two years.

Treat trees by placing the iron product in rings of holes in the ground beneath the dripline (outer reaches of the branches). Make holes one and a half to two inches in diameter, six inches deep and twelve inches apart in rings two feet apart. For smaller trees, make two to three rings of holes. For large trees, create four to five or more rings of holes which may need to extend beyond the drip line. No holes should be made within two and a half to four feet of the tree trunk on established trees. [**Figure 2**]

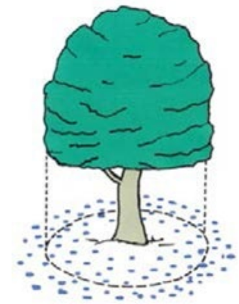

Figure 2. Place soil additive in a ring of holes around the drip line of the tree.

Drill holes in the soil with a power or hand auger, bulb planter, or small trowel, removing the soil core. Using a punch bar that makes holes by compacting the surrounding soil may be less effective. To avoid damage to shallow utility lines, call 811 before starting to have any buried lines marked. [**Figure 2**]

> **In soils with a pH above 7.5**, only special chelates formulated for a high pH are effective. Examples include EDDHMA (Miller's Ferriplus®) or EDDHA (Fe Sequestrene™ 138). Due to their higher cost, these products have limited availability. See product label for specific application rates.
>
> **In acid to slightly alkaline soils**, try other chelates like EDTA (Fe Sequestrene® 330, Fertilome Liquid Iron) and DTPA (Miller's Iron Chelate DP). They lose effectiveness quickly as the pH rises above 7.2 to 7.5. See product label for specific application rates.

Soil Applications of Iron Sucrate

Iron sucrate, a relatively new iron source, is manufactured from iron oxide and molasses to form an iron-containing organic complex with limited water solubility. It is less prone to staining due to its low solubility.

Iron sucrate merits consideration in high pH soils, and additional scientific evaluation is warranted for Colorado soils. It is marketed as Lilly Miller Iron Safe.

Foliar Sprays

Foliar sprays of iron sulfate or iron chelates may provide a quick response, often in a matter of days. However, the treatment is often spotty and only temporary. Multiple applications per season may be needed and the effects will not carry over into subsequent years.

Both types of products are equally effective, but iron chelates are more expensive. See product labels for specific application rates and instructions. With foliar applications, spray in the evening or on cloudy days when drying time is slower. A few drops of liquid dishwashing soap or commercial wetting agent will enhance sticking properties.

Foliar applications are not recommended due to application limitations. Complete coverage of all leaves is essential, individual leaves not treated may remain chlorotic. Coverage on large trees is impractical to impossible.

There is a small margin between an iron concentration that will green up the leaves and a concentration that will cause leaf burn. Leaf tissues are prone to turn black from an iron burn. Following an iron sulfate foliar treatment, it is common to see leaves that remain chlorotic, leaves that green up, and leaves with black burn spots on the same plant. Spray hitting the sidewalk, house, and other objects may leave a permanent rusty discoloration. Chelated iron sprays are inactivated by sunlight.

Trunk Injections

Professional arborists have trunk implant or injection methods available for treating iron chlorosis on large trees and they may last from one to five years. Refer to product information for application details. Injections may create pathways for decay organisms to enter a tree.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, PhD, USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised October 2015. Reviewed June 2023 by Tamla Blunt, PhD, CSU Extension.

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CMG GardenNotes #224

Saline Soils

Soluble Salts

Salts are mineral compounds made up of ions (+ charge cations and - charge anions). **Soluble salts** are the salt ions dissolved in the soil's water. Some salts such as gypsum (calcium sulfate) are less soluble. Limestone (calcium carbonate) dissolves only in acidic water. Table salt (sodium chloride) dissolves very easily and bonds with water molecules, making it hard for plants to absorb the water.

Salts are another soil factor limiting crop growth in some areas of Colorado, especially in the Western Colorado Valleys. The salty layer of the Grand Valley is Mancos shale that can have a depth up to 4,150'. Some salt ions, such as boron, chloride, and sodium, can be toxic to plants even when the overall salt content of a soil is not very high.

Impact of High Salt on Plant Growth

High salt levels can reduce water uptake by plants, restrict root growth, cause marginal burning of the foliage, inhibit flowering, limit seed germination, and reduce fruit and vegetable yields. Irregular bare spots in gardens and uneven crop growth suggest salinity problems. Crop yields may be reduced as much as 25% without easily visible damage to plants. Salt injury generally is more severe during periods of hot dry weather, when water use is high.

Salt Burn on bean leaf from high salts in compost.

Sensitivity to soluble salts differs among plant species/cultivars and is dependent on their state of growth. Seed germination and seedling growth are more sensitive to salt stress than mature plants. [**Table 1**]

Table 1. Relative Salt Tolerance of Cultivated Plants

Non-tolerant 0-2 dS/m	Slightly Tolerant 2-4 dS/m	Moderately Tolerant 4-8 dS/m	Tolerant 8-16 dS/m
begonia	apple	beet	arborvitae
carrot	cabbage	black locust	asparagus
cotoneaster	celery	boxwood	juniper
green bean	cucumber	broccoli	Russian olive
onion	grape	chrysanthemum	Swiss chard
pea	forsythia	creeping bentgrass	
radish	Kentucky bluegrass	geranium	
raspberry	lettuce	marigold	
red pine	linden	muskmelon	
rose	Norway maple	perennial ryegrass	
strawberry	pepper	red oak	
sugar maple	potato	spinach	
viburnum	red fescue	squash	
white pine	red maple	tomato	
	snapdragon	white ash	
	sweet corn	white oak	
		zinnia	

Note: dS/m is the unit used to measure salt content. It measures the electrical conductivity of the soil. dS/m = mmhos/cm.

Factors Contributing to Salt Problems

Drainage

A common sign of salt problems is the accumulation of salts at the soil surface due to limited percolation in compacted and/or clayey soils. Soluble salts move with the soil water. Deep percolation of water down through the soil profile moves salt out of the rooting zone. Surface evaporation concentrates the salts at the soil surface. Salt deposits can sometimes be seen as a white crust on the soil surface. As you drive around Colorado, it is common to see these soils with the white salt accumulation in low spots of fields and natural areas.

In some areas, salt naturally accumulates due to limited rainfall to leach the salt out. Salt levels drop when the soil undergoes irrigation. In other areas, salts may build-up when poor soil drainage prevents precipitation and irrigation water from leaching the salt down through the soil profile. In this case, corrective measures are limited to improvements in soil drainage.

Soil Amendments

Manure, biosolids, and compost made with manure or biosolids may be high in salt. When using manure or compost made with manure, routinely monitor salt levels. For more information, see section on Adding Soil Amendments, page 4.

Excessive/Unnecessary Fertilizer Applications

Unwarranted application of fertilizers (such as phosphate or potash) increases soil salt levels. On soils marginally high in salts, potash fertilizers should be avoided unless a potassium deficiency is identified by soil tests. Over-fertilization also has other environmental impacts.

Placing fertilizer and salty soil amendments too close to seeds or plant roots creates a salt burn of the tender roots. Germination failure or seedling injury can result.

De-Icing Salts

The use of **de-icing salts** on streets and sidewalks frequently results in high salt levels in adjacent soils. Along roads, salt injury has become a major concern. Highway salts may reach plants in two ways: movement to soil and uptake by plant roots, or movement onto plant stems and foliage through the air as vehicle “splash-back.” Salts deposited on both soil and foliage have high potential to cause plant injury. Highway salts in road-melt runoff is another concern for plants and the wider environment.

Pet Urine

Damage by pet urine, which contains alkaline salts and nitrogen, is also salt problem. Water moves by osmotic pressure from the roots to the high salt concentration in the soil, dehydrating and killing roots. Train your pet to eliminate in a plant free zone or follow other salt management methods below.

Measuring Soil Salt Levels

Bean plants are rather salt sensitive and can be used to help assess salt problems. In a garden, if beans are doing well, soluble salts are not a problem. If the beans are doing poorly, consider salts as a possibility. Beans, tomatoes, and other easily germinated seeds can be used in a “pot test” on a windowsill to live assay the salt content of a soil. Assess plants’ performance considering **Table 1**.

The amount of salt in a soil can be quantified only by a soil test. A soil test for soluble salts can be useful when investigating the cause of poor plant growth, determining the suitability of a new planting site, or monitoring the quality of fill soil or soil amendments for use on a landscape area.

Soil tests for soluble salts are based on electrical conductivity. Pure water is a very poor conductor of electric current, whereas water containing dissolved salts conducts current approximately in proportion to the amount of salt present. Thus, measurement of the electrical conductivity, (**ECe**), of a soil extract gives an indication of the total soluble salt concentration in the soil. The ECe is measured in deciSiemens per meter (dS/m) or millimhos per centimeter (mmhos/cm). 1 dS/m = 1 mmhos/cm. [**Table 2**]

Table 2. Soluble Salt Test Values and Relative Sensitivity Levels of Plants

Electrical Conductivity[1] (dS/m)	Salinity Level	Effect on Plant Growth
0 to 2	non-saline	none
2.1 to 4	very slight saline	sensitive plants are inhibited
4.1 to 8	moderately-saline	many plants are inhibited
8.1 to 16	strongly-saline	most cultivated plants are inhibited
over 16	Very strongly-saline	few plants are tolerant

[1] Saturated paste extract

Managing Soil Salts

Leaching Salts

Leaching is the only practical way of removing excess salts. This is effective only to the extent that water moves down through the soil profile and beneath the root zone (drainage must be good). The amount of salts removed depends on the quantity and quality of water leached through the soil profile during a single irrigation period. Water should be low in salts (high quality) and must not run off the surface. It should be applied slowly so amounts do not

exceed the ability of the soil to take in water (infiltration rate). If you see pets urinate on a plant, rinse, and flush with water within 8 hours.
The following amounts of water applied in a single, continuous irrigation will dissolve and decrease soil salts by these fractional amounts:

- 6 inches of water will leach about 1/2 the salt.
- 12 inches of water will leach about 4/5 of the salt.
- 24 inches of water will leach about 9/10 of the salt.

Salty soils are not reclaimable when the soil's clay content, compaction, or hardpan prevents leaching.

Adding Soil Amendments

Because manure, biosolids, and compost made from manure or biosolids may be high in salts, do not add more than 1 inch per season without a soil test to evaluate salt levels. An amendment with up to 10 dS/m total salts is acceptable if mixed through the upper six to eight inches of a low-salt soil (less than 1 dS/m). Amendments with a salt content greater than 10 dS/m are questionable. Avoid these soil amendments in soils that are already high in salts (above 3 dS/m) and when growing salt sensitive plants.

Note: Because soil amendments are not regulated in Colorado, do not assume that products sold in bags or by bulk are necessarily low in salt content and good for the garden's soil. Many commercially available sources of manure, biosolids, and compost made with manure or biosolids have excessively high levels of salt. Some companies do test, so ask if they have recent salt levels of the amendment.

On marginally salty soils, concentrate on gradually improving the soil organic content and activity of soil microorganisms and earthworms. Do not exceed recommended rates per application as large quantities of organic matter can hold salts next to plant roots and cause injury. Organic amendments applied over time improve soil tilth, which then will improve the potential for effective leaching as well as plant growth.

Other Management Techniques

Plants grown on salty soils are less tolerant of dry soil conditions because high salt levels make it difficult for plants to uptake water. Plants will require more frequent irrigation, with reduced amounts of water.

Within pedestrian and vehicle safety limits, avoid the use of de-icing salts. Consider the use of sand or other abrasive materials for use on slick sidewalks and pavement. Where de-icing salts are routinely used, expect to find salt problems in adjacent soils and drainage swales where the snowmelt runs. Because soil salt levels from de-icing salts easily rise above the tolerance of even the most salt- tolerant plants, a rock mulch area without plants may be a better landscape design solution in salt use areas.

For additional details on soil salt issues, refer to the following CSU Extension Fact Sheets:
- #7.227, Growing Turf on Salt-Affected Sites.
- #0.503, Managing Saline Soils.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised October 2015 by Susan Carter, CSU Extension. Reviewed August 2022 by Sarah Schweig, CSU Extension.

MASTER GARDENER
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CMG GardenNotes #231

Plant Nutrition

Outline:

Nutrition and Fertilization

Plant nutrition refers to the chemical elements required for plant growth and reproduction. Most plants require at least sixteen different elements. Those that are used in greater amounts (Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, and Sulfur) are known as ***macronutrients***; those used in smaller amounts as ***micronutrients*** (Iron, Manganese, Zinc, Copper, Boron, Molybdenum, Chlorine, Nickel, and Cobalt). Both macro- and micro-nutrients are essential to plant growth; the prefixes refer to *amount required* rather than importance.

The term ***fertilization*** refers to the application of plant nutrients to supplement the nutrients naturally occurring in the soil. Nutrients may be applied as synthetic fertilizers, organic fertilizers, and/or as a component of other soil amendments, e.g., compost. Organic fertilizers and soil amendments are typically lower in plant-available nutrient content than their synthetic counterparts, i.e., more is required for the same nutritional benefit. Fertilizers are standardized and labeled with their nutritional content; soil amendments are not.

Adequate soil fertility is only one of the many soil-related factors affecting plant growth. Fertilizers will increase desirable plant growth only if the plant is deficient in the nutrient(s) applied and other growth factors are also not significantly limiting. **Fertilization will not compensate for poor soil preparation, the lack of water, weed competition, or other non-nutrient growth limiting factors!** Fertilization will not enhance desired growth if the nutrients applied are not deficient.

Plants obtain the macronutrients carbon, hydrogen, and oxygen from the air and water. The remaining plant nutrients must be absorbed as ionic forms from the soil. Typically, these ions are made available to the plant by the activity of soil microbes, though a few are provided by chemical reactions not requiring mediation by other organisms. A plant cannot “tell” if applied nutrients come from a manufactured fertilizer or a natural source. Soil microorganisms must break down organic soil amendments, organic fertilizers, and many manufactured fertilizers before the nutrients become usable by plants.

From a nutritional perspective, the primary difference between synthetic and organic fertilizers or soil amendments is the concentration of nutrients and the speed at which they become available for plant use.

A non-nutritional benefit of certain organic fertilizers and soil amendments includes improved soil tilth (suitability of the soil to support plant growth). This should not be confused with fertilization, a distinctly different soil management objective.

Plant Nutrients

Because nitrogen, phosphorus, and potassium are used in the largest amounts by plants, they are often the most supplemented in the form of fertilizers, particularly in agriculture or intensive growing. [**Table 1**]

Micronutrients are needed in amounts typically available in most soils and are only supplemented in situations where soil chemistry particular to a place renders them less available, or in soilless growing systems like containers or hydroponics. [**Table 1**]

Table 1. Essential Plant Nutrients

Nutrient, Chemical Abbreviation	Ions Absorbed by Plants
Macronutrients	
Carbon, C	CO_2
Hydrogen, H	H_2O
Oxygen, O	O_2
Nitrogen, N	NO_3^-, NH_4^+
Phosphorus, P	$H_2PO_4^-$, HPO_4^{-2}
Potassium, K	K^+
Calcium, Ca	Ca^{2+}
Magnesium, Mg	Mg^{2+}
Sulfur, S	SO_4^{-2}
Micronutrients	
Boron, B	H_3BO_3; $B(OH)_4^-$
Chlorine, Cl	Cl^-
Cobalt, Co	Co^{+2}
Copper, Cu	Cu^{+2}
Iron, Fe	Fe^{+2}, Fe^{+3}
Manganese, Mn	Mn^{+2}
Molybdenum, Mo	MoO_4^{-2}
Zinc, Zn	Zn^{+2}

Roots take up nutrients as *ions* dissolved in the soil's water. The ions may be positively charged (***cations***) or negatively charged (***anions***). The nutrient ion soup in the soil water is in a constant state of flux as the variety of ions dissolve into and precipitate out of solution.

Clay particles and organic matter in the soil are negatively charged, attracting the positively charged cations (like ammonium, NH_4^+, and potassium, K^+) and making the cations resistant to leaching.

The ***Cation Exchange Capacity, CEC***, is a measurement of the soil's capacity to hold cation nutrients. More precisely, it is a measurement of the capacity of the negatively charged clay and organic matter to attract and hold positively charged cations. CEC is useful in comparing the potential for different soils to hold and supply nutrients for plant growth.

Negatively charged anions (like nitrate, NO_3^-) are prone to leaching from soil, quickly becoming unavailable to plants. They can become a water pollution problem.

Colorado Soils and Plant Nutritional Needs

While any particular soil could have a wide range of mineral concentrations and potential deficiencies for any given crop, a few more commonly cause problems for gardeners in much of the state.

Nitrogen

Nitrogen is the one nutrient most often limiting plant growth. The need for nitrogen varies from plant to plant. For example, tomatoes and vine crops (cucumbers, squash, and melons) develop excessive vine growth at the expense of fruiting with excess nitrogen. Potatoes, corn and cole crops (cabbage, broccoli, and cauliflower) are heavy feeders and benefit from high soil nitrogen levels. Bluegrass turf and many annuals also benefit from routine nitrogen applications. Trees and shrubs have a low need for nitrogen compared to vegetables and annuals, and many drought-tolerant plants are not limited by nitrogen in most cases. Plants growing in Colorado soils benefit from nitrogen fertilization of the right amount and frequency to meet plant needs. General symptoms of nitrogen deficiency are shown in **Figure 1**.

Figure 1. Symptoms of Nitrogen Deficiency

Leaves
- Uniform yellowish green.
- More pronounced in older leaves.
- Small, thin leaves.
- Fewer leaflets.
- High fall color.
- Early leaf drop.

Shoots
- Short, small diameter.
- May be reddish or reddish brown.

Soil tests have limited value in indicating nitrogen needs for a home garden or lawn because the nitrogen levels are constantly changing due to microbial activity, plant uptake, and changes in temperature and water. Soil tests for nitrogen need to be repeated at regular intervals through the growing season to be of use.

Plants can absorb nitrogen in its three ionic forms: **ammonium** (NH_4^+), **nitrite** (NO_2^-), and **nitrate** (NO_3^-). Ammonium is generated when microbes break down organic matter in the soil. Being positively charged, ammonium is attracted to the negatively charged soil particles and thus is resistant to leaching (movement down through the soil profile). Because microbial activity is closely tied to soil conditions, the temperature, moisture, pH, and soil oxygen can all have significant effects on soil nitrogen availability. Other soil microorganisms quickly convert ammonium to nitrate in well oxygenated soils. Nitrite and nitrate, being negatively charged, readily leach below the root zone. Nitrite is toxic to plants but extremely short-lived, usually being quickly further oxidized to nitrate, so is not absorbed by plants in most cases. Most plant nitrogen is absorbed as nitrate. Nitrate either quickly is absorbed by plant roots or is leached from the soil profile, so it is rarely found in soil tests of the root zone. Prevent water pollution by avoiding over-fertilization with nitrogen. Certain plants (legumes) develop mutualistic relationships with nitrogen-fixing bacteria and can therefore access elemental nitrogen (N_2) directly from the atmosphere.

Soil microorganisms release nitrogen tied up in organic matter over a period of time. Release rates from compost are very slow (years). The need for nitrogen fertilizer is based on the organic matter content of the soil. [**Table 2**]

Table 2. Need for Nitrogen Fertilizer Based on Soil Organic Content

Soil Organic Content	Routine Application Rate For Gardens
1%	2 pounds actual N / 1000 square feet
2-3%	1-pound actual N / 1000 square feet
4-5%	0

Iron

Most of the iron in soil is in the form of stable mineral compounds. At high pH, iron oxides (rusts) are resistant to entering the soil water solution. Only at lower pH can iron be reduced to a form that can be absorbed by plants. For every unit of increase in pH, the solubility of iron decreases by a factor of 1,000. Many soils in Colorado have high pH, making some plants grown in them susceptible to iron chlorosis. ***Iron chlorosis*** refers to a yellowing of leaves caused by an iron deficiency in the leaf tissues. Primary symptoms include ***interveinal chlorosis*** (yellowing of leaves with veins remaining green). Because iron is not readily moved within plants once incorporated, symptoms appear on younger leaves and on new growth. In severe cases, leaves may become pale yellow or whitish, while veins retain a greenish tint. Angular brown spots may develop between veins and the leaf margins may ***scorch*** (become brown along the edge). Symptoms may show on a portion or on the entire plant. General symptoms of iron chlorosis are shown in **Figure 2**.

Figure 2. Symptoms of Iron Chlorosis

Leaves
- General yellowing of leaf with veins remaining green.
- More pronounced in younger leaves and new growth.
- Angular brown spots and marginal scorch.
- Smaller.
- Curl, dry up, and fall early.

Branches
- May show on a single branch or the entire plant.

In western, high pH soils, iron is not deficient in an absolute sense, rather, it is unavailable for plant uptake due to the soil's high pH. At high pH, iron is quickly oxidized into rust compounds. Plant-available iron is the result of microbial activity generating local supplies of reduced iron (that is, not oxidized into rusts) in the soil profile. In addition to high pH, iron chlorosis can be exacerbated by conditions that reduce soil microbial activity, including the following:

- **Cool, wet soils in spring**. Attention to irrigation management can help correct iron chlorosis.
- **Soil compaction** and low soil oxygen (which limit microbial activity).

Furthermore, iron chlorosis can be a symptom of physical damage to trees and shrubs, including trunk-girdling roots and bark injury associated with winter sunburn.

Attention to these contributing factors can solve a chlorosis issue without the need for adding iron products.

Iron fertilizers typically take the form of ***chelated*** (KEY-lated) ***iron***; iron that is part of a soluble complex of organic molecules. Not all chelation products are effective at high soil pH; in soils with a pH above 7, as in much of Colorado, only the product abbreviated EDDHA is capable of supplying iron to plants. Many plants, particularly those native to the arid regions of the western USA, are naturally able to extract iron from high pH soils and rarely display iron chlorosis.

Phosphorus

Phosphorus, **P**, is a primary nutrient in plant growth. ***Phosphate***, P_2O_5, is an ionic compound containing two atoms of phosphorus and five atoms of oxygen. The *phosphorus* content of fertilizer is measured in percent *phosphate*.

Phosphorus may be present in high concentrations in soils; however, it may not be in a plant available form. Deficiencies are most likely to occur in new gardens where the organic matter content is low, and the soil has a high pH (7.8 to 8.3). A soil test is the best method to determine the need for phosphorus fertilizers.

Phosphorus deficiency is difficult to diagnose because other growth factors will give similar symptoms. General symptoms include sparse, green to dark green leaves. Veins, petioles, and lower leaf surface may be reddish, dull bronze, or purple, especially when young. Phosphorus deficiency may be observed on roses in the early spring when soils are cold, but the condition corrects itself as soils warm.

Excessive phosphorus fertilizer can aggravate iron and zinc deficiencies, and increase the soil salt content. Many home gardener soils are significantly over fertilized with phosphates, aggravating soil salts and iron chlorosis. Typically, the over fertilization results from over application of compost.

Potassium

Potassium*, K**, is a primary nutrient in plant growth. The word ***potash, refers to various mined or manufactured potassium salts, including potassium chloride and potassium sulfate. The potassium content of fertilizer is measured in percent potash.

Potassium levels are naturally adequate and even high in most Colorado soils. Unlike nitrogen and phosphorus, which are usually found in soils in organic compounds, potassium is usually in minerals or mineral lattices and can therefore still be largely unavailable to plants, even if absolute potassium levels are high. Deficiencies more commonly occur in sandy soils low in organic matter. Organic matter and clay particles, with their many negatively charged binding sites, provide a reservoir of potassium that is available to plants.

A soil test is the best method to determine the need for potassium fertilizers.

Potassium deficiency is difficult to diagnose because other growth factors, including nitrogen deficiency, will cause similar symptoms. General symptoms include marginal and interveinal chlorosis (yellowing), followed by scorching that moves inward. Older leaves are affected first, because potassium is highly mobile within plants. Leaves may crinkle and roll upward. Shoots may show short, bushy, zigzag growth, with dieback late in the season.

Excessive potassium fertilizer can aggravate soil salt levels. Many home garden soils are over fertilized with potash, leading to salt problems.

Zinc

Zinc concentrations in the soil are naturally quite low, and particularly low in soils with high pH and that contain calcium carbonates.

Sweet corn, beans, and potatoes are the most likely vegetables to be affected by zinc deficiency. Symptoms include a general stunting of the plant due to shortening of internodes (stem length between leaves). Leaves on beans typically have a crinkled appearance and may become yellow or brown. On young corn, symptoms include a broad band of white-to-translucent tissue on both sides of the leaf midrib starting near the base of the leaf, but not extending to the tip.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised October 2015 by Dan Goldhamer, CSU Extension. Reviewed August 2023 by John Murgel, CSU Extension.

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MASTER GARDENER
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CMG GardenNotes #232

Understanding Fertilizers

Fertility is only part of the soil management process. Colorado soils are naturally low in organic matter. To maximize productivity, our soils also need routine applications of organic matter to improve soil tilth. For flower and vegetable gardens, it is desirable to raise the soil organic content, over time, to 4-5%.

Manufactured fertilizers are popular with gardeners because they are readily available, inexpensive, easy to apply, and generally provide a quick release of nutrients for plant growth. Application rates depend on the nutrient need of the soil and the percentage of nutrients in the specific fertilizer. **In products containing multiple nutrients, the application rate is always based on the nitrogen content.**

Fertilizer or Soil Amendment?

By legal definition, the term **fertilizer** refers to a soil amendment that guarantees the minimum percentages of nutrients (at least the minimum percentage of nitrogen, phosphate, and potash).

An **organic fertilizer** refers to a soil amendment derived from natural sources that guarantees, at least, the minimum percentages of nitrogen, phosphate, and potash. Examples include plant and animal by-products, rock powders, seaweed, inoculants, and conditioners. These are often available at garden centers and through horticultural supply companies.

These should not be confused with substances approved for use with the **USDA National Organic Program (NOP)*.*** The USDA NOP, with its "USDA Organic" label, allows for the use of only certain substances. The Organic Materials Review Institute, https://www.omri.org/, and the Washington Department of Agriculture (WSDA), https://agr.wa.gov/, review and approve brand name products made with ingredients from the "national list" for use in certified organic production. If a fertilizer is not OMRI or WSDA approved, it may still be allowed for organic production but has not been reviewed and deemed suitable for use in certified production. To learn more about which inputs are allowed and which are prohibited refer to https://www.ams.usda.gov/rules-regulations/national-list-allowed-and-prohibited-substances.

Many of the organic fertilizers listed here will meet NOP standards based on the National List. Growers participating in the NOP should consult with their certifier to ensure compliance for organic certification.

The term **soil amendment** refers to any material mixed into a soil. **Mulch** refers to a material placed on the soil surface. In Colorado, soil amendments contain no legal claims about nutrient content or other helpful or harmful effects they will have on the soil and plant growth. In Colorado, the term **compost** is also unregulated, and could refer to any soil amendment regardless of active microorganism activity.

Many gardeners apply organic soil amendments, such as compost or manure, which most often do not meet the legal requirements as a "fertilizer" but add small amounts of nutrients.

What is in a Fertilizer?

Analysis or Grade

By law, all products sold as fertilizer require uniform labeling guaranteeing the minimum percentage of nutrients. The three-number combination (fertilizer **grade** or **analysis**) on the product identifies percentages of nitrogen, N, phosphate, P_2O_5, and potash K_2O, respectively. For example, a 20-10-5 fertilizer contains 20% nitrogen, 10% phosphate, and 5% potash.

Note: **Phosphorus, P**, is a primary nutrient in plant growth. The word **phosphate**, P_2O_5, refers to the ionic compound containing two atoms of phosphorus with five atoms of oxygen. The phosphorus content of fertilizers is measured in percent phosphate.

Note: **Potassium, K**, is a primary nutrient in plant growth. The word **potash**, K_2O, refers to the ionic compound containing two atoms of potassium with one atom of oxygen. The potassium content of fertilizers is measured in percent potash.

The product may also identify other nutrients, such as sulfur, iron, and zinc, if the manufacturer wants to guarantee the amount. This may be done by placing a fourth number on the product label and identifying what nutrient was added in the ingredients.

Ratio

Fertilizer **ratio** indicates a comparative proportion of nitrogen to phosphate to potash. For example, a 15-10-5 fertilizer has a ratio of 3-2-1, and an 8-12-4 fertilizer has a ratio of 2-3-1. **Fertilizer recommendations from a soil test are given in ratios.**

When shopping for a fertilizer, select a product with a ratio somewhat similar to what is desired. For example, if a soil test recommended a 2-1-0 ratio, the ideal fertilizer would be something like 8-4-0, 10-5-0, or 20-10-0. However, if you cannot find that exact fertilizer, an 8-4-2 would be similar. If a garden soil test calls for a 1-0-0 ratio, a 21-0-0 or 24-2-2 fertilizer would be similar.

Formulation

The **formulation** tells what specific kinds of fertilizer are in the product. **Table 1** gives examples of manufactured fertilizers that could be mixed to derive any specific analysis, ratio, or brand name.

Table 1. Examples of Manufactured Fertilizers

Product	N%	P_2O_5%	K_2O%
Ammonium nitrate	34	0	0
Ammonium sulfate	21	0	0
Urea	48	0	0
Ammoniated super-phosphate	3-6	48-53	0
Di-ammonium phosphate	11	48	0
Mono-ammonium phosphate	11	48	0
Super-phosphate	0	18-50	0
Triple super phosphate	0	46	0
Potassium chloride	0	0	60
Potassium nitrate	13	0	44
Potassium sulfate	0	0	50
Potassium-magnesium sulfate	0	0	22

What else is in the fertilizer? In a manufactured fertilizer, the grade does not add up to 100% because the fertilizer also contains other elements like carbon, hydrogen, oxygen, sulfur, iron, zinc, etc. For example, ammonium nitrate, NH_4^+ NO_3, has a grade of 34-0-0 with 34% of the content from nitrogen and 66% from hydrogen and oxygen. Ammonium sulfate, NH_4^+ SO_2^- , has a grade of 21-0-0 with 21% from the nitrogen and 79% from the hydrogen, sulfur, and oxygen.

Time release or **slow-release** fertilizers contain coatings or are otherwise formulated to release the nutrients over a period of time as water, heat, and/or microorganisms break down the material. [**Table 2**]

Table 2. Examples of Quickly and Slowly Available Nitrogen

Quickly available nitrogen • Lasts 4-6 weeks	Ammonium sulfate Ammonium nitrate Calcium nitrate Potassium nitrate Urea
Slowly available nitrogen • Available over weeks to months • Regulated by solubility or microorganism activity	Resin-coated urea Sulfur-coated urea Isobutylidene diurea (IBDU) Methylene urea Urea formaldehyde Manure Poultry wastes Blood meal

In an "organic" type fertilizer, the base is decomposed or processed plant and/or animal by-products. For example, fish emulsion is ground and processed non-edible fish or fish scraps. Its nutrient content would be around 8-4-2, with 8% from nitrogen, 4% from phosphate, and 2% from potash.

Some manufactured and "organic" fertilizers contain fillers, which are used to prevent caking, control dust, derive the desired grade, or to facilitate ease of application.

Complete fertilizer is a term used to identify fertilizers that contain nitrogen, phosphorus, and potassium. In the national home garden trade, most fertilizers are complete. However, in Colorado many gardens do not need phosphorus or potassium. It is advisable to avoid heavy applications of phosphate and potash when unneeded as they contribute to soil salts.

Nitrogen Applications

Nitrogen is the nutrient needed in largest quantities as a fertilizer. Nitrogen is annually applied by manufactured fertilizer, organic fertilizers, and/or organic soil amendments. **Application rates are critical, because too much or too little directly affects crop growth.**

Application rate is based on the soil organic content. As the organic content increases, nitrogen will be slowly mineralized (released) by the activity of soil microorganisms. Standard application rates for gardens are given in **Table 3**.

Nitrogen fertilizer can be broadcast and watered in or broadcast and tilled into the top few inches of soil. It can be banded 3-4 inches to the side of the seed row. Do not place the fertilizer in the seed row or root injury may occur.

For additional information on fertilizers refer to the CMG GardenNotes #234*,* Organic Fertilizers, and GN#711*,* Vegetable Gardens: Soil Management and Fertilization.

Table 3. Nitrogen Fertilizer Application Rates for Home Gardens

	Soil Organic Content		
	Typical garden soil low in organic matter (0-1% organic matter)	Moderate level of organic matter (2-3% organic matter)	High level of organic matter (4-5% organic matter)
Nitrogen needed	**0.2 lb. actual N per 100 square feet**	**0.1 lb actual N per 100 square feet**	**0**
Fertilizer to apply			
Ammonium sulfate 21-0-0	1 lb. fertilizer per 100 square feet approximately 2 cups	0.5 lb. fertilizer per 100 square feet approximately 1 cup	0
OR Ammonium nitrate 34-0-0	0.6 lb. fertilizer per 100 sq. ft. approximately 1 1/3 cups	0.3 lb. fertilizer per 100 sq. ft approximately 2/3 cup	0
OR Urea, 45-0-0	0.4 lb. fertilizer per 100 sq. ft. approximately 1 cup	0.2 lb. fertilizer per 100 sq. ft approximately ½ cup	0

Phosphate and Potash Applications

A soil test is the best method to determine the need for phosphate and potash. When a fertilizer contains a combination of nitrogen with phosphate and/or potash, the application rate is always based on the nitrogen percentage, because nitrogen levels are most critical to plant growth. Phosphate and potash fertilizers are best applied in the spring or fall when they can be tilled into the soil.

Phosphorus

Phosphorus may be present in high concentrations; however, it may not be in a plant available form. With annual applications of compost or manure, phosphorus levels will likely be adequate. Deficiencies are most likely to occur in new gardens where the organic matter content is low and in soils with a high pH (7.8 to 8.3).

Excessive phosphorus fertilizer can aggravate iron, zinc deficiencies, and increase soil salt content.

Where phosphate levels are believed to be low, the standard application rate without a soil test is ¼ to 1 pound triple super phosphate (0-46-0) or ammonium phosphate (18-46-0) per 100 square feet.

When a phosphate fertilizer is applied to a soil, the phosphorus is quickly immobilized in the soil profile. It typically moves only about an inch. Therefore, it needs to be tilled into the rooting zone to be most effective.

Phosphorus and Water Quality

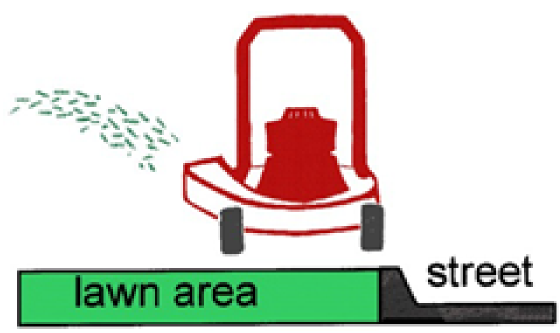
In surface water, low phosphorus levels limit the growth of algae and water weeds. However, when the phosphorus content of surface water increases, algae and water weeds often grow unchecked, a process called eutrophication. This significant decrease in water quality is a major problem related to manure management in production agriculture and the handling of yard waste from the landscape environment.

Popular press articles often incorrectly point to phosphorus-containing lawn and garden fertilizers as the major source of phosphate water pollution. Phosphate fertilizers are rather immobile when applied at correct rates to lawn and garden soils.

However, high rates of manure applied year after year will build soil phosphorus content where leaching becomes a water quality problem. In sandy soils coupled with high rainfall/irrigation, excessive application rates of organic or manufactured fertilizers may also lead to water quality concerns.

The primary source of water polluting phosphorus in the landscape environment is the mowing, sweeping, or blowing of lawn clipping and leaves onto the gutter and street. When mowing, mow in a direction that blows the clippings onto the lawn rather than onto the sidewalk or street. Also sweep any grass on the sidewalk/driveway onto the grass. Avoid blowing autumn leaves into the street. [**Figure 1**]

Figure 1.
Grass clippings and leaves mowed or blown into the street are the major source of phosphate pollution from the landscape environment. Mow in a direction to discharge clippings back onto the lawn and not into the street.



Phosphate in fertilizer is immobilized upon contact with soil and is not a source of phosphate pollution when applied to a lawn (or garden) soil. However, fertilizer over-spread onto the sidewalk, driveway, and street moves with surface runoff into local lakes, streams, and ponds. Exercise caution when fertilizing to keep the phosphate out of the street.

It is also important to leave an un-mowed buffer strip edging all lakes, streams, ponds, and wetlands rather than mowing plant residues into the water.

Second to yard waste management, over-spreading fertilizers onto hard surface (sidewalks, driveways, and streets) adds to surface water pollution. When applying fertilizer, avoid spreading the fertilizer onto hard surfaces where it will wash into local surface water through the storm sewer system. Sweep any fertilizer that landed on the sidewalk/driveway onto the lawn area.

Another particularly important source of phosphorus pollution in the landscape setting is soil erosion from new construction sites, unplanted slopes, and poorly maintained landscapes. When the soil moves, it takes the soil bound phosphorus with it. For good water quality, sloping ground needs to be planted with year-round plant cover to prevent soil erosion.

Potassium

Potassium levels are naturally adequate to high in most Colorado soils. With annual applications of compost or manure, potassium levels will likely be adequate. Deficiencies occasionally occur in new gardens low in organic matter and in sandy soils low in organic matter. A soil test is the best method to determine the need for potassium.

Excessive potash fertilizer can increase soil salt content.

Where potash levels are believed to be low, the standard application rate without a soil test is ¼ to ½ pound potassium chloride (0-0-60) or potassium sulfate (0-0-50) per 100 square feet.

Movement of potassium in soils is dependent on soil texture. As the clay content increases, movement decreases. For most soils, it is important that applied potash be tilled into the root zone. In sandy soils, potassium could leach down past the root zone.

Specialty Fertilizers

Specialty fertilizers may be preferred for specific purposes. For example, slow-release fertilizers are recommended for lawns (see lawn care information for details). Slow release or time release fertilizers give out small quantities of nutrients over a period of time. The release may be controlled by water, temperature, or microbial activity. For trees and shrubs, use only slow-release products.

For planters and hanging baskets, two popular specialty fertilizers include time release products (e.g., Osmocote) and water solubles (e.g., Miracle-Gro, Peters, etc.).

Time release fertilizers such as Osmocote are designed for indoor and outdoor potted plants. Each time the soil is watered, a small amount of nutrients is released. Depending on the specific formulation, it would be applied to the soil once every 3 to 9 months. In outdoor pots watered daily, it releases faster, having about half the life span of the product used on indoor plants. Gardeners sometimes see the Osmocote pellets in potted plants and mistake them for insect eggs.

Numerous brands of water solubles are popular in the home garden trade, (e.g., Miracle-Gro, JR Peters, Schultz Plant Food, Fertilome Root Stimulator, etc.). Water soluble fertilizers are mixed with irrigation water, typically giving a blue or green color. This can be done in a bucket or hose-on fertilizer applicator. It is important to water the soil with the fertilizer water, not just wet the leaves. Water solubles are the standard in greenhouse production where the fertilizer is injected into the irrigation water.

Note: Hose-on fertilizer applicators and hose-on pesticide sprayers are not the same thing.

Fertilizer applicators apply a higher volume as the purpose is to water the soil. Pesticide applicators release a lower volume, as wetting the leaf is the objective.

For herbaceous transplants (flowers and vegetables), water soluble fertilizers are recommended at planting and two and four weeks after planting, depending on soil organic matter content. These are often marketed as root stimulators. It is the nitrogen content that promotes growth rather than any hormones or vitamins in the product. In cool springtime soils, the readily available phosphate may also be helpful. Woody plants - trees and shrubs, do not respond to water soluble fertilizer at planting. Always read the label directions to avoid over-fertilization.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Revised 2015 and reviewed July 2022 by Dan Goldhamer, CSU Extension.

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CMG GardenNotes #233

Calculating Fertilizer Application Rates

Steps to Calculating Fertilizer Application Rate

Example is for a 40-foot by 100-foot lawn area, using a 20-10-0 fertilizer.

1. **Calculating size of area to be fertilized**

   Feet long x feet wide = square feet

   Example: 40 feet x 100 feet = 4000 square feet

2. **Calculating fertilizer application rate**

   $$\frac{\text{Pound nutrient per square foot}}{\text{\% nutrient in fertilizer}} = \text{pounds fertilizer/ square feet}$$

   Example:
   $$\frac{\text{1 pound nutrient per 1000 square feet}}{\text{20\% nutrient in fertilizer}} = \text{5 pounds fertilizer/1000 square feet}$$

3. **Calculating pounds of fertilizer to apply**

   Lawn or garden area x application rate = pound of fertilizer per garden or lawn

   $$\frac{\text{\_\_\_\_ square foot}}{\text{garden or lawn}} \times \frac{\text{\_\_\_\_ pounds fertilizer}}{\text{\_\_\_\_ square foot}} = \frac{\text{pounds fertilizer}}{\text{garden or lawn}}$$

   Example:
   $$\frac{\text{4000 square feet}}{\text{lawn}} \times \frac{\text{5 pounds fertilizer}}{\text{1000 square feet}} = \frac{\text{20 pounds fertilizer}}{\text{lawn}}$$

Because soil test recommendations for any given soil do not exactly match a fertilizer, select a fertilizer that gives comparative amounts of nitrogen, phosphorus and potassium as recommended by the soil test. In fertilizer application, it is most important to match the nitrogen requirement and compromise some for the phosphorus and potassium. The amount of fertilizer to apply that will give the recommended amount of nitrogen can be obtained from the following table:

Table 1. Fertilizer Application Rate Table

Amount of Fertilizer to Apply Based on Actual Nitrogen Recommendations			
Nitrogen Rate:	0.1 pound nitrogen per 100 square feet	0.2 pound nitrogen per 100 square feet	1 pound nitrogen per 1000 square feet
Fertilizer Grade	Pounds fertilizer to apply per 100 square feet	Pounds fertilizer to apply per 100 square feet	Pounds fertilizer to apply per 1000 square feet
45-0-0 (urea)	0.2	0.4	2.2
37-3-3	0.3	0.5	2.7
36-6-6	0.3	0.6	2.8
33-0-0	0.3	0.6	3.0
32-4-4 32-3-10	0.3	0.6	3.1
30-4-4 30-0-10	0.3	0.7	3.3
28-3-3 28-4-6	0.4	0.7	3.6
27-7-7 27-3-3	0.4	0.7	3.7
25-5-5 25-3-12	0.4	0.8	4.0
24-8-16 24-0-15	0.4	0.8	4.2
22-4-4 22-6-3	0.5	0.9	4.5
21-0-0 21-3-12	0.5	1.0	4.8
20-20-20 20-4-8	0.5	1.0	5.0
19-19-19 19-11-12	0.5	1.0	5.3
18-6-12 18-3-6	0.6	1.1	5.6
16-8-8 16-4-8	0.6	1.3	6.3
15-15-15 15-5-5	0.7	1.3	6.7
13-3-9 13-25-12	0.8	1.5	7.7
12-12-12 12-4-4	0.8	1.7	8.3
10-10-10 10-20-10	1.0	2.0	10.0
10-5-5 10-10-20	1.0	2.0	10.0
6-12-12 6-2-0	1.7	3.3	16.7
5-10-10 5-10-5	2.0	4.0	20.0

Example: If the N (nitrogen) recommendation is for 0.1 lb. N/100 square foot and the fertilizer grade selected has a ratio of 18-6-12 (column 1), apply 0.6 lb. of this fertilizer per 100 square feet.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; and Carl Wilson, CSU Extension, retired.
Reviewed October 2015 and July 2022 by Eric Hammond, CSU Extension.

Reviewed July 2022

CMG GardenNotes #234

Organic Fertilizers

Terms

The term ***soil amendment*** refers to any material mixed into a soil to improve soil properties.

Mulch refers to a material placed on the soil surface and is, therefore, not a soil amendment.

Fertilizer refers to a product that contains at least one essential available plant nutrient.

An ***organic fertilizer*** refers to a product derived from natural sources that contains at least one essential available plant nutrient. Examples include plant and animal by-products, rock powders, and seaweed. Organic fertilizers are often available at garden centers and through horticultural supply companies. Nutrients in organic fertilizers are often in a form inaccessible to plant uptake and need to be converted by soil microorganisms into bioavailable forms before plants can uptake these nutrients. As a result, organic fertilizers often result in the slower release of nutrients, compared to inorganic (or synthetic) fertilizers, and can also improve soil properties through the addition of organic matter.

These should not be confused with substances approved for use with the ***USDA National Organic Program (NOP).*** The USDA NOP, with its “USDA Organic” label, allows for the use of only certain substances. The Organic Materials Review Institute, https://www.omri.org, and the Washington Department of Agriculture (WSDA), https://agr.wa.gov, review and approve brand name products made with ingredients from the “national list” for use in certified organic production. If a fertilizer is not OMRI or WSDA approved, it may still be allowed for organic production but has not been reviewed and deemed suitable for use in certified production. To learn more about which inputs are allowed and which are prohibited, refer to https://www.ams.usda.gov/rules-regulations/national-list-allowed-and-prohibited-substances. Many of the organic fertilizers listed here will meet NOP standards based on the National List. Growers participating in the NOP should consult with their certifier to ensure compliance for organic certification.

Many gardeners apply *organic soil amendments*, such as ***compost*** or manure, which typically do not meet the legal requirements as a “fertilizer” but adds small amounts of nutrients. The term **compost** refers to organic matter that has been biologically degraded. While Colorado requires that commercial compost be sufficiently composted to reduce pathogens and vector transfer (C:N ratio must be 18:1 or less), there is no standard regarding the compost’s state of decomposition.

Two important terms related to the use of all soil amendments are the release time and the application of the product:

- **Release Time** – Organic products require the activity of soil microorganisms before nutrients are available for plant uptake. Microorganism activity is dependent on soil temperatures greater than 50ºF in the presence of sufficient soil moisture. Dry and/or cold soil conditions will delay the release of nutrients from these organic sources. This period refers to how long these products are available if applied to the soil. Use this information to time the application of the product.
- **Application** – Products may be applied in various ways. Some may be tilled in (worked into the soil with a machine or hand tool), others may be applied as a foliar spray (mixed with a surfactant and sprayed in a fine mist on the leaf surface while temperatures are below 80ºF), and some may be injected into a drip or overhead irrigation system (fertigation with a siphon mixer). Application rates in this fact sheet are generalized and based on some manufacturers' recommendations. Over- or under-fertilization may occur using these recommendations.

Before applying a fertilizer, conduct a soil test to determine what deficiencies your soil might have.

Plant By-Products

Alfalfa Meal or Pellets

Alfalfa meal or pellets are often used as animal feed. They are used primarily to increase organic matter in the soil but do offer nutrients and a high availability of trace minerals. They contain triacontanol, a natural fatty-acid growth stimulant.

Alfalfa Meal or Pellets	
Typical NPK analysis	2-1-2
Release time	1-4 months
Pros	Available at feed stores
Cons	May contain seeds
Application	Till in 2-5 pounds per 100 square feet

Corn Gluten Meal

Corn gluten meal has a high percentage of nitrogen. Products carry a warning to allow one to four months of decomposition in the soil prior to seeding. Allelopathic properties will inhibit the germination of seeds. However, there is no danger to established or transplanted plants.

This product is also marketed as a pre-emergent weed control for annual grasses in bluegrass lawns.

Corn Gluten Meal	
Typical NPK analysis	9-0-0
Release time	1-4 months
Pros	Very high nitrogen
Cons	Germination inhibitor, some are GMOs
Application	Till in 20-40 pounds per 1000 square feet

Cottonseed Meal

Cottonseed meal is a rich source of nitrogen. Buyers should be aware that many pesticides are applied to cotton crops and residues tend to remain in the seeds. Pesticide-free cottonseed meal is available.

Cottonseed Meal

Typical NPK analysis	6-0.4-1.5
Release time	1-4 months
Pros	High nitrogen
Cons	Pesticide residues, most are GMOs
Application	Till in 10 pounds per 100 square feet

Soybean Meal

Soybean meal is used primarily as an animal feed product. It is available bagged at many feed stores. Soybean meal may inhibit the germination of seeds, so it should be applied several weeks before planting.

Soybean Meal

Typical NPK analysis	7-2-1
Release time	1-4 months
Pros	High nitrogen, available at feed stores
Cons	Almost ½ the conventionally grown soy is GMO
Application	8 pounds per 100 square feet

Animal By-Products

Bat Guano

Bat guano (feces) harvested from caves is powdered. It can be applied directly to the soil or made into a tea and applied as a foliar spray or injected into an irrigation system. Bat guano can have a high nitrogen content, or it can also be processed for high phosphorus content.

Bat Guano – High N

Typical NPK analysis	10-3-1
Release time	4+ months
Pros	Stimulates soil microbes
Cons	Cost
Application	Till in 5 pounds per 100 square feet or as a tea at 3 teaspoons per gallon of water

Bat Guano – High P

Typical NPK analysis	3-10-1
Release time	4+ months
Pros	Stimulates soil microbes
Cons	Cost
Application	Till in 5 pounds per 100 square feet or as a tea at 3 teaspoons per gallon of water

Blood Meal

Blood meal, made from dried slaughterhouse waste, is one of the highest non-synthetic sources of nitrogen. If over-applied, it can burn plants due to excessive ammonia.

Blood Meal

Typical NPK analysis	12-0-0
Release time	1-4 months
Pros	Available at feed stores
Cons	Can burn. Expensive at garden centers
Application	Till in 5-10 pounds per 100 square feet

Bone Meal
A well-known source of phosphorus, bone meal is steam processed and widely available at feed stores and in garden centers. If purchased at feed stores, phosphorus is expressed on the label as elemental phosphorus and is 2.3 times higher than numbers shown on garden center labels for phosphate (i.e. – 12% phosphate is the same as 27% phosphorus). **However, recent CSU research has shown that phosphorus from bone meal is only available to plants in soils that have a pH below 7.0.**

Bone Meal

Typical NPK analysis	3-15-0
Release time	1-4 months
Pros	High plant available form of phosphorus
Cons	Cost
Application	Till in 10 pounds per 100 square feet

Feather Meal
Sourced from poultry slaughter, feather meal has fairly high nitrogen levels but is slow to release the nitrogen.

Feather Meal

Typical NPK analysis	N varies 7-12% on process
Release time	4+ months
Pros	Long term fertilizer
Cons	Cost versus speed of nitrogen release
Application	Till in 2.5-5 pounds per 100 square feet

Fish Emulsion
Infamous for its foul smell, emulsions are soluble, liquid fertilizers made of fish waste that have been heat and acid processed.

Fish Emulsion

Typical NPK analysis	5-2-2
Release time	1-4 months
Pros	Adds needed micronutrients
Cons	Some have foul smell
Application	Mix 6 tablespoons per gallon of water

Enzymatically Digested Hydrolyzed Liquid Fish
Enzymatically digested hydrolyzed liquid fish products use enzymes to digest the nutrients from fish wastes instead of using heat and acids. This retains more of the proteins, enzymes, vitamins, and micronutrients than emulsions.

Enzymatically Digested Hydrolyzed Liquid Fish

Typical NPK analysis	4-2-2
Release time	1-4 months
Pros	More nutrients than emulsions
Cons	More expensive than emulsions
Application	Mix 5 tablespoons per gallon of water

Fish Meal
Fish meal is ground and heat dried fish waste.

Fish Meal

Typical NPK analysis	10-6-2
Release time	1-4 months
Pros	N and P source
Cons	Heat processed
Application	Till in 5-10 pounds per 100 square feet

Fish Powder
Fish powder is dried with heat and turned into water-soluble powder. It is a high source of nitrogen. It can often be mixed into a solution and injected into an irrigation system.

Fish Powder

Typical NPK analysis	12-0.25-1
Release time	Immediate to 1 month
Pros	Adds micro-nutrients
Cons	Heat processed
Application	Till in 1-2 ounces per 100 square feet OR mix at 1 tablespoon per gallon of water

Rock Dust or Rock Powders

Rock dust or rock powders are made of finely crushed rock and can be used to supply the soil with certain minerals. A common example of rock dust is gypsum or lime, which is used as a source of calcium. Gypsum and lime are typically not needed in Colorado due to the naturally high calcium levels of many of our soils.

Rock powders that serve as a potassium source (greensand, feldspar, potassium sulfate, biotite, etc.) are typically not necessary here either, as many Colorado soils are naturally high in potassium.

For phosphorus deficiencies, home gardeners can use colloidal phosphate. Colloidal phosphate releases a small and steady supply of available phosphate (2-3%) and other micronutrients over several years. However, CSU research concluded that no rock phosphorus, regardless of mesh size, is available for plant use unless the soil pH is below 7.0. As a result, most Colorado gardeners will benefit from using plant or animal sources of phosphorus rather than rock phosphorus. If you are making annual applications of manure and/or compost to your garden to add nitrogen, you should have sufficient levels of phosphorus in your soil.

Seaweeds

Kelp is the most common form and is valued not for its macronutrient (nitrogen, phosphorus, and potassium) contributions but for its micronutrients.

Kelp is often mixed with fish products to enhance growth.

Three processes are available: extracts (as kelp meal or powder), cold-processed (usually liquid), and enzymatically digested (liquid).

In regard to quality of content and plant availability, they are ranked (highest to lowest) as 1) enzymatically digested, 2) cold-processed, and 3) extracts.

Kelp Meal
Kelp meal, a product of the ocean, is used primarily as a trace mineral source. It is often combined with fish meal to add nitrogen, phosphorus, and potassium.

Kelp Meal	
Typical NPK analysis	Negligible
Release time	4+ months
Pros	Adds micro-nutrients
Cons	Insignificant nitrogen, phosphorus, potassium
Application	Till in 1 pound per 100 square feet

Kelp Powder
Kelp powder is similar to kelp meal but it is ground fine enough so that it can be put into a solution and applied as a foliar spray or injected into an irrigation system.

Kelp Powder	
Typical NPK analysis	1-0-4
Release time	Immediate to 1 month
Pros	Adds micronutrients
Cons	Insignificant nitrogen, phosphorus, potassium
Application	Mix ¼ to ½ teaspoon/gallon of water

Liquid Kelp
Usually cold processed, liquid kelp will have higher levels of growth hormones than extracts. Some may also be enzymatically digested, making the growth hormones even more available to the plants.

Liquid Kelp	
Typical NPK analysis	Negligible
Release time	Immediate to 1 month
Pros	Adds micronutrients plus helps plants with stress
Cons	Insignificant nitrogen, phosphorus, potassium
Application	Mix 1-2 Tablespoons per gallon of water

Authors: Adrian Card, CSU Extension; David Whiting, CSU Extension, retired; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Revised October 2015 by Dan Goldhamer, CSU Extension. Reviewed March 2023 by Hania Oleszak, former CSU Extension employee.

Reviewed March 2023

MASTER GARDENER
COLORADO STATE UNIVERSITY
EXTENSION

CMG GardenNotes #241
Soil Amendments

Outline:

Terms

The term ***soil amendment*** refers to any material mixed into a soil to improve soil properties or plant growth.

Mulch refers to a material placed on the soil surface, often to suppress weeds, retain moisture, or reduce erosion.

Compost refers to organic matter that has been biologically degraded. While Colorado requires that commercial compost be sufficiently composted to reduce pathogens and vector transfer (C:N ratio must be 18:1 or less), there is no standard regarding the compost's state of decomposition.

Fertilizer refers to a product that contains at least one essential available plant nutrient.

Organic fertilizer refers to a product derived from natural sources that contains at least one essential available plant nutrient. Examples include plant and animal by-products, rock powders, seaweed, and inoculants. These are often available at garden centers and through horticultural supply companies. Nutrients in organic fertilizers are often in a form inaccessible to plant uptake and need to be converted by soil microorganisms into bioavailable forms before plants can uptake these nutrients. As a result, organic fertilizers often result in the slower release of nutrients, compared to inorganic (or synthetic) fertilizers, and can also improve soil properties through the addition of organic matter.

These should not be confused with substances approved for use with the ***USDA National Organic Program (NOP).*** The USDA NOP, with its "USDA Organic" label, allows for the use of only certain substances. The Organic Materials Review Institute, https://www.omri.org/, and the Washington Department of Agriculture (WSDA), https://agr.wa.gov/, review and approve brand name products made with ingredients from the "national list" for use in certified organic production. If a fertilizer is not OMRI or WSDA approved, it may still be allowed for organic production but has not been reviewed and deemed suitable for use in certified production. To learn more about which inputs are allowed and which are prohibited refer to https://www.ams.usda.gov/rules-regulations/national-list-allowed-and-prohibited-substances. Many of the organic fertilizers listed here will meet NOP standards based on the National List. Growers participating in the NOP should consult with their certifier to ensure compliance for organic certification.

Managing Soil Texture and Structure

Routine applications of organic matter should be considered an essential component of gardening and soil management. Organic matter improves the water and nutrient holding capacity of coarse-textured sandy soil. In a fine-textured clayey soil, the organic matter helps to bind the tiny clay particles into larger chunks, called aggregates, creating greater porosity. This improves water infiltration and drainage, air infiltration (often the most limiting aspect of plant growth) and allows for deeper rooting depths (allowing the plant to tap a larger supply of water and nutrients). Plants vary in their soil condition preferences, so consider those preferences and soil test results *before* adding organic matter or amending soils. For additional discussion, refer to CMG GardenNotes #213, *Managing Soil Tilth: Texture, Structure, and Pore Space*.

When using organic soil amendments, it is important to remember that only a portion of the nutrients in the product are available to plants in any one growing season. Soil microorganisms must first process the organic compounds into chemical ions ($NO3^-$, $NH4^+$, $HPO4^{-2}$, H_2PO4^-, K^+) before plants can use them.

Cultivate or hand-turn the organic matter thoroughly into the soil. Never leave it in chunks as this will interfere with root growth and water movement.

Table 1. Routine Application Rate for Compost

Site	Incorporation Depth[1]	Depth[2] of Compost[3] Before Incorporation
One-time application for lawns.	6 inches.	1-2 inches.
First-time application when installing vegetable or flower gardens.	8-12 inches.	3-4 inches.
Annual application to existing vegetables or flower gardens.	8-12 inches, or as deep as possible.	0.25 inch.

1. According to the indicated incorporation depth, cultivate compost into the top of the soil profile using a digging fork, spade, or rototiller if necessary. On compacted/clayey soils, anything less may result in a shallow rooting depth predisposing plant to reduced growth, low vigor, and low stress tolerance. If the actual incorporation depth is different, adjust the rate accordingly.
2. Three cubic yards (=81 cubic feet) covers 1,000 square feet approximately 1 inch deep.
3. These application rates are based on the use of plant-derived compost (compost made solely of plant materials, such as leaves, grass clippings, wood chips and other yard wastes) or compost known, by soil test, to be low in salts. For compost made with manure or biosolids and compost known, by soil test, to be high in salts, application rates will need to be reduced substantially. Excessive salts are common in many commercially available products sold in Colorado.

When consistently repeating annual applications, application rates can be lowered over time. An annual soil test will be the best measure for the need for compost.

Selecting Soil Amendments

Desired Results – In selecting soil amendments, first consider the desired results. To improve the water and nutrient holding capacity on sandy, gravelly, and decomposed granite soils, select well decomposed materials like finished compost and aged manure. To improve aeration and infiltration (improve structure on clayey soils) select fibrous materials like composted wood chips and straw.

Potential for Routine Applications – Another important consideration is the potential for routine applications to improve the soil over time, as in a vegetable garden or annual flowerbed. In many landscape settings, the amendment is a one-time application added before planting lawns, perennials, trees, and shrubs.

Longevity – Products that decompose rapidly (like grass clippings and manure) give quick results, while products that decompose slowly (like wood chips and bark chips) provide longer lasting results. For quick improvement that lasts, use a combination of materials. Longevity of the product merits consideration.

Salts – Products made with manure and/or biosolids are often very high in salts, which can stress and/or kill plants if over-applied. Salt levels may increase in the composting process, although water moving through the compost pile can leach out the salts. Use with caution! Plant-based products are naturally low in salts.

Regulations – When purchasing products, gardeners need to understand that there are no regulations about the quality of the product, salt content, or other beneficial or harmful qualities of bagged products. Use with caution, as many soil amendments sold in Colorado are high in salts! Voluntary standards for bulk products may help in product evaluation. For example, the US Composting Council provides lab testing, labeling, and information disclosure that can help gardeners judge the quality of compost products.

Need for Nitrogen Fertilizer – Over time, soil microorganisms break down organic matter and, through this process, release nitrogen that is tied-up in organic matter. Nitrogen release rates from organic matter are very slow (can occur over a period of years) and organic matter typically has low nitrogen content, so compost is usually not an effective substitute for fertilizer.

The need for nitrogen fertilizer generally depends on the soil organic matter content of the soil. The more organic matter a soil contains, the greater its nitrogen content and the less nitrogen it requires from a fertilizer. **Table 2** provides approximate recommendations for N application rates based on soil organic matter content. However, soil organic matter content is not the only factor that affects the need for nitrogen fertilizer. The type of crop, level of production, and soil nitrate levels should also be considered when determining the N application rates.

Table 2. Approximate Recommendations for N Fertilizer Based on Soil Organic Matter Content

Soil Organic Matter Content	Routine Application Rate for Gardens
0%	3 pounds N / 1,000 square feet
1%	2.5 pounds N / 1,000 square feet
2%	2 pounds N / 1,000 square feet
3%	1.5 pounds N / 1,000 square feet
4%	1 pound N / 1,000 square feet
>5%*	0 pounds N / 1,000 square feet

These are approximate recommendations based on soil organic matter content. When determining application rates, consider crop, level of production, and soil nitrate levels as well.

* If there are low nitrate levels in the soil when OM is 5% or higher, it is recommended to apply N.

Over Amending

Over-amending is a common problem. Some gardeners try to fix their soil limitations by adding large quantities of amendment in a single season. This can result in the following problems:

- High salts.
- High nitrogen.
- Low nitrogen (from the tie-up of nitrogen due to a high carbon to nitrogen ratio imbalance).
- Holding too much water.
- High ammonia (burns roots and leaves).

Problems may also arise, over time, from the continual application of high rates. This can result in the following problems:

- High salts.
- Excessive nitrogen, phosphorus, and potassium.
- Ground water contamination.
- Micronutrient imbalance.

Evaluating the Quality of Organic Amendments

The quality of organic amendments can be determined by both visual evaluation and laboratory testing.

Visual Evaluation

- **Color** – Dark brown to black.
- **Odor** – Earthy, no ammonia smell.
- **Texture** – Less than one to two inch particle size; lawn top dressing less than 3/8 inch.
- **Foreign Materials** – Less than 1% and smaller than ½ inch size.
- **Uniformity** – Observed within the batch.
- **Consistency** – Observed between different batches.
- **Raw Materials** – Concern of heavy metals (biosolids), human pathogens (manure), and salts (manure and biosolids).
- **Weed Seeds** – Test by germinating some material.

Laboratory Testing

C:N Ratio – Ratio of carbon to nitrogen.

- Less than 20:1 is acceptable, while 12:-1 – 15:1 is desirable.
- Woody composts may have C:N ratios above 20:1 and may tie-up nitrogen.

Organic Matter

- 40-60% is desirable, based on % dry weight basis.
- Organic matter content under 25% may indicate large amount of soil/sand, whereas over 65% organic matter content may indicate the product has not been composted enough.

pH

- May be higher in manure.
- Near neutral (6.8 to 7.2) is best for most plants.

Electrical Conductivity (EC) – A measure of soluble salts. Acceptable levels depend on use, but are typically recommended to be between 0-4 mmhos/cm.

- Potting grade: < 2.5 mmhos/cm.
- Potting media amendment: < 5 mmhos/cm.
- Top dressing: < 5 mmhos/cm.
- Soil amendment in a low salt soil: <10 mmhos/cm.

Moisture Content – Amendments with moisture contents above 60% may be difficult to spread, while amendments with moisture contents below 40% may be dusty.

Nitrate Nitrogen (NO_3-N) – A plant available form of nitrogen.

- Levels from 200-500 mg/kg or ppm are typically recommended.
- Higher levels of ammonium may damage sensitive plants.

Ammonium Nitrogen (NH_4-N) – A plant available form of nitrogen.

- Levels <500 mg/kg or ppm are typically recommended.
- Lower levels indicate a lack of plant available nitrogen.

Heavy Metals – A concern with biosolids. Colorado has specific compliance standards for commercial soil amendments in regard to levels of various heavy metals.

Pesticide Residues – Generally not a problem as they breakdown in composting.

Pathogens – *E. coli*, salmonella, and other human pathogens are a concern, particularly in manure. Colorado has specific compliance standards for commercial soil amendments regarding *E. coli* and salmonella levels.

Stability (Respiration Rate) – Less than 2 mg CO_2-C per g organic matter per day, preferred. Relative measurement of the completeness of microbial activity. The lower the number, the more completely composted the product.

Maturity – Broad classification that indicates a product is suitable for use. Stability is one measure of maturity.

Nutrient Content – This varies greatly from product to product.

Germination Test – Seeds are started to check potential of toxic chemicals.

Bacterial and Fungal Diversity – Some studies have indicated that compost with higher microbial diversity may suppress plant diseases.

Examples of Soil Amendments

There are two broad categories of soil amendments: organic and inorganic. Organic amendments come from something that is or was alive. Inorganic amendments, on the other hand, are either mined or manufactured. Organic amendments include sphagnum moss/peat moss, coconut coir, wood chips, grass clippings, straw, compost, manure, biosolids, sawdust, and wood ash. Inorganic amendments include vermiculite, perlite, tire chunks, pea gravel, and sand.

Sphagnum Moss and Peat Moss

Generally, bogs consist of **sphagnum moss**, the living layer of moss, and **peat moss**, the sunken, decaying layer of moss that builds up over time. Both sphagnum moss and peat moss are used as soil amendments to promote water retention, particularly in sandy soils. However, the use of these amendments has negative environmental consequences. Bogs sequester large amounts of carbon through the buildup of peat so, by harvesting and draining peatlands, we are eliminating carbon sinks that are critical to combat global warming.

Because peat moss is created over decades to centuries, it is not possible to harvest sustainably. Sphagnum peat, however, may be commercially farmed and sustainably harvested. Coconut coir is a popular soil amendment that can be used as an alternative to sphagnum moss and peat moss.

Colorado mountain peat should not be used as a soil amendment. Mountain peat is mined from high-altitude wetlands, which provide homes for many rare species. This mining is extremely disruptive to these species, as well as to hydrologic cycles.

Coconut Coir

Coconut coir is a by-product of the coconut fiber industry. It is renewable and lasts longer than peat but may be more expensive due to transportation costs. Coir has a higher pH (5.5-6.8) and more soluble salts than peat. Additionally, it is easier to wet than peat. Depending on fertilization practices, coir can become acidic.

Coir can be blended as a high proportion of mixes (up to 80% reported in the literature with success). Coir is commonly blended with perlite and compost.

Biosolids

Biosolids (sewage sludge, Milorganite®) add slow-release nutrients and organic matter to soil. They are available from some communities or sewer treatment districts in bulk and from garden stores in bags.

Some biosolids are extremely high in salts. For example, tests on MetroGro report a salt content of 38.3 mmhos/cm, which is considerably above acceptable tolerances for soil amendments. (A soil amendment above 10 mmhos/cm is considered questionable.) For details on salty soil amendments, refer to CMG GardenNotes #224, *Saline Soils*.

Biosolids typically have 5-6% nitrogen content. Annual applications should be made only when the biosolids and garden soil are routinely tested for salt content.

Worm Castings

Worm castings (i.e., worm feces) have a slow-release performance due to a mucus covering which is slowly degraded by microorganisms. Castings are neutral in pH and contain highly available forms of plant nutrients that are water-soluble, as well as trace elements, enzymes, and beneficial microorganisms. Nutrients within the castings are generally released over the course of several months. For continual release of nutrients, repeat applications approximately at four-month intervals.

Castings can be used in potted plants, soil mixes, and in garden beds. Castings can be harvested every three to four months from a vermicompost bin, and then applied as a top dressing (1/2 to 1 inch deep) to potted plants or incorporated into a soil mix (casting should make up no more than 25% of the mix by volume). Avoid direct contact between the castings and plants, as castings may have a higher soluble salt content. Some batches made from livestock manure may have high salts depending on whether the animals producing the manure had access to a salt lick and if the vermicompost maker leached them out or not.

Due to the high cost in Colorado, castings are generally used in small gardens or potting mixes.

Perlite and Vermiculite

Perlite and vermiculite are common inorganic amendments used in potting soils and planter mixes.

Vermiculite is made from heat expanded silica. It helps increase pore space and has a high-water holding capacity.

Perlite is made from heat expanded volcanic rock. It is used to increase pore space and promote drainage.

Summary: Considerations in Selecting Soil Amendments

Choosing a soil amendment depends on your specific situation. What is practical and available varies from place to place. The important points are that 1) soils are routinely amended to improve soil tilth and 2) the gardener follows the limitations for the specific product used. The following summarizes selection considerations:

Goals:

- Purpose of amending soil.
- Longevity of amendment (fast-acting vs slow-release; one-time addition vs. routine applications).

Cost/Availability:

- Local availability.
- Cost of product.
- Quantity needed (based on size of area to be treated, depth of incorporation, and application rate).
- Transportation costs.
- Difficulty in incorporating product (established perennials, hardscapes, etc.).

Need for Fertilizer After Amending:

- Soil organic matter content.
- Nitrogen content of soil.

Precautions With Specific Products:

- Salts (manure and biosolids).
- Weed seeds (manure and compost).
- Plant pathogens (compost).
- Human pathogens (manure).

Alternatives to Amending:

- Accepting a reduction in plant growth and vigor.
- Accepting increased maintenance requirements.
- Selecting plants more tolerant of poor soils.
- Avoid crowding plants competing for limited soil resources.

- Mulching with organic mulch slowly improves soil over time.
- Container and raised-bed gardening.
- Prevent compaction forces.

For more information, please refer to these additional resources:
CSU Fact Sheets, https://extension.colostate.edu/topic-areas/yard-garden/:

- #7.214, *Mulches for Home Grounds*.
- #7.235, *Choosing a Soil Amendment*.

CMG GardenNotes, https://cmg.extension.colostate.edu/volunteer-information/cmg-gardennotes-class-handouts/:

- #218, *Earthworms*.
- #232, *Understanding Fertilizers*.
- #234 *Organic Fertilizers*.
- #243, *Using Compost in the Home Garden*.

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MASTER GARDENER
COLORADO STATE UNIVERSITY
EXTENSION

CMG GardenNotes #242

Using Manure in Colorado Gardens

For some gardeners in Colorado, manure is readily available as a source of organic matter to build soils and add small amounts of nutrients. However, follow precautions with manure applications or they could become more detrimental than beneficial.

E. coli, a Health Issue

Due to the potential of transmission of human pathogens such as *E. coli*, animal-based manures should only be used on fruits and vegetables when specific precautions are taken. Apply non-composted (fresh) animal manures in the fall and mix it into the soil. Do not leave it on the soil surface. When applying fresh animal manure, it is best to wait three to four months from application to harvest in order to give plenty of time for the manure to break down and reduce any pathogen threats. Never apply fresh manure to growing food crops. Plant-based composts can be used safely during the growing season and does not pose the same health risks as animal manures.

Nitrogen Release Rate is Slow

Manure contains small amounts of plant nutrients and micronutrients. The nutrient composition of farm manure varies widely depending on bedding material, moisture content, exposure, and aging, even for the same species of animal. Where manure is routinely added, garden soils will likely have adequate phosphorus and potassium. Manure is a great source of micronutrients like zinc. **Table 1** gives approximate amounts of nitrogen, phosphate, and potash.

The nitrogen in manure is not all available to growing plants the first year as much of it may be tied up in organic forms. Organic nitrogen becomes available to plants when soil microorganisms decompose organic compounds, such as proteins, and then convert the released N to NH_4. This process, known as mineralization, begins almost immediately, but fully occurs over a period of years. [**Table 2**]

Table 1. Approximate Nutrient Content of Manure*			
Type	**N**	**P2O5**	**K2O**
Beef:			
With bedding.	1.1%	0.9%	1.3%
Without bedding.	1.1%	0.7%	1.2%
Dairy Cattle:			
With bedding.	0.5%	0.2%	0.5%
Without bedding.	0.5%	0.2%	0.5%
Horse:			
With bedding.	0.7%	0.2%	0.7%
Poultry:			
With litter.	2.8%	2.3%	1.7%
Without litter.	1.7%	2.4%	1.7%
Rabbit:	2.0%	1.3%	1.2%
Sheep:			
With bedding.	0.7%	0.5%	1.3%
Without bedding.	0.9%	0.6%	1.3%
Swine:			
With bedding.	0.4%	0.4%	0.4%
Without bedding.	0.5%	0.5%	0.4%
Turkey:			
With litter.	1.0%	0.8%	0.7%
Without litter.	1.4%	1.0%	0.9%

*At time of land application.
Sources: CSU Extension Bulletin 552A, Utilization of Animal Manure as Fertilizer except for rabbits from Western Fertilizer Handbook of the California Fertilizer Association.

Table 2. Approximate Percentage of Organic N Mineralized in First Year After Application	
Manure Source	**Percent of Organic N Mineralized**
Beef	35%
Dairy	35%
Horse	20%
Poultry	35%
Sheep	25%
Swine	50%

Source: Nebraska Cooperative Extension Bulletin EC89-117, Fertilizing Crops with Animal Manures.

The amount mineralized in the first year depends upon the manure source, soil temperature, moisture, and handling. **In general, about 30% to 50% of the organic nitrogen becomes available the first year. Thereafter, the amount gradually decreases. A general estimate is 50% the first year, 25% the second year, 12.5% the third year, and so forth.**

In gardens low in organic matter, it is common to find nitrogen deficiencies when the gardener relies solely on manure and/or compost due to the slow-release rates. The gardener may need to supplement with a high nitrogen organic or manufactured fertilizer. As the soil organic matter builds over the years, the problems with low nitrogen levels will improve.

Salts

Salt content may be high in fresh manure and decreases with exposure to rains and irrigation as salts are leached out. **Continual and/or heavy applications of manure can lead to a salt build-up.**

To avoid salt problems associated with the use of manure or compost made with manure, limit applications to one inch per year and thoroughly cultivate the manure or compost into the soil six to eight inches deep. When cultivation is less than six to eight inches deep, lower the application rate accordingly. Have a soil test for salt content before adding large amounts.

Manure or compost made with manure containing up to 10 dS/m (10 mmhos/cm) total salt is acceptable if cultivated six to eight inches deep into a low-salt garden soil (less than 1 dS/m or 1 mmhos/cm). Manure with a salt content greater than 10 dS/m (10 mmhos/cm) is questionable. Avoid use of manure on soils that are already high in salts (above 3 dS/m (3 mmhos/cm).

Note: dS/m or mmhos/cm are the units used to measure salt content. It measures the electrical conductivity of the soil.

Other Disadvantages of Farm Manure

Other disadvantages of farm manure include:

- Potential burning of roots and foliage from high ammonia.
- Potential residual herbicide damage to crops.
- High potential for weed seeds.
- Labor and transportation necessary to apply the manure to the garden.

Horse manure is legendary in its potential to introduce a major weed seed problem into a garden. Composting the manure before application may kill the weed seeds if the pile heats to above 145ºF and the pile is turned to heat process the entire product.

Horses eating grass hay treated with broadleaf herbicides containing clopyralid and aminopyralid can convey the herbicide in their manure. If grasses were treated with these herbicides in the eighteen months prior to cutting and baling as hay, then the risk of horse manure containing the herbicide is present. Gardeners can test a small sample of the manure by mixing an amount proportional to what would be applied to soils into a large flowerpot with garden soil. Plant seeds of crops intended for that growing season in the flowerpot and observe for any signs of herbicide stress or injury such as: low germination, yellowing, twisted growth, dead leaves, stunting, or death of entire plant. These are clear signs that the herbicide is still active in the manure.

Feedlot manure is often high in salts if a salt additive is used in the livestock diet.

Poultry manure is particularly high in ammonia and readily burns if over-applied. The ammonia content will be higher in fresh manure compared to aged manure. Laying hen manure can raise soil pH due to the calcium supplements in their diet. Occasionally, gardeners may want to “fix” their soil by adding large quantities of organic matter at one time. Excessive applications of manure can lead to a reduction of plant growth due to excessive levels of nitrogen, ammonia burn, and salt damage to the roots.

Composted Manure

A growing trend in the use of manure is to compost it before application. Bagged composted manure is readily available in garden stores and nurseries. Composted manure has fewer odors. It is easier to haul and store than fresh manure because of the reduction in the weight of water and a decrease in overall volume by four to six-fold. The composting process may kill weed seeds and pathogens if the pile heats above 155ºF and the pile was turned to heat-process the entire product. Salts can be concentrated during composting as moisture is lost and volume is reduced. Many bagged manure products sold in Colorado are high in salts.

In composted dairy manure, only 5-20% of the nitrogen will be available the first year. In soils low in organic content, this can lead to a nitrogen deficiency unless an additional quick release nitrogen source is added. This could be supplied with blood meal (one to two pounds per one hundred square feet) or with a manufactured fertilizer like ammonium nitrate (2/3 cup per 100 square feet) or ammonium sulfate (one cup per 100 square feet). The ammonia content drops due to volatilization during composting, thereby reducing the burn potential.

Fresh manure without bedding materials is difficult to compost, because of the high ammonia and moisture content. To speed decomposition and minimize foul odors from anaerobic decay, add some high carbon material, such as sawdust, straw, dried leaves, or wood chips. Depending on climatic conditions, on-farm manure composting takes six to ten or more weeks if turned weekly.

Follow the same residual herbicide risk precautions with composted manure as detailed above.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Revised October 2015 by Dan Goldhamer CSU Extension. Reviewed June 2023 by Adrian Card, CSU Extension.

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MASTER GARDENER
COLORADO STATE UNIVERSITY
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CMG GardenNotes #243

Using Compost in Colorado Gardens

For information on home composting see Colorado State University Extension Fact Sheet #7.212, *Composting Yard Waste.*

Compost Products

The term ***compost*** refers to organic matter that has been biologically degraded. Organic matter, which is essentially anything that is made of carbon, is a critical component in soils for numerous reasons. For one, organic matter is the food source for the soil organisms that form the base of the soil food web. Soil life slowly mineralizes the nutrients in organic matter through decomposition, making the nutrients available for plants to use. Organic matter also promotes the aggregation of soil particles, which can ultimately improve the physical characteristics, like porosity and water infiltration, of the soil over time. Additionally, organic matter has a high water and nutrient holding capacity, which can improve sandy soil's tilth. Having adequate levels of soil organic matter supports a healthy soil ecology and, ultimately, benefits gardeners.

Compost can be made at home using kitchen scraps and garden waste. Making homemade compost is an environmentally sustainable way to convert both kitchen and yard wastes, which would otherwise be taken to a landfill, into valuable soil-building resources. One of the main advantages of homemade compost is that the gardener controls what goes into the compost pile and, therefore, can avoid weed seeds, diseased plants, and salt problems.

There are also many compost-based products available in the retail trade. Compost can be purchased either in bags from a variety of retailers, or in bulk from large compost producers or landscape supply companies. They can be derived from any combination of plant residues, manure, and/or biosolids, and may also have added fertilizers or animal by-products. Many suppliers of compost will have information on what the product is made from and may even have a laboratory analysis of the product available upon request.

While Colorado requires that commercial compost be sufficiently composted to reduce pathogens and vector transfer (C:N ratio must be 18:1 or less), there is no standard regarding the compost's state of decomposition. As a result, it is important to be mindful when purchasing a compost since the quality of compost will vary based on the materials being composted, the process being used, the duration of composting, etc.

Application Rates and Salt Problems

Routine application rates of organic soil amendments depend on the desired results, type of amendment, salt potential of the material, and the depth to which it will be cultivated into the soil. Before applying any amendment, it is best to do a soil test. **Table 1** gives approximate application rates for plant-derived compost.

Table 1. Routine Application Rate for Compost

Site	Incorporation Depth[1]	Depth[2] of Compost[3] Before Incorporation
One-time application for lawns.	6 inches	1-2 inches
First-time application when installing vegetable or flower gardens.	8-12 inches	3-4 inches
Annual application to existing vegetable flower gardens.	8-12 inches, or as deep as possible	0.25-1 inch

1 According to the indicated incorporation depth, cultivate compost into the top of the soil profile using a digging fork, spade, or rototiller if necessary. On compacted/clayey soils, anything less may result in a shallow rooting depth predisposing plant to reduced growth, low vigor, and low stress tolerance. If the actual incorporation depth is different, adjust the rate accordingly.

2 Three cubic yards (=81 cubic feet) covers 1,000 square feet approximately 1 inch deep.

3 These application rates are based on the use of plant-derived compost (compost made solely of plant materials, such as leaves, grass clippings, wood chips and other yard wastes) or compost known, by soil test, to be low in salts. For compost made with manure or biosolids and compost known, by soil test, to be high in salts, application rates will need to be reduced substantially. Excessive salts are common in many commercially available products sold in Colorado.

* When consistently repeating annual applications, application rates can be lowered over time. An annual soil test will be the best measure for the need for compost.

Compost derived from manure or biosolids has the potential to have a high salt content, so application rates will need to be reduced substantially unless a laboratory analysis of the compost shows a low salt level.

An amendment with up to 10 dS/m (10 mmhos/cm) total salt is acceptable when incorporated into a low-salt garden soil (less than 1 dS/m or 1 mmhos/cm). Any amendment with a salt level above 10 dS/m (10 mmhos/cm) is questionable. Note: dS/m or mmhos/cm is the unit used to measure salt content. It measures the electrical conductivity of the soil.

Generally, compost needs to be thoroughly mixed into the upper six to eight inches of the soil profile. Do not leave compost in chunks, as this will interfere with root growth and soil water movement.

As the soil organic content builds in a garden soil, the application rate should be reduced. A soil test is suggested every few years to establish a baseline on soil organic matter content.

Nitrogen Release Is Limited and Slow

The typical macronutrient content of compost is 1.5% to 3.5% nitrogen, 0.5% to 1% phosphate, and 1% to 2% potassium, plus micronutrients. As with other organic soil amendments, the nitrogen release rate from compost is very slow (i.e., over a period of years). Thus, compost is not considered an effective substitute for fertilizer due to the low levels of nutrients present and the slow rate of release. In gardens where compost is routinely added, phosphorus and potassium levels are likely to be adequate to high.

The need for nitrogen fertilizer generally depends on the soil organic matter content of the soil. The more organic matter a soil contains, the greater its nitrogen content and the less nitrogen it requires from a fertilizer.

4-5% Organic Matter – Soils with 4-5% organic matter from compost will mineralize (release to plants) about 0.2 pound of nitrogen per one hundred square feet per year. This should be sufficient for plant nitrogen needs.

2-3% Organic Matter – Soils with 2-3% organic matter from compost will mineralize about 0.1 pound of nitrogen per one hundred square feet per year. Additional nitrogen fertilizer will be needed for high nitrogen crops like broccoli, cauliflower, cabbage, potatoes, and corn.

<2% Organic Matter – In soils with less than 2% organic matter, the release rate for nitrogen will be too low to adequately provide the nitrogen needed for crop growth. A supplemental organic or manufactured nitrogen fertilizer may be needed.

However, soil organic matter content is not the only factor that affects the need for nitrogen fertilizer. The type of crop, level of production, and soil nitrate levels should also be considered when determining the N application rates.

Beware of Unfinished Compost

Using unfinished compost can be problematic for several reasons. For one, the carbon to nitrogen (C:N) ratio of unfinished compost may be too high. Ideally, a finished compost will have a C:N ratio of approximately 20:1. However, depending on the kinds of materials that the compost is derived of, the C:N ratio of compost can be as high as 600:1. When C:N ratios are high, the microbes performing decomposition don't have enough nitrogen to break down the high amount of carbon, so they will scavenge nitrogen from other places. If those other places happen to be your garden soils because you applied unfinished compost with a high C:N, the microbes may immobilize nitrogen in your garden soils from plant uptake. To prevent nitrogen immobilization, compost with a high C:N ratio must be sufficiently composted.

However, C:N ratio does not necessarily indicate the maturity of compost. Compost derived from vegetable wastes, for example, will naturally have a low C:N ratio (approximately 10-20:1). Immature compost with low C:N has a higher proportion of nitrogen which, if not finished properly, may be available in the form of ammonium. At high levels, ammonium can be toxic to plants, burning plant roots (when applied to the soil) or plant leaves (when applied as mulch).

Furthermore, microbes consume oxygen (O2) during decomposition so, if applying unfinished compost near plants, the microbes can potentially consume all of the O2 from the root zone as they continue to decompose the compost and, as a result, can greatly inhibit root growth.

Additionally, unfinished compost may not have fully destroyed any potential pathogens or weed seeds present in the compost.

Finished compost will have an earthy smell and will not resemble its original contents anymore. Compost maturity can be assessed in a laboratory by measuring the carbon dioxide (CO2) production by the microorganisms living in the material. Lower levels of CO2 indicate more mature compost (i.e., microbial activity is low because they have used the available nitrogen to decompose the carbon in the compost). Conversely, if microbes are producing CO2, they are still actively decomposing the material in the compost.

When making compost at home, it is advisable to turn the pile when the compost pile temperatures drop below 120ºF and before the compost pile temperatures exceed 160ºF. To encourage active microorganism processing, moisten the pile so that it feels like a wrung-out sponge. When temperatures do not rise above 120ºF after turning to reheat, compost has entered its curing stage. It should cure for at least forty-five days before being considered finished so that the compost can reach a chemically stable end point.

Weed Seeds and Diseased Plants

It is advisable not to compost diseased plants or weeds loaded with seeds. If the compost pile did not heat adequately or was not turned, the compost could be a source of weed seeds or plant disease pathogens. All parts of the compost should reach 145ºF to kill weed seeds and plant disease pathogens. Because only the inner layers of the pile will reach this temperature, it is important that the outer layers are folded into the inner layers and the pile is allowed to reheat to 145ºF. These temperatures must be maintained for at least 3 days. Temperatures of 130ºF will somewhat minimize weed seeds and pathogens.

Livestock manure (horse, sheep, cow, swine, etc.) can also be a source of weed seeds if the animals were fed hay that contained weed seeds or if seeds blew into a pile of manure.

Pet Manure

Do not add companion animal (cat, dog, etc.) feces to compost as this can increase disease transmission to humans, as well as the incidence of nuisance animals rummaging through the compost pile.

Authors: David Whiting, CSU Extension, retired; Adrian Card, CSU Extension; Carl Wilson, CSU Extension, retired; and Jean Reeder, Ph.D., USDA-ARS, retired. Reviewed December 2015 by Dan Goldhamer, CSU Extension. Revised May 2023 by Hania Oleszak, CSU Extension and Eric Hammond, CSU Extension.

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CMG GardenNotes #244

Cover Crops and Green Manure Crops

Terms: Green Manure and Cover Crop

A ***cover crop*** is a vegetative cover used to improve soil health, erosion or degradation in quality that is seeded annually in a garden or field. Cover crops can include grasses, legumes, or herbaceous plants. When the cover crop is tilled into the soil it is referred to as a ***green manure*** crop. These two terms are often used interchangeably.

Why Is a Cover Crop Beneficial?

Cover crops can protect the soil from wind and water erosion, suppress weeds, fix atmospheric nitrogen, build soil structure, and reduce insect pests.

Erosion Protection – The primary erosive force for Colorado is wind. Winter winds are especially destructive, carrying away small particles of topsoil from the soil surface. Another source of erosion can be from water movement, especially on sloped surfaces without much vegetative cover to hold the soil in place. A thick stand of a cover crop protects the soil surface from wind erosion and the cover crop's roots hold soil in place against water erosion during heavy downpours.

Weed Suppression – Cover crops left in place for all, or part, of a growing season can suppress most annual and some perennial weeds. Among the grasses, annual rye has allelopathic properties that prevent weed seeds from germinating and suppresses weed seedlings around the root zone of the rye.

Nitrogen Fixation – Legumes, inoculated with their specific Rhizobium bacteria, will take nitrogen out of the air (present in the soil), and store it in their plant tissues via nodules on the roots of the legume. This is a symbiotic relationship, as the bacteria uses the plant's sugar in return for nitrogen. Some of this nitrogen is available as roots die, but the majority becomes available when the legume is tilled under as green manure.

Soil Structure Creation – Plant roots exude a sticky substance that glues soil particles together, creating structure. Grasses are exceptional in their ability to do this.

Insect Pest Reduction – Cover crops encourage beneficial insect populations, often minimizing or eliminating the need for other insect control measures when cover crops are in place.

Why Is a Green Manure Crop Beneficial?

The use of green manure enhances soil fertility and soil structure by feeding soil organisms and gluing together soil particles into aggregates.

Soil Fertility – When fresh plant material decomposes in the soil, its carbon-to-nitrogen ratio becomes low, allowing the nitrogen to be easily released into the soil chemistry by bacteria. **Table 1** shows how nitrogen accumulation is greater with legumes, which have nitrogen-fixing Rhizobium bacteria growing in nodules on the legume roots. Notice the lower figure for rye.

Table 1. Nitrogen Accruement of Selected Cover Crops

Cover Crop	Nitrogen Accruement *
Hairy Vetch	3.2 lbs./1000 ft^2
Crimson Clover	2.6 lbs./1000 ft^2
Austrian Winter Pea	3.3 lbs./1000 ft^2
Winter (Annual) Rye	2.0 lbs./1000 ft^2

* Nitrogen accumulated in growing crop prior to tilling under.
Source: ATTRA: Overview of Cover Crops and Green Manures.

Table 2 shows values of nitrogen fixation for legumes. Rates vary due to differences in the activity level of the Rhizobium bacteria.

Table 2. Potential Nitrogen Fixation Rates of Selected Legumes for Colorado

Legume Crop	Pounds N per 100 ft^2
Crimson Clover	1.6-3.0
Field Peas	2.0-3.4
Hairy Vetch	2.0-4.6
Medics	1.1-2.8
Red Clover	1.6-3.4
Sweet Clover	2.0-3.9
White Clover	1.8-4.6

Source: *Managing Cover Crops Profitability*, Sustainable Agriculture Network

Soil Structure – Microorganisms decomposing plant material and the plant material itself produce substances that glue soil particles together. These substances include slime, mucus, and fungal mycelia, which contain gums, waxes, and resins. These are aggregate soil particles, thereby enhancing the tilth, porosity, and water holding capacity.

Basic Recipes for Cover Crops and Green Manure Crops in the Garden

Spring-Planted

Most gardeners do not have enough area to surrender the space to a cover crop for an entire growing season. However, if you do, a spring seeded clover would give your soil a great boost. Some seed companies will “rhizo-coat” seed with the specific Rhizobium bacteria or apply

Rhizobium as specified on the bag. Rhizobium comes in a black powder specific to the species of clover and has a definite shelf life, so check the expiration date. To apply, you would broadcast the seed-Rhizobium mix at a specified rate after the last frost has passed using either a handheld broadcaster or other broadcasting method. The mixture should be applied to a loose seedbed and shallowly incorporated and watered consistently, until germination and seedling growth have occurred. Monitor water as you would in a lawn.

Till the cover crop under at least two weeks prior to planting. Decomposing plant material consumes soil oxygen and can create plant health problems if not tilled in ahead of time. More than one tilling may be necessary to get an acceptable kill of the clover.

Fall-Planted for Spring Till

Most will opt for a fall cover crop that is then tilled under as a spring green manure. Seeding dates for fall planted cover crops should be done by mid-October. Mid-September is ideal for the Colorado Front Range and the western valleys. In mountain elevations, plant in August or earlier. A rye-Austrian winter pea or rye-hairy vetch mixture will overwinter in Colorado. Hairy vetch is hardier than winter pea. Rye is extremely winter hardy.

Newer winter cover crops include Daikon radish, tillage radish, and turnips. There are many cover crop mixes available as well, usually referred to by the number or species per mix (for example, a 3-way mix). Prepare as above and broadcast at the rates in **Table 3**.

Table 3. Seeding Rates for Selected Winter Cover Crops

Cover Crop	Ounces per 100 Square Feet	Pounds per 1000 Square Feet
Winter Rye	4-6	2.5-3.75
Austrian Winter Pea	4-6	2-4
Hairy Vetch	2-3	1-2
Radish, Daikon	-	8-12 lbs./acre

Source: *Managing Cover Crops Profitability*, Sustainable Agriculture Network

Over-wintered cover crops become readily available salad-bar to geese and deer when other food resources are scarce. A cover crop that is well established prior to winter temperature extremes should rebound from wildlife grazing in late winter/early spring.

Till the cover crop in mechanically or turn it under with a spade one month before you plan to plant to seed into that area. Decomposing plant material consumes soil oxygen and can create plant health problems if not tilled in ahead of time.

Landscape Uses

Bare soil presents erosion and aesthetic issues. During droughty periods, watering restrictions and the lack of natural precipitation may make plants or turf establishment difficult or impossible. A temporary cover crop or long-term xeric grass may be the answer. In this scenario, the homeowner must understand that a cover crop will not look or feel like a healthy Kentucky bluegrass lawn but should satisfy the need to cover the soil.

Establishment and Care

Before Seeding – Prepare a seedbed for fine grass seed, ideally amending the soil with compost and tilling as deeply as possible. If possible, fence off the area from traffic.

Seeding – Water the area prior to seeding, if possible, to establish ample soil moisture levels. Broadcast the correct number of seed per area onto a loosely tilled, fine (no soil pieces bigger than 1/4 inch) seedbed. Shallowly incorporate seed with garden rake (not a leaf rake) to a depth of 1/4 to 3/4 inch deep.

For larger areas consider hydromulching the seed. This will save time and increase germination of seeds. When seed is applied with the mulch (hydroseeding) typically consists of applying a mixture of wood fiber, seed, fertilizer, and stabilizing emulsion with hydromulching equipment.

After Seeding – Consider laying a thin layer (<1" deep) of seed-free straw to hold in moisture and increase germination and survival of grass seedlings. Bird netting over the straw fastened to the ground with landscape fabric staples will keep the straw from blowing away.

Check moisture levels in the upper inch of soil at least every other day (soil should feel as moist as a wrung-out sponge) and water if necessary (and if possible).

Mowing – If necessary, mow as high as possible or use a weed eater to reduce the height or remove seed heads.

Removing Cover Crops – For most cover crops, either till under, mow and mulch heavily, or spray herbicide before it goes to seed.

Choosing a Cover Crop for Colorado

There are several options of cover crops for use in Colorado, however, they differ in their attributes and life cycles.

Cereal rye, winter wheat, and oats can all be grown as a thick mat to help prevent erosion and weed suppression. Oats will not survive the winter, whereas winter and cereal rye can be planted in the fall, overwinter as dormant plants and begin growth again in the spring. This ability for cover crops like winter wheat or cereal rye to remain in place over many months makes them a good fit to use in conjunction with warm-season crops such as tomatoes. This is done by removing the cover crop just prior to planting and seeding it again in the fall once the warm season crops are finished for the summer season.

Clovers can be used for cover-crops as they are readily available, easy to grow and add nitrogen to the soil through nitrogen fixation. Many species are cold-tolerant and will survive a mild winter, however red and crimson clover have low survivability with Colorado winters. Avoid white clover as a perennial crop as it is difficult to remove.

Buckwheat and rapeseed are both broadleaf cover crops that grow well in warmer temperatures and are effective at weed suppression. However, it is very important not to allow flowering or seed set of these crops, as they are very prolific with hundreds of seedlings emerging from dropped seed. Rapeseed is moderately cold hardy and may survive a mild winter, whereas buckwheat has no frost tolerance.

Alfalfa and hairy vetch also fix nitrogen and will survive our Colorado winters and regrow with warmer spring temperatures. However, alfalfa is a high-water crop with complex management needs and is also difficult to remove due to being a deep-rooted perennial. Hairy vetch should be terminated prior to setting flowers to prevent it from becoming weedy.

Peas and beans are another type of legume that fixes nitrogen and can be used as cover crops. In addition, they can be grown as green manures or edible crops by harvesting the pods and turning under the plants. Most will not survive Colorado winters.

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CMG GardenNotes #245

Mulching

Mulch and Soil Amendments

The term ***mulch*** refers to a material placed on the soil surface. By contrast, a ***soil amendment*** refers to any material **mixed into** a soil.

Benefits of Mulching

Depending on the materials used, mulches can have many benefits. Mulch can:

- Reduce evaporation from soil surface.
- Increase soil microorganism activity, which in turn, improves soil tilth and helps lessen soil compaction.
- Stabilize soil moisture.
- Prevent soil compaction.
- Suppress weeds.
- Moderate soil temperature extremes.
- Control erosion.
- Increase water infiltration.
- Give a finished look, improving aesthetic quality.

Edging and Soil Grade

It is a common practice to add mulch above grade level. Without a defined edge, the mulch can spread off the bed onto lawns or sidewalks, creating a mowing or trip hazard. [**Figure 1**]

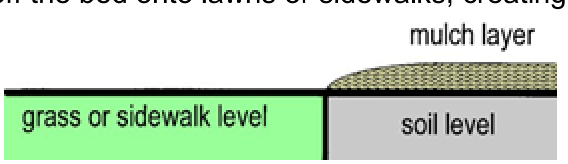

Figure 1.
Mulch added above grade spills out onto the lawn or sidewalk.

An effective alternative is to drop the soil level on the mulch bed three inches, so the top of the mulch is at grade level. However, ensure that the mulched bed does not fill with water draining from higher areas. [**Figure 2**]

Figure 2.
To keep mulch in place, drop the soil level in the mulch bed so the top of the mulch is at the grass or sidewalk level.

Another effective alternative is to round down the soil level along the edge of the bed. This gives a nice, finished edge at grade level, creates a raised bed effect for the flowerbed, and saves a lot of digging! [**Figure 3**]

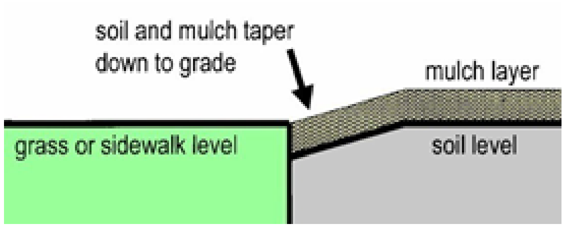

Figure 3.
An alternative is to taper the soil level along the edge of the bed.

Wood Chip and Bark Mulch

Wood chip or bark mulch can be great around trees, shrubs, perennials, and small fruits as seen in **Figure 4**. Wood chip and bark mulches can create a favorable environment for earthworms and soil microorganisms. Over time, this helps reduce soil compaction.

In perennial and shrub beds, wood chip mulch can reduce the need for irrigation by as much as 50%. Mulching materials that mesh are more effective at reducing water evaporation from the soil. However, these same mulches are also effective at reducing precipitation infiltration into the soil. Be sure to install irrigation beneath the mulch and understand how water moves (or does not move) through your mulch for the best success. Bark mulches, particularly shredded bark products, are more resistant to water transmission than wood chips.

An important consideration for wood chip and bark mulch stems from the intense sunlight and typically dry conditions across much of Colorado. Wood chips exposed to high surface temperatures from intense sunlight can become hydrophobic, preventing water infiltration to the soil. Wood chip or bark mulch, therefore, is not recommended for use in xeriscapes or with open planting plants unless it can be frequently checked and distributed to maintain its ability to conduct water to the soil. Wood chips under a canopy of leaves or in regularly irrigated settings are typically not affected by hydrophobicity.

Figure 4. Wood chip or bark mulch in the perennial and shrub bed enhances soil tilth over time.

Wood chips or bark mulch can be less effective in areas with persistent winds, as even relatively large pieces can be blown away in gusty conditions. Plant cover and wind breaks reduce the susceptibility of the mulch to being blown out of landscapes.

Sometimes people can be concerned that wood chips and bark mulch will reduce nitrogen availability in the soil or that plant diseases or plant defense compounds that are present in the wood chips and bark mulch could harm landscape plants. Thankfully, claims of infertile soils and toxic mulch are not supported by much evidence.

When placed on the soil surface as mulch, wood chips and bark mulch do not tie-up soil nitrogen. However, incorporating wood chips or bark mulch into a soil can create a nitrogen deficiency. Soil microbes, which consume the wood, also require nitrogen; wood or wood products mixed into the soil can cause a population boom for microbes and result in a lack of nitrogen available for plants.

Buried wood can take ten or more years to decompose. Using nitrogen fertilizer can compensate for the nitrogen used in the decomposition process in order to remediate soils with wood chips or bark mulch already incorporated.

In vegetable or annual flowerbeds where the soil is routinely cultivated to prepare a seedbed, be sure to keep wood mulch from mixing into the soil. Rake the mulch away thoroughly before beginning and replace it when seedlings have sprouted (or once plants have been planted).

Plant pathogenic fungi can persist on un-composted wood chips but would need to travel into the soil in order to infect healthy roots of susceptible landscape plants. Wood chips that have been dried, as in the case of most purchased mulch, do not carry pathogens. Fresh mulch or mulch that remained damp from production to application could transfer pathogens into above-ground wounds or to roots if they were to come into contact with the mulch. This is another reason to avoid mixing mulch into the soil and to keep mulch from piling up around the stems and trunks of landscape plants. Furthermore, most common plant pathogenic fungi are ubiquitous in the environment and opportunistic. Susceptible plants in the right environmental conditions will likely develop disease regardless of the mulch. Keeping plants healthy by minimizing stress is a more fruitful way to prevent disease than fretting about mulch contamination.

In addition to pathogens, claims that plant secondary compounds from mulch will leach into soils and kill plants can be found in the popular press. “Cedar mulch” and mulch made from the wood of black walnut trees are often specifically cited. No evidence supports that any tree going by the common name “cedar,” including *Juniperus*, *Cedrus*, or *Thuja* produces allelopathic chemicals (compounds that function as herbicides on neighboring plants). While juglone, the compound in black walnut trees, can have harmful effects on certain plants, the compounds do not persist long in mulch. Using aged mulch and/or leaching mulch with water quickly mitigates any possible problems. Seedlings and shallowly rooted plants are more susceptible to allelopathic compounds; mature landscape plants are not likely to be affected in any case.

Rock Mulch

Rock and gravel mulch are often maligned as not beneficial to plant growth. Because they are sometimes grouped together as a single product, conclusions about them from research can be hard to draw. For example, many studies do not specify rock size when discussing “rock mulch” in comparison to wood mulches. In studies that have differentiated among rock sizes, though, mulch with gravel less than one centimeter in diameter has been shown to suppress weed growth and reduce water loss from evaporation similarly to wood chip mulch. Additionally, surface temperatures in planting beds mulched with gravel remain cooler than paved surfaces or surfaces mulched with wood chips.

Landscapes in dry climates are most likely to benefit from gravel mulches. Pea gravel has been shown to improve water infiltration into the soil, especially in short, intense precipitation events like thunderstorms; larger rocks increase runoff. Even a thin layer of gravel mulch has been shown to double the amount of precipitation that infiltrates the soil; a three-inch layer can increase water infiltration manyfold. In order to function as mulch, though, stones must be small enough – no more than around a half-inch in diameter. Larger stones do not confer the benefits of mulch.

Gravel mulch can improve the soil too – by increasing the available soil moisture and warming the soil temperature beneath it, plant roots and microbes get a boost. The increased biologic activity can result in improved organic matter content and subsequent tilth, even though the mulch itself does not decompose.

Grass Clippings or Leaf Mulch

Grass clippings and leaves make good mulch when applied dry or when applied gradually in thin layers and allowed to dry between applications. Grass clippings and leaves decompose rapidly, requiring additional layers during the growing season but providing nutrients to soil microorganisms as they "compost in place." A grass clipping or leaf mulch recycles its nutrients into the garden bed or lawn that generated it.

Figure 5. Grass clipping are great for the vegetable garden and around annual flowers. Directly from the bag, place them around the plants in thin layers, allowing each layer to dry before adding more.

They are not as resistant to compaction as wood chips or gravel mulch.

Do not apply fresh grass in thick layers as it will mat, produce foul odors, reduce air- and water infiltration, and even become hydrophobic. Do not use clippings from lawns that have been treated with herbicides or other pesticides.

Grass clippings and leaves are an excellent choice in vegetable and annual flower beds that receive annual cultivation to prepare a seedbed. [**Figure 5**]

Product Selection

The selection of a mulch depends on its intended use. Consider your goals and the size of the area in relation to the cost of materials and availability.

If the main objective is soil improvement, consider an organic mulch that gradually breaks down, like wood chips. If the area is used primarily for annual flowers, it often is more practical to use a quickly decomposing organic mulch, such as composted leaves or grass clippings, that can be turned under each fall. Make sure these materials have not been treated with persistent herbicides or they may damage your landscape plantings.

If the main objective is water infiltration or xeriscaping, consider rock mulch. Any stones used for mulch should be smaller than a half-inch in diameter for the benefits of water conservation and weed suppression. Larger stone sizes do not function well as mulches and can actually inhibit plant growth but may provide landscape interest.

Mulch changes the way that heat is transferred to the ground and surrounding structures. Gravel mulch transfers more heat to underlying soil than wood chip mulch. This may serve to keep landscape plants in better overall health in cold-winter temperate climates like ours. On the other hand, it can also transfer heat to buildings and utilities or cause some tender plants to begin growing too early in the spring. Wood chip mulch insulates the soil against temperature swings, but the surface temperature of sun-exposed wood mulch can be hotter than that of gravel mulch. Match your mulch to your situation.

Black plastic (polyethylene) and woven plastic weed barrier fabrics (polypropylene) are not recommended beneath mulch in landscape areas. Black plastic is impermeable therefore no oxygen exchange can occur to the soil. Lack of oxygen to the roots and soil microbes significantly reduces plant growth. Black plastic also prevents water penetration. Woven weed barrier fabrics initially allow some minor oxygen and water exchange to the soil, but eventually become clogged and create the same issues. Weeds easily germinate on top of the fabric and root into or through it. Both plastic and woven plastic fabrics disrupt the life cycles of many pollinators and other soil invertebrates. Synthetic fabrics and plastic sheeting, *used alone,* can be good choices for large-scale vegetable production where regular maintenance and replacement is easily performed. In gardens and landscapes, the correct application of other mulches is a better option.

General Use

- **Depth**
  In order to suppress weed growth, wood chip, gravel, grass clipping, and other mulch should be four inches deep. More is not better, though! Applying mulch too deeply can reduce air exchange to the soil and reduce the growth of your desirable plants.

  Mulch applied to the correct depth does not require underlayment with fabric, newspaper, cardboard, etc.; these products can interfere with water and air exchange in the soil. Choose the correct mulch, apply it deeply enough, and forget the fabric or newspapers.

- **Around Trees**
  Wood chip mulch is great for trees and shrubs, protecting trees from lawnmower damage. However, do not make “mulch volcanoes” around tree trunks by applying chips up against a tree’s trunk, as seen in **Figure 6**. Wet chips piled up against the trunk can cause bark problems and interfere with growth. Keep the mulch back at least six inches from the trunk, and do not apply too deeply.

Figure 6. Never make a “mulch volcano.” It leads to decay of the bark and interferes with trunk taper. Keep mulch back six inches from the trunk.

Converting Lawn to a Mulch Area

If a lawn will be changed over to a mulched garden bed, again consider timing, expense, and end-goal. Many techniques can be successful. Once a lawn is dead and gone, be sure to apply mulch in the new garden.

- **Spray With a Non-Selective Herbicide**
  This method is a relatively fast, inexpensive, and easy way to kill your lawn. It maintains the soil’s structure and microbiology and leaves the organic content (dead grass and roots) in place to decompose. Because you are not disturbing the soil, weed seeds are not brought to the surface to germinate. Different herbicides have different risks and effectiveness. Read and follow the label instructions for safe application.

- **Solarize**
  Water thoroughly and cover the area you want to kill with clear plastic, making sure that the edges are sealed. Leave it there for four to eight weeks. This method is most effective in the hottest months from June through August. It is not aesthetically pleasing and may invite complaints from the neighbors, but it is a low-effort option. Leave the dead grass or rake it

up. Avoid disturbing the weed seed bank by not tilling it in. Research has shown that there is only a temporary reduction in soil microbial activity from solarizing – the soil microbes quickly recover.

- **Mow Close and Cover**
  In early spring, scalp the grass by mowing it as short as possible. A weed whacker works well for this. Then cover the area with a thin layer of compost and an eight to twelve inch layer of woodchip mulch. Water well to encourage decomposition. Many gardening sites recommend using layers of newspaper or overlapping pieces of cardboard. This will slow down an already lengthy process, and it temporarily reduces soil microbial activity which is important for soil and plant health. Be aware that this will take a season or more and still may not kill all of the grass.

- **Use a Sod Cutter or Dig It Up**
  If your lawn is in good condition, you can cut strips with a sod cutter, roll them up and give them away. First, mow and water your lawn. Cut overlapping strips of sod and roll them up. Cut strips short enough to be moved easily. This method is quick but requires heavy equipment and you are left with the dilemma of how to get rid of the rolls of sod. Alternatively, you can flip the sod over to decompose in place, keeping the organic matter in your yard or garden. You then treat it like the 'mow and cover' method. Cover with compost, mulch, and water, to promote decomposition.

Mulch and Fire-Resistant Landscaping

Mineral mulch (gravel) is the best option for making landscapes more fire-resistant. Organic mulch materials have a broad spectrum of flammability, particularly if ignition is from point sources like cigarette butts or spent fireworks. In low-wind conditions, moistened wood mulch resists ignition from such sources; dry wood chips, bark, pine needles, and other small-particle organic mulches are more ignitable. Larger and denser mulch pieces make for the most fire-resistant wood mulch. Rubber mulch will always burn and should be avoided.

The continuous, wind-driven accumulation of embers, as occurs in wildfires, will ignite any organic mulch. One study showed ignition and combustion of wood mulch with 83% moisture content in winds of only eighteen miles per hour. In rural areas and in the wildland-urban interface (WUI), choosing the right mulch (e.g., gravel or rocks) is an important component of creating defensible space.

Summary: Considerations in Selecting Mulch

Gardeners often inquire about the best mulch. No one mulch is best for every situation. What is practical and available varies from gardener to gardener and within different communities. The following summarizes considerations in selecting mulches to ask yourself:

Site
- Plants: trees, shrubs, perennials, annuals, specialty crops.
- Annual soil preparation: annual flowers versus perennial beds.
- Landscape goals and maintenance.

Function
- Soil improvement goals and potential.
- Frequency of reapplication.
- Water infiltration and irrigation method.

- Depth needed for weed management.
- Appearance.
- Soil temperature (heating or insulation).
- Off-site movement by wind, water, and gravity.
- Safety (children, lawn mowers).

Cost

- Local availability.
- Cost of product.
- Size of area to be treated.
- Depth of application.
- Transportation costs.

Authors: David Whiting, CSU Extension, retired; Carl Wilson, CSU Extension, retired; Catherine Moravec, former CSU Extension employee; and Jean Reeder, Ph.D., USDA-ARS, retired. Artwork by David Whiting. Used with permission. Revised December 2015 by Eric Hammond, CSU Extension. Reviewed April 2023 by John Murgel, CSU Extension, and Deryn Davidson, CSU Extension.

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MASTER GARDENER
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CMG GardenNotes #246

Making Compost

Essential ingredients for the composting process include microorganisms, organic matter, water, and air (oxygen). The microbes that cause decomposition naturally occur on plant wastes. Compost starters or inoculums are not needed to start decomposition. The compost needs to be moist to the touch, but not soggy (excluding air). Air (oxygen) is essential for microbes. Too fine of particle size, excessive water, large amount of soil, and packing of materials may decrease oxygen levels.

What Items Should and Should Not be Composted?

Materials To Use

- Leaves.
- Garden debris free of diseases and weed seeds (i.e., carrot tops, chopped corn stalks, pea vines, spent flowers, etc.).
- Weeds, free of seeds.
- Kitchen scraps free of meat, dairy, fats, and oils.
- Shrub and tree trimmings smaller than one-quarter inch in diameter.
- Hay, straw, and other plant residues.

Materials To Avoid

- Weeds with seeds; seed may not be killed if compost pile(s) do not heat to 145°F.
- Diseased plants, including tomato and potato vines and potato peelings.
- Tree branches greater than quarter inch in diameter; large sizes should be run through a chipper first, as they will be very slow to decompose.
- Fats, oils, grease, meat, and dairy products (slows decomposition and attracts pests.)
- Kitchen scraps with meat, dairy, fats, oils, or grease.
- Pet or human feces may transmit diseases.
- Synthetic or plastic fiber does not decompose.
- Wood ash and lime drive up the pH of the soil.

Materials To Use With Limitations

Large amounts of grass clippings. Due the small particle size and high nitrogen of grass clippings, they tend to smell unless mixed with brown materials. Instead recycle the nutrients back into the lawn by not bagging.

Manure. Manures may contain strains of *Escherichia coli* and other bacteria that cause human illness. If manure is composted for food gardens, a four-month curing process following composting is necessary to reduce pathogens.

Large amounts of plants/weeds treated with pesticides (including herbicides, insecticides, and fungicides). Most pesticides readily break down in the composting process and present no threat as long as the decomposition process has been completed.

Large amounts of high tannin-containing leaves (oak and cottonwood). These are slow to decompose but can be used in small quantities if chopped well and mixed with other materials.

Large amounts of juniper, pine, spruce, and arborvitae trimmings. Resins in these highly resinous wood and leaf cuttings protect these materials from decomposition and extend the time needed for composting in comparison with other plant materials.

Large amounts of paper products. Newsprint is best recycled through recycling collection operations rather than converted to compost. If paper is composted due to a shortage of dry materials, add no more than 10% of the total weight of the material being composted. Higher amounts create imbalances in the carbon to nitrogen ratio. Do not use color printed glossy magazines as inks may not be safe as a soil additive.

Large amounts of soil. Some gardeners like to sprinkle small amounts of soil into the compost bin as a source of microbes. However, this is not necessary as small amounts of soil are routinely added with the roots of weeds and other plants. Large amounts of soil increase weight, decrease oxygen infiltration, and can suffocate microorganisms.

What Is the Carbon to Nitrogen Ratio?

For optimum processing, the ratio of carbon to nitrogen in the compost needs to be around thirty to one. This is typically the combination of two parts green materials with one-part brown materials. Compost piles too high in carbon will be slow to process or may not decompose. Piles too high in nitrogen develop strong ammonia odors. [**Table 1**]

Processing works best if the green and brown materials are mixed before adding to the pile. An alternative is to layer the green and brown materials. Layers should not be more than two inches deep for fine materials and six inches deep for coarse materials.

When only brown materials are used, nitrogen fertilizer may be added to supply the needed nitrogen for decomposition. The standard rate is one half cup ammonium sulfate (or equivalent) per bushel of brown materials.

Table 1. Examples of Green and Brown Materials

Green Materials	Brown Materials
Vegetable wastes (12–20:1)	Dry leaves (30–80:1)
Coffee grounds (20:1)	Corn stalks (60:1)
Grass clippings (12-25:1)	Straw (40–100:1)
Cow manure (20:1)	Bark (100–130:1)
Horse manure (25:1)	Paper (150–200:1)
Poultry manure, fresh (10:1)	Wood chips and
Poultry manure, with litter (13–18:1)	Sawdust (100–500:1)

What Is the Ideal Location for the Compost Bin?

Choose a composting site carefully. Considerations include the following:

- **Partial shade** avoids baking and drying in summer but provides some solar heating to start the composting action.
- **Wind protection** prevents too much moisture loss.
- **Water source** to keep the pile moist but not soggy.
- **City ordinances** often prohibit compost bins within ten to twenty feet of property lines.
- **Convenience** for loading and unloading of materials away from yard activities.

What Is the Ideal Size and Type of Compost Bin?

Structures are not necessary for composting but do help prevent wind and marauding animals from carrying away plant wastes. Open compost piles can be used in less-populated rural locales, but structures are necessary in urban areas. Many composting structures can be purchased or built. They vary in how well they can be managed to meet the requirements for effective decomposition under Colorado environmental conditions.

Wire and wood structures are common for home composting. An inexpensive, easy-to-build type is made from hardware cloth (a stiff, lightweight wire mesh found with fencing materials at many hardware stores). A four-foot high by thirteen-foot length will make a small bin four feet across. Use wire to hold the length of hardware cloth into a round hoop. To unload the bin, unhook the wires holding the hoop in the circle.

Structures built of wire dry out faster, depending on exposure to drying winds. Plastic covers or tarps are often used to protect the outer layer from drying out. Covers are removed to add water and plant materials and to aerate the pile.

Figure 1.
Simple compost bin made with wooden pallets for $5 to $25.

Wood structures do not dry out as much but are more expensive to purchase or build.

An inexpensive and easy to build bin is made from a wooden pallet. Use wire and deck screws to fasten sides, add hinges to the front section for easy access. The cost runs between $5 and $25. [**Figure 1**]

An efficient wood structure is the three-chambered bin system that allows plant material to be aerated by turning it from one bin to the next as it decomposes. New materials are put in the first bin to begin decomposition. After a few weeks, it is turned to the second bin for active decomposition. As the process naturally slows, it is turned to the third bin for further curing. [**Figure 2**]

Figure 2.
Three chambered compost bin build for $20 to $80.

Many brands of small home compost bins are available commercially typically running $80 to over $100. Some are manufactured from recycled plastics. They work well for small yards that produce few plant wastes. [**Figure 3**]

Figure 3.
Earth Machine™ compost bin.

Size – A minimum volume of material is necessary to build up the heat for efficient composting. When materials are heavy in green materials, keep the bin smaller to allow for better aeration. Three feet by three feet by three feet is considered the minimum size to allow for heating. This small size may be adequate for small yards with limited materials to compost. If composting fall leaves and materials high in brown materials, a larger bin (measuring five feet by five feet) may keep the processing going through the winter months.

In-ground pit composting presents problems with turning or aerating the plant material and can pool water, which leads to undesirable low oxygen conditions.

What Is the Routine Care of a Compost Pile?

The breakdown of organic yard wastes is a biological process dependent on microorganism activity. Like most living things, these microbes require favorable temperatures, moisture, oxygen, and nutrients.

Temperature – Plant-digesting microbes operate in a temperature range of 70°F to 140°F, with breakdown occurring slowly at the lower temperatures. Well-managed compost rapidly breaks down in summer when compost temperatures quickly reach 120°F to 130°F. If summer heat plus the heat produced by active microbes causes the temperature of the plant mass to exceed 160°F, the microbes will die.

In Colorado winter temperatures, a well-constructed five foot by five-foot pile will continue processing throughout the winter. Smaller piles will cool, stopping microbe activity and extending the time required to produce a finished product. In the spring, small piles may need to be turned and mixed with additional materials to enhance processing.

Moisture and Oxygen – Moisture and oxygen are essential to microbial activity. In a region with limited rainfall such as Colorado, add moisture regularly to maintain composting. If parts of the composting material dry out, many microorganisms in the dry areas die. Even when moisture is added, the microbes that remain require time to multiply and resume plant digestion. The net result is slower composting. However, excess moisture displaces air and slows breakdown. Surplus water creates low oxygen conditions, favorable for certain microbes to multiply and produce foul odors. The best description of the proper moisture level is moist or damp but not soggy. The entire mass of plant wastes should be moistened uniformly to the point where only a few drops of water can be squeezed from a fistful of plant material.

The size of plant particles that go into the compost also affects aeration. Large particles allow a lot of air to circulate around the plant chunks, but breakdown is slow because microbes can act only on the outside, not on the inside of the large chunks. Particles chopped into smaller chunks increase the surface area for microbes to operate. Particles chopped too small will compact and restrict air flow. Moderate-sized plant pieces of 0.5 to 1.5 inches are the best size to use and can be produced by hand or machine shredding. Chop woody materials into a smaller size. Leave soft plant parts in larger pieces for effective composting. Fluff or turn the material with a pitchfork or aerator tool at regular intervals to provide additional aeration and to distribute microbes throughout the compost.

Nutrients – The microbes that break down plants use the plants for food. Nitrogen is the most important food nutrient because a nitrogen shortage drastically slows the composting process. Woody and dried plant materials tend to contain little nitrogen in comparison to the total mass of the material. However, green plant material contains a high percentage of nitrogen. A mix of two parts green to one-part brown material yields the best nitrogen balance. Add a plant fertilizer high in nitrogen when green materials are scarce.

Maintenance

How should materials be layered in the compost pile?
Mixing of green and brown materials before placing it in the bin speeds decomposition. Otherwise, alternate layering of green and brown materials.

Does a compost pile require turning?
No, but turning speeds decomposition and turns weed seeds and diseased plants into the center of the pile where temperatures are higher. Use an aeration tool to reach into the compost and lift and move plant materials. Turn the entire mass occasionally to provide uniform aeration.

What other routine care does a compost pile require?
Keep it moist but not soggy. If overly wet, it will stink. Being dry stops the activity of microbes. The compost should feel moist to touch. However, it is too wet if more than a few drops of water can be squeezed out.

Will the compost process kill plant disease organisms and weed seeds?
Only if the pile heats above 145°F and is turned regularly. Few home compost piles heat adequately; thus it is advisable not to compost weeds with seeds and diseased plants.

Can fresh materials be added to the bin during processing?
Yes, if small amounts are occasionally added. However, if a lot of materials are available, it would be better to start a new pile rather than combining a lot of fresh materials with nearly finished compost.

How can you tell when compost is finished? It will reduce in size by about half, will have lost the identity of the materials, and will smell “earthy.” It typically takes three to nine months, depending on type of materials, climatic conditions, and tending.

Compost Troubleshooting [Table 2]

Table 2. Compost Troubleshooting		
Problem	**Cause**	**Solution**
Rotten Odor	• Anaerobic conditions (the lack of oxygen). • Excess moisture. • Compaction. • Small particle size.	• Turn the pile. • Make smaller pile. • Add dry porous materials.
Ammonia Odor	• Too much nitrogen (low C:N ratio).	• Mix in brown materials. • Note: If compost high in ammonia is used as mulch, it may burn tender foliage. If mixed into soil as an amendment, it can burn roots.
Outside Couple of Inches Is Dry	• Dry Colorado air.	• Water regularly and cover outer edge with tarp.
Low Temperature	• Pile too small. • Insufficient moisture. • Poor aeration. • Lack of nitrogen. • Cold weather.	• Make larger pile. • Add water when turning pile. • Turn pile to aerate. • Mix in green materials or add N fertilizer. • Increase pile size in winter.
Pests (Rats, Bears, Raccoons, Insects)	• Presence of meat, dairy, or fatty wastes.	• Do not compost kitchen scraps with meat, dairy, fats, oils, or grease.

Authors: David Whiting, CSU Extension, retired. Artwork by David Whiting. Used with permission. Reviewed October 2022 by Sherie Shaffer, CSU Extension.

MASTER GARDENER
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CMG GardenNotes #251

Asking Effective Questions About Soils

Communications

Education, the product of Colorado State University Extension, is about communication. Are there ways we can make our communications with clients more effective? One way is to improve our questioning technique. Another is to focus on soil conditions, which contribute to a large percentage of landscape plant disorders. If we don't know how to ask our clients effective questions about their soils, we will have difficulty diagnosing their plant problems.

Many of the questions asked should be about physical soil properties, not chemical ones. Poor physical soil conditions for plant growth make up the bulk of soil concerns. Soil tests tell us about texture but little else relating to soil's physical conditions. A routine soil test is often a poor tool for figuring out a plant growth problem. Compaction, poor drainage, and low oxygen levels are the most frequent causes of poor root growth, which are not assessed by a soil test.

Physical properties of soil include texture (mineral solids), soil structure, and pore space of a soil.

Ask Open Ended Questions

Ask questions that require long answers. While occasional yes-no answers may help, be sure to stay on track with questions requiring more detailed answers. Do this by using **what**, **how**, **when**, **where,** and perhaps **why** leads:

- Tell me about your soil.
- Describe your soil for me.
- Is the soil part of your landscape or one that you brought in?
- How does your soil react when you water it?
- How do you care for your soil?
- Have you/when did you amend your soil?
- How often do you till your soil?
- What do you add to the soil?
- What worms or other living things do you see in the soil?

Be careful with “why” questions. They can sound accusatory and get in the way of gathering information.

Piggyback Questions

Remember to “piggyback” your new questions on top of the answers already obtained. Example – “Let’s talk about your soil in a little more detail. Is it a clayey or a sandy soil?” Avoid negative presuppositions. For example, ask “Have you amended your soil? What amendment did you use?” Do not accusingly ask, “You didn’t amend your soil with fresh manure, did you?” Other questions to consider are:

- Have you dug down into the soil?
- What is it like?
- Was it easy to dig?
- How deep did you dig down?

The following questions aim at assessing compaction and what may have been done to prevent it.

- Have you tried inserting a screwdriver into the soil? Did it go in easily or was it hard to insert?
- Do people frequently walk over that soil?
- Does any equipment or vehicles run over the soil?
- Does water enter easily or run off the soil?
- Is the soil mulched? What mulch was used?

Active Listening

Use “active listening” techniques or paraphrasing to restate what you have learned. By stating what is understood, both you and the client confirm a reference point to proceed in the conversation. An example is “So, you’re saying that your soil is a clay that is not mulched and not frequently walked on?”

This may lead to a clarifying statement such as “That is not what I’m saying. What I mean is …” This is okay because it can clarify important points in the communication.

Neutral Comments

Another way to keep the exchange moving is to use neutral comments. These comments acknowledge listening and prompt further information. Tone is important in using neutral comments. Sound interested but do not insert judgmental overtones into the comments. Examples of neutral comments are:

- You noticed a white substance in the soil.
- You didn’t find any earthworms.
- You used deicing salts on the walk.

Wait Time

Use “wait time.” Don’t be afraid of “dead air” in a conversation. It’s common to want to keep the conversation going by keeping the air filled with talk. Ask the client a question then pause for the answer. They may take some time to get their thoughts together, remember what happened, or consider how to get their words out before they respond. Don’t be tempted to fill in a question before they have a chance to answer the last one.

- Does your soil crumble easily when you press on the clods? *PAUSE.*
- How much compost did you add to the soil when you planted? *PAUSE.*

Listen For

Listening for information is an important skill to develop. When listening for information, you pick up clues to pursue with further questions. This approach has a higher probability of leading to solving a problem. It is very different than a ***"listen from"*** point of view that tries to fit information into a preconceived scenario. "Listen for" often pursues false leads, eliminates them, and then pursues other trails. This kind of detective work can be fun, and only practice will enable you to develop this skill.

Authors: Carl Wilson, CSU Extension, retired. Revised July 2016 by Mary Small, CSU Extension, retired. Reviewed April 2023 by Cassey Anderson, CSU Extension.

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