Certified Nursery &
Landscape Professional

CNLP

New York State Certified Nursery & Landscape Professional

Training Manual

New York State Nursery & Landscape Association

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New York State Nursery & Landscape Association

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SOILS & NUTRIENT MANAGEMENT

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Introduction

Soils & Nutrient Management

Having a basic understanding of soil and its management is critical for the successful establishment, maintenance, and growth of plants in nurseries and landscapes. Knowledge of topics including what components make up soil, how water and nutrients flow through soil, soil porosity and aeration, will help you better understand and provide the conditions required for healthy plant growth and development. It is important to understand that soil is a living system that serves many functions and differs depending on location, climate, geology, and plant type. Soils are constantly forming and changing. Soil is not dirt!

Many people confuse plant nutrition with fertilization. Plant nutrition refers to the needs of the plant and how a plant uses the basic chemical elements. Fertilization is the term used when these elements are supplied to the soil as amendments.

Section 1 - Soil Moisture, Texture, and Aeration

Soil Basics

Soil is something every agricultural and horticultural professional depends on; yet there is a widespread lack of understanding about what soil is, the many functions it provides, and the critical role it has in overall plant and landscape health. Much of this confusion is due to the complexity of the soil-plant system, and the diversity of soil types and plants being grown. Knowledge of the soil environment is vital if healthy plants are to be grown. This fundamental knowledge is gained through both practical experience and scientific research.

What is the soil?

Soil is a dynamic natural system comprised of mineral and organic solids, gases, liquids, and living organisms that can serve as a medium for plant growth. Soils form as a result of many influences including local climate, organisms, topography, bedrock (underlying parent material), and time. Soil is a very complex medium that serves many different functions depending on the environment and context of use. To an engineer soil is the foundation for supporting buildings and other heavy structures, while to us as plant care professionals it is the foundation for many types of plants to grow and thrive. It is important we distinguish this because the properties of the soil to serve these different functions differ greatly and the quality of the soil determines the capacity of the land to support a particular function. Soil has five main components – air, water, minerals, microorganisms, and organic matter (some may describe soils as only have four components, leaving out microorganisms, but remember soil is living and the microbes play a critical role in soil and plant health). The proportions of these components vary in both time and space, and are described in terms of their physical, chemical, and biological properties. Soil physical properties are what we can see and feel, soil chemical properties can be measured and often corrected with fertilizer, lime, and soil amendments, and soil biology is the billions of organisms that live in the soil. In addition to the physical, chemical, and biological properties used to describe soils.

Soil is a three-phase system with:

1) solid,

2) liquid, and

3) gas phases.

In every soil the same basic physical interrelationship exists among these three phases. The following sections will discuss each of these three phases and connect them with soil properties. However, soil chemical properties (eg. soil pH and cation exchange capacity) are largely presented in the fertilizer sections of this chapter.

Solid Phase

The solid phase of the soil, the soil matrix, is the framework or backbone of the soil, and provides some initial insight into the soils overall character. The soil matrix is made up of millions of tiny mineral and organic particles of different sizes. These particles are defined by their size - sand, silt, or clay. Sand is any particle ranging in size from 2-0.5mm, silt ranges from 0.05-0.002mm, and clay are the smallest particles of anything less than 0.002mm. The relative proportions of these particles describe a soils texture and textural class (Figure 1). All soils contain fractions of each texture unless they have been manufactured or altered to contain a particular size fraction. Soils that contain a greater percentage of clay are classified as finer soils, and those with more sand are classified as coarse soils. Soils with a loam textural classification are often considered as the most favorable for plant growth because they have a good proportion of sand, silt, and clay sized particles. Knowing a soils texture helps us describe and manage soils better. For example, soil texture plays a large role in the infiltration, percolation, and runoff of water and nutrients from landscapes. In the field an easy method to determine soil texture is the soil texture by feel method (Thien, 1979). This method using soil and water to try and make a 'ribbon' of soil, depending on the length of that soil ribbon between your thumb and forefinger before it breaks and the grittiness or smoothness gives you an idea of the soil textural classification.

Soil particles, particularly the finer clay particles tend to group together, or form clumps called aggregates. Soil organic matter further helps soil particles bind together and form soil aggregates. The extent and arrangement of these aggregates – size, shape, and strength- as well as the amount of clay and organic matter present, form what is called soil structure (Figure 2). About 50% of the space that makes up soil structure is actually open space, or pores, in between soil aggregates and individual soil particles. So, if 50% is pore space that means the other 50% is the solid phase (soil particles plus organic matter). The total soil porosity depends on the sizes and degree of aggregation and packing of the solid matrix (Figure 3). Soil pores are largely classified as either macro- (large) or micro- (small) pores. Soil pore volume and size distribution are directly connected to soil structure which changes over time as a result of factors including freezing and thawing, root growth, animal activity, and/or compaction. Compaction,

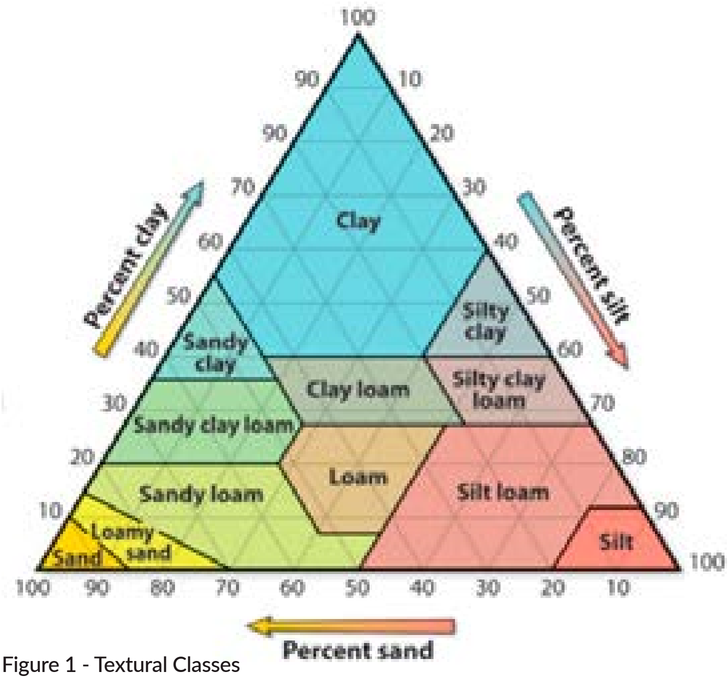


Figure 1 - Textural Classes

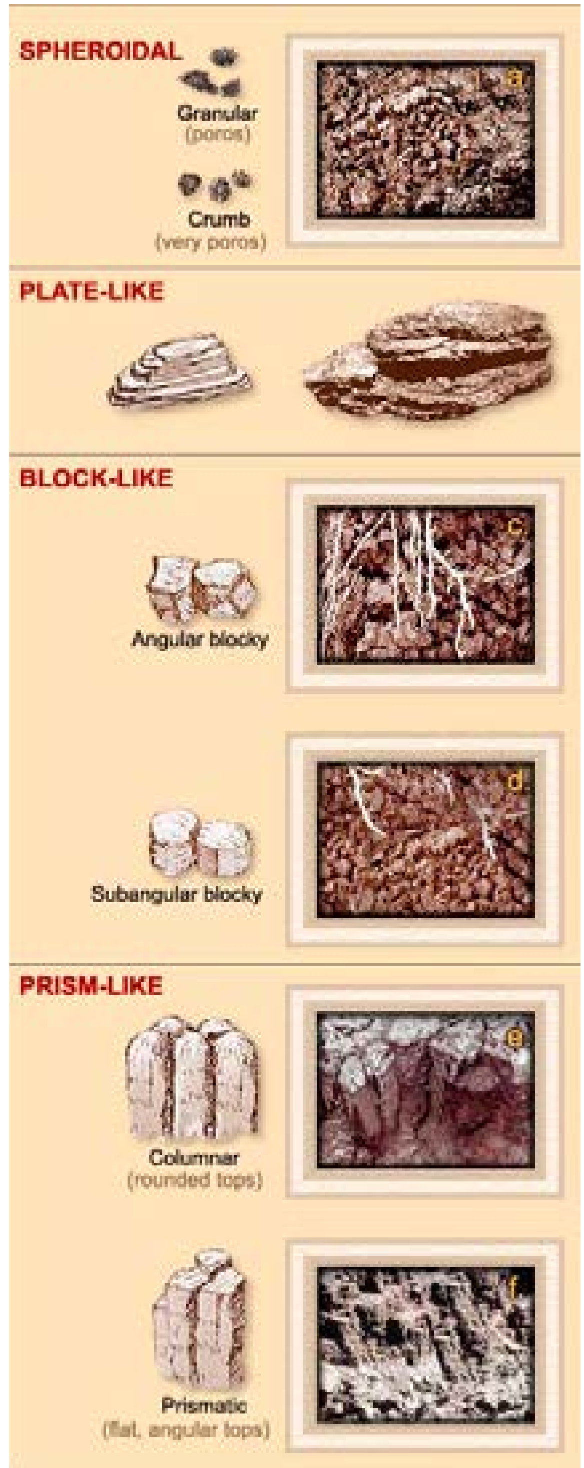


Figure 2 - Soil Structure

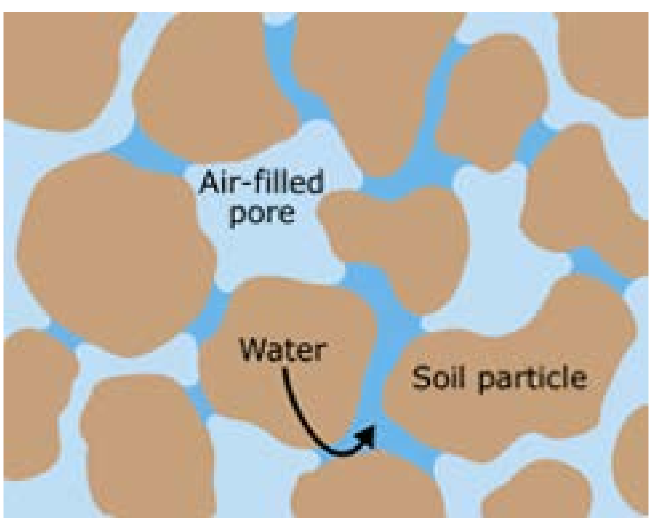


Figure 3 Soil Matrix

the packing of soil particles, is a form of physical soil degradation, and is one of the major reasons for limited plant growth or plant productivity decline over time. This is particularly true of plantings in urban environments. Compaction and pore space are directly connected to a soil physical property called bulk density. Bulk density is the mass of dry soil per total volume of soil and is dependent on soil texture. The lower the bulk density the greater the pore space, vice versa. Compaction increases bulk density, destroys soil aggregates, alters soil microbial populations, and reduces pore spaces which negatively impacts soil water retention and aeration. When combined soil texture and structure have a large impact on a soils ability to hold water and thus nutrients, support biological life, and plant growth; helping to determine the agricultural and horticultural value of a soil.

Another critical component of the soils solid phase is the organic matter component. Soil organic matter (SOM) occupies the smallest soil fraction but has the biggest impact on overall soil function. SOM typically makes up only about 5% of the soil matrix in productive agricultural soils (Figure 4). As organic matter levels increase in soil, pore space increases and bulk density decreases. Thus, organic matter also has a direct impact on soil water and nutrient retention in soils. The property of a predominantly organic soil will be different than a predominantly mineral soil. Organic matter is critical for retaining water and nutrients in soil and is a main reason why compost, mulch, and/or other soil amendments are added to soil. Organic matter breakdown faster in soil than the mineral fraction so distinguishing these two materials is important.

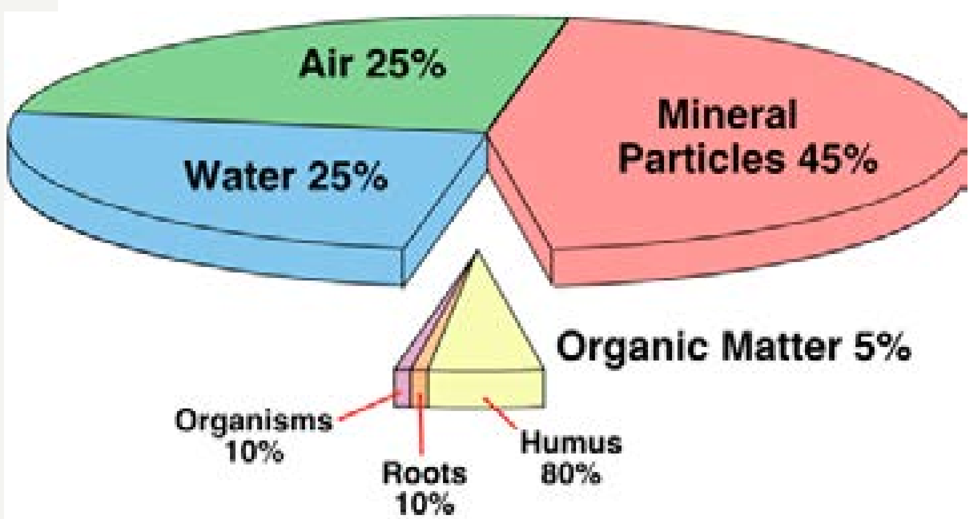


Figure 4 - Soil Matrix in AG Soil

Liquid Phase

The liquid phase of the soil, more commonly known as the soil solution, is a critical part of the soil discussion. In fact, soil and water cannot be discussed in isolation because all soil properties are impacted by water (soil moisture) and nutrients cannot be taken up by plants unless they are in the soil solution. Soil moisture levels greatly influence the suitability of a soil to support the growth of particular plants and biological life. However, the soil solution is more than just water, it consists of water, dissolved salts, nutrients, and dissolved gases. Water, and the nutrients carried with it, is retained in the soil as films of moisture that wet the surface of the soil particles or bound to other water molecules. The amount of water that can be retained by a soil depends on the total particle surface area, the distribution of pore sizes and the total volume of soil pores within the soil matrix. The amount of water in the soil is usually measured as percent volume on a dry weight basis.

This measure is valuable in determining the total amount of water that a soil holds and the proportion of that water that is potentially available for plant use (Figure 5). Soils that have a higher water holding capacity have a larger percentage of micropores compared to macropores, while soils with more macropores have a lower water holding capacity. For example, clay soils have a higher water holding capacity than sandy soils. However, the water holding capacity of a soil does not necessarily directly relate to how much water is available to plants (plant available water). Overall soil texture and structure impact the amount of water a soil holds.

The degree to which soil is held in soil pores and to the surface of soil particles is grouped as follows:

gravitational water,

capillary water, and

hygroscopic water. (Figure 18)

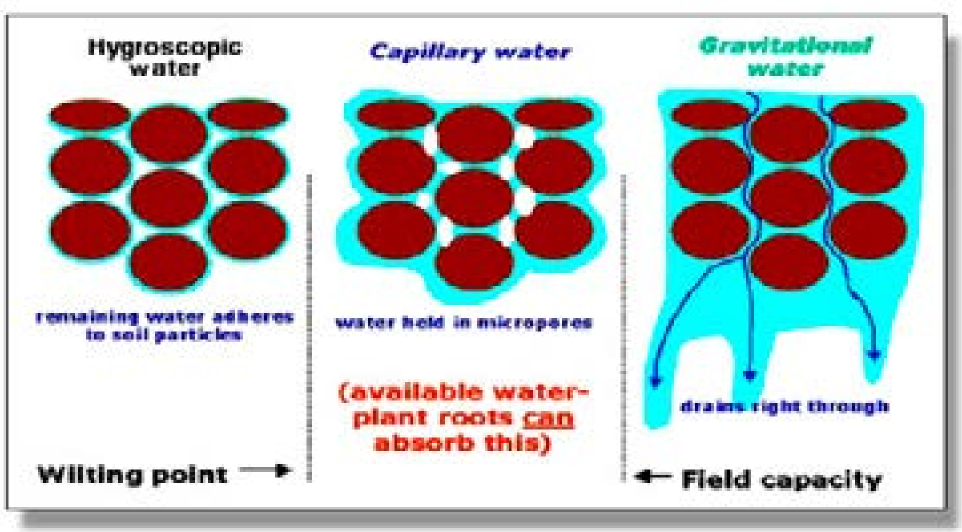


Figure 5 - Water available for plant use.

Gravitational water is the water that is not retained on soil particles and drains from macropores by the force of gravity. This water moves freely out of soil pores and once it has all drained a soil is considered to be at field capacity. Capillary and hygroscopic water on the other hand remains adhered to soil particles. Specifically, capillary water is the water that remains held to soil particles after gravity drainage has occurred. This water is free to move from particle to particle and is still available for uptake by plant roots. Hygroscopic or bound water is held to soil particles more tightly than capillary water and is not free to move around in soil pores. This water is too strongly adhered to the particle surfaces that it cannot be taken up by plant roots. Symptoms of water stress in plants typically occur when all the available water in the soil matrix is depleted. When prolonged water stress occurs and a plant cannot recover, this is referred to as the permanent wilting point.

When water is absorbed on soil particles or held in soil pores, it loses a certain amount of energy. The more strongly it is absorbed, the more energy it loses. In order to remove the water from the soil, work must be done on the water by the plant. The more strongly it is held, the more work must be done to remove it. A measure of the strength with which the water is held in the soil is called soil suction, soil moisture tension or matric potential. This is the easiest and probably the most useful measure of soil moisture status for practical purposes, as water movement through the soil and into the plant is primarily determined by the energy status of the water or the tightness with which the water is held to the soil particles.

Gas Phase

The gas phase or soil air is dominated or controlled almost entirely by the other two phases; yet its status is still important in determining the overall nature of a soil. The soil air space consists of essentially the same composition as the above ground or atmospheric air, just in slightly different concentrations. In soil air, the oxygen content is usually lower and the carbon dioxide and water vapor contents are usually higher. The air space in soil pores acts as the pathway for the intake of oxygen and output of carbon dioxide for plant root and microorganism respiration (yes, they breath just like us!). This process of oxygen and carbon dioxide exchange is called soil aeration.

Aeration in the soil can be described in three ways:
1) gas composition (qualitative),
2) amount or volume per unit soil volume (quantitative), and
3) rate of movement or diffusion (supply).
When this gas exchange is limited or restricted, a condition of poor aeration prevails, for example in saturated or waterlogged soils. When gas exchange is not limited, good aeration prevails, for example moist soils but unsaturated soil conditions. The terms "poor" and "good aeration" are somewhat arbitrary, because it depends on the plant being grown, however, landscape plants do best under conditions of good aeration.

Connecting the three soil phases

The basic relationship among the three soil phases can be thought of as a simple addition and subtraction of volumes between the different phases. One way to illustrate this relationship is by beginning with a single soil phase and adding the other two in sequence. For example, in an empty container only one of the three phases is present, the air. If the container is filled with dry solid particles, the basic soil matrix is formed, and part of the volume previously occupied by only air is now occupied by solid particles. Lastly, if some water is added to the container it occupies or replaces more of the initial volume of soil air and now there are all three soil phases in the container. This illustrates that the volume of soil air not only depends on the soil matrix but also on the soil water content. So, the potential water content of a given soil depends not only on the total amount of solid surface area present, but the size, distribution, and total volume of the pores; all of which are determined by soil texture and structure.

Plant Water: an introduction

Why is water important to plants?

Simply put - plants, and life in general, cannot exist without water! Water is the most important nutrient needed by plants for growth and activity. Plants consist almost entirely of water; between 80-95% of the weight of actively growing plant tissue and of most herbaceous tissue (soft tissue such as leaves and flowers) is water. Plants are literally living, growing containers of water. Water is more than just an inert filler in plants; it influences every plant function. Plants not only contain a lot of water; they also often use hundreds of times this amount during growth. An herbaceous plant weighing 200 grams (one gram is 1/28 ounce) contains about 180 grams of water (90%) and may have absorbed over 100 times, 180 or 18,000 grams during its growth; the actual amount depends on the specific plant and environment. Since water is quantitatively and qualitatively the most important nutrient required by plants, every plant professional should know the nature and function of plant water and how it affects growth, development, and survival.

Distribution of Water - Where is water in plants?

Figure 6 - Plant Cell

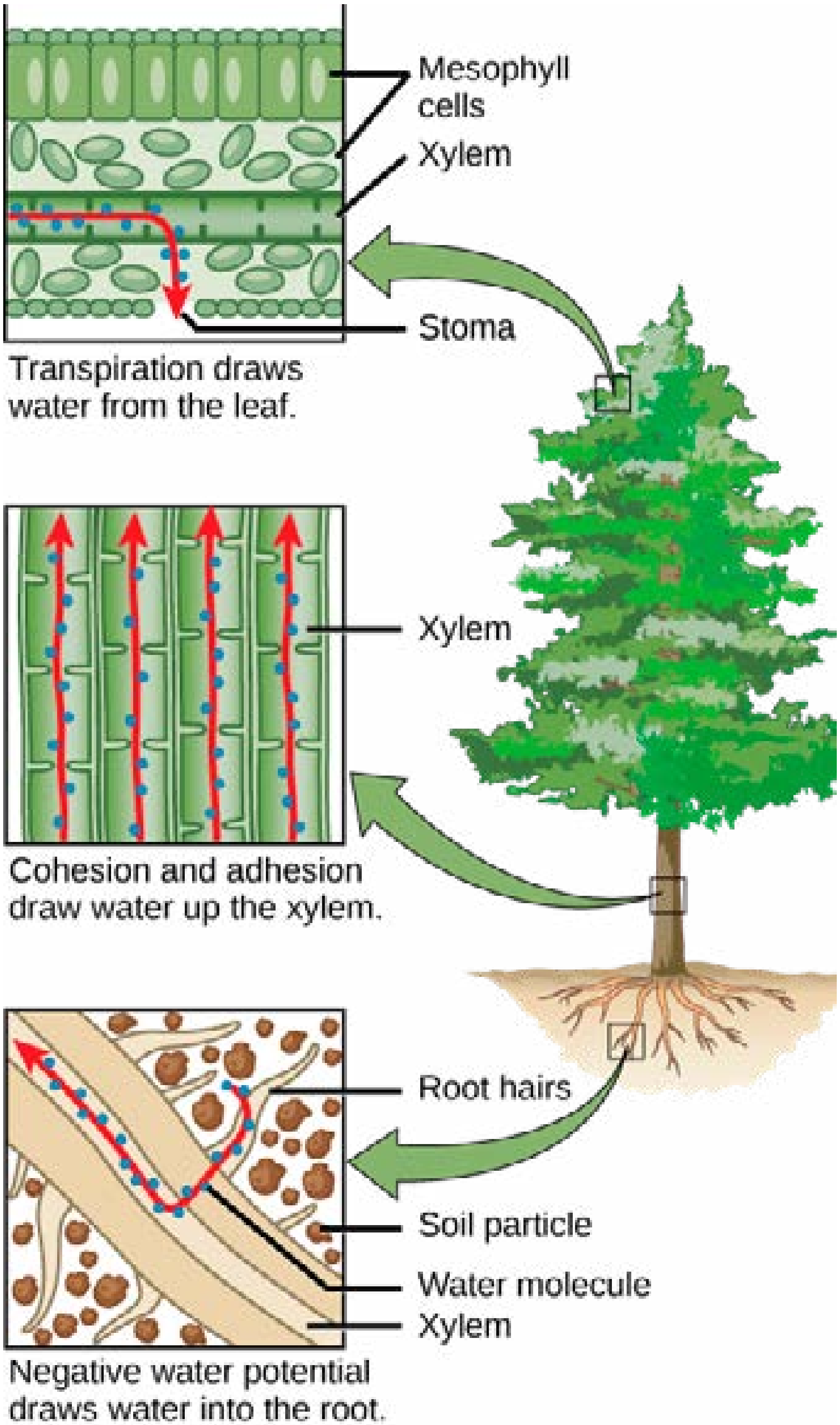
Plant water content averages about 90%; however, the actual range of water content in different plant tissues can vary from less than 5% to more than 98%. Most water is found in plant cells; water is found also in the cell walls and open spaces between cells (Figure 6). Living plant cells usually contain 95-98% water. The living part (protoplasm) usually consists of about 95% water and the vacuole about 98% water. Cell walls have a relatively low water content, typically less than 40%. Water in the open space between cells (intercellular spaces) occurs as a vapor filling the spaces and may also occur as a thin film wetting cell surfaces. Intercellular water is normally a very small part of the total weight. The actual amount of water in the cell walls and intercellular spaces depends on the plant species, tissue, growth stage, and environmental conditions. Herbaceous plant tissues generally contain more water than woody tissues (90 vs. 40-80%); younger, actively growing tissues, such as root and stem tips, usually contain more than older, non-growing tissues (90 vs. 70-85%), and vegetative tissues usually contain more than seed (80-95 vs. 5%).

If all of the solid structures of a plant were invisible so that only the plant water could be seen, it would be clear that the plants form is not changed by the presence of water, but that water forms a continuous phase throughout the plant. The movement of water in plants is primarily due to this continuous water phase, which makes plants little more than a water pipeline from the soil to the atmosphere. The very strong cohesive properties of water means that if water is pulled into the leaves of a plant, this pull is felt at the plants roots; in other words, water movement in plants behaves like a rope extending through the plant, and a pull or tension on one end is felt at the other end. Water in one major part of the soil-plant-atmosphere continuum, and the water status of the roots influences the water status of the shoots, and vice versa. Overall, water is present in all parts of the plant and what happens at one end (roots) impacts the other (shoots), and vice versa.

Plant Water Movement - How does water move through plants?

In a simplified way: the path of water through plants begins where it is absorbed and taken up by plant roots in the soil, its translocation through the plant, and ends where it is evaporated off of leaves into the atmosphere as water vapor in a process known as transpiration; with less than 5% absorbed by plants (Figure 7). Three components describe the movement of water and nutrients from the soil solution to the root surface: mass flow, diffusion, and root interception. The area near the root tip and within the region of active root hair growth is the region of most active water uptake by plants, with the permeability of roots to water decreasing with root age and proximity to the root cap. Root hairs are fine thin-walled epidermal cells that greatly increase the adsorptive area and capacity of plants to uptake water and other nutrients in the soil. Water moves radially across the outside part of the root (epidermis and cortex) through channels known as aquaporins, which are located in the plasma membrane, until it reaches the inside part of the root (endodermis and stele). Water movement across the endodermis occurs only through cells and not through cell walls or intercellular spaces. The permeability of roots to water depends on cell physiological condition, age, and plant water status, all of which directly influence the rate of water absorption. Numerous soil properties including soil aeration, temperature, salinity, pH, and

Figure 7 - Water movement in plants



pathogens impact water absorption by their effect on root physiological activity. Additionally, water and nutrient uptake by plants can be increased by mycorrhizae present in the soil. Mycorrhizae, meaning ‘fungus root’, is the symbiotic relationship between a fungus and plant root. Mycorrhizae play an important role in plant (and soil) health because they essentially extend plant roots into other areas of the soil profile to access additional water and nutrients.

Once water penetrates the inner part of roots and enters the vascular system of the plant, the xylem and phloem, it is more easily and often rapidly translocated throughout the plant, mostly to the leaves. At the leaves, water evaporates from the cell walls into the substomatal air space and then diffuses into the atmosphere through small pores in the leaf surface called stomata. However, the majority of the leaf surface is coated with a waxy, multilayered water-impermeable deposit called the cuticle to reduce water loss, so stomata only cover a small area of leaves. Stomata on most plants open in the light when actively photosynthesizing and close in the dark or when the plant loses turgidity or wilts and is trying to conserve water. The driving force of this water movement through the plant and transpiration from the leaves is due to a difference in vapor pressure between the internal air spaces of the leaf and the surrounding atmospheric air.

Since water movement in plants occurs through differences in gradients or pressure potentials, a change in pressure in one part of the plant is felt in other parts, resulting in water movement. A general term describing the pull or tension which causes water to move is suction (also called water potential, water tension, diffusion pressure deficit, etc.). The term water potential is used more frequently to describe the status of plant water than water suction and will be used here. Water, just like all molecules, move from a region of higher concentration to a region of lower concentration, or down a concentration gradient. For example, when water is lost from the leaves via transpiration, it is because the vapor pressure in the interior of the leaf is higher than the vapor pressure in the atmosphere. Water movement through the transport pathways in plants can be described as either passive or active, however, most water and nutrients are actively transported through the cellular membrane. Water flow is also impacted by salts and other soluble materials present in the soil solution. Environmental factors further influence the rate of transpiration in plants and thus water and nutrient movement. Factors such as temperature, wind speed, and humidity impact the rate of water vapor diffusion (transpiration). For example, when the atmosphere is dry (low relative humidity) and the plants stomata are open, plant water loss is high. In summary, water moves into the plant through the roots, is moved throughout the plant by vascular tissues, the xylem and phloem, due to differences in pressure or gradients, and is lost mainly through the leaves as water vapor in a process called transpiration.

Function of Water in Plants - What does water do in plants?

Virtually every plant activity is influenced by water, providing several direct functions in plants. Water functions as a hydraulic agent which maintains cells in a fully expanded condition (turgid) necessary for growth in size and for support. During growth, water enters cells, exerting pressure which stretches cell walls. Water serves as a transport agent in which all nutrients and gases are moved into and throughout plants. Water is the main constituent of the cell protoplasm where it not only functions as a filler or dispersant but provides important structural support. Water also functions as a biochemical reagent in many physiological reactions including photosynthesis. Waters impact on plant growth and development and temperature regulations is also critical. Remember: all life depends on water!

Plant Water Stress - How does a lack of water affect plants?

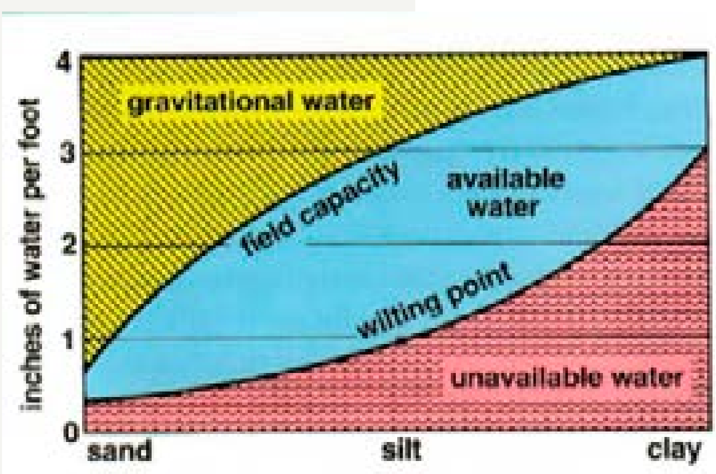


Figure 8 - Plant water stress.

Plant water stress occurs whenever plants either have excess (too much) water or deficit (too little) water for a period of time (Figure 8). Plant functions are very sensitive to changes in environmental conditions including changing water availability. Flooding is an example of excess water and directly impacts the oxygen supply to plant roots, which in turn effects respiration, nutrient uptake, and many other plant functions. However, this section focuses on plant water deficient, often called drought stress, because it is more common.

In general, during a period of plant water stress, plant processes are reduced or slowed due to a lack of water (Figures 9). Both water content and suction change during water stress, with the degree of change primarily dependent on the severity and duration of the deficiency. Plant growth and development is impacted in several ways, with the overall effect dependent on the severity and duration of the deficiency, the plant species, and other environmental conditions. The initial effect of a water stress that is visible, is wilting or a loss of turgidity in plant leaves which is the direct result of decreased water content in plant tissues. Water stress leads to membrane damage as various plant organs and metabolic functions slow or stop completely due to low water potential and desiccation. Photosynthesis is impacted by water stress in two ways 1) closure of stomata on plant leaves to reduce further water loss from transpiration, and 2) decrease structural integrity of the photosynthetic system. Plant respiration, protein synthesis, and other critical plant functions are greatly reduced when a plant is water stressed, and prolonged or severe water stress can lead to cells and tissues being permanently injured. Many plants have found ways to adapt to repeated or prolonged water deficiency such as succulents; leaf size and shape, location of leaves, having thorns in place of leaves are all examples of plants adapting to try and conserve water. Furthermore, water stress can also impact the breaking of dormancy, development, flower initiation, change in fruit size, morphology, and lead to stunting, among many other effects that depend on the plant species and other environmental conditions.

Figure 9 - Plant Water Stress Example

Summary and Conclusions

Plants consist almost entirely of water and all plant functions are influenced by water. Water is the most important plant nutrient and a lack of it can greatly reduce growth and many other critical functions. Decreased growth and development of most horticultural plants often means decreased product quality. It is critical that horticulturists and all plant care professionals understand the importance of water and water management. It would be impossible to publish water recommendations for each specific plant or growing environment; however, with an understanding of the basic principles, it is possible for each grower to improve soil-plant-water relations.

The Nature of Soil Moisture

Why is soil moisture important?

In agriculture and horticulture, soil moisture impacts plant growth more often than any other soil factor. Water is the most important nutrient needed by plants. Plants have a greater content and use of water than of any other nutrient required for their growth. Every plant function is directly or indirectly influenced by water and plants cannot live without water. The water content of the soil, which is affected by the soils physical, chemical, and biological properties, has a huge influence on plant growth. This section briefly considers the nature and behavior of soil moisture in relation to plant water use.

The soil, which remember is full of soil pores, can be thought of as a reservoir that stores water and other nutrients for plant use. Water occurs in all three forms in soil, as a solid, liquid, and gas. The liquid phase or soil water is the most critical for plants. Soil water is also referred to as the soil solution. This solution is a very dynamic pool that contains organic and inorganic substances, nutrients, and organic matter that plants require. It connects all components of the soil-plant-water system: the atmosphere, surface, soil particles, etc., and serves as the essential pathway for all nutrients to be absorbed by plant roots. Nutrient concentrations in the soil solution vary depending on soil physical, chemical and biological conditions and in response to any fertilizer, lime, and organic matter additions. Soil type and environmental conditions influence the relative proportions of each state of water in a given soil. In typical landscape and agricultural soils, the solid and gas phases of soil water make up less than 1% of the total soil mass and is water not available for plant uptake. On the other hand, liquid water (soil solution) constitutes more than 30% of the total soil mass and may occupy 50% or more of the total soil volume under saturated conditions. The forces that hold water in the soil matrix and the amount of water in a soil are the most important characteristics of the soil water phase.

In summary, soil water also referred to as the soil solution consists of liquid water and all the substances and nutrients for plants. Nutrients are taken up by plants roots directly from the soil solution.

Soil Moisture Retention - How is water held in soils? How strongly?

Water is held in soil pores either bound to soil particles or to other water molecules (Figure 10). The soil water adheres to soil particles and is held in soil pores by a tension that is a combination of adhesive and cohesive forces. Adhesive forces are between water and solid surfaces (eg., soil particles) and are responsible for capillary rise in soils, while cohesive forces are between water molecules and produce surface tension. Surface tension is a tightly stretched 'membranelike' film of water at the air-water interface. It tends to hold water in or out of pores. The combination of adhesive and cohesive forces between water and soil particles within the soil matrix are often visualized using the capillary tube model, with these capillary forces controlling water retention in soils. The strength of water retained in soils can vary tremendously between soils or within a given soil as conditions change. A measure of the strength of soil water retention is called soil water potential. The greater the soil water potential, the more tightly water is held in soil pores and the harder it is for plants to use it. Various terms commonly used to describe soil moisture retention are listed in [Part A of the Glossary](#).

Figure 10 - Cohesion vs Adhesion

Soil Moisture Content - How much water is in the soil?

Soil moisture content is the amount of water held in the soil. Since water is held in soil pores it is not just the total amount of pores in the soil but the size distribution of soil pores, which are determined by soil texture and structure, that affect the amount of water retained in a given soil. Soils with smaller pores (finer, clayey soils) retain more water following rainfall/irrigation and drainage than soils with larger pores (coarser, sandy soils). Finer-textured and less-compacted soils have greater surface area and total porosity than coarser-textured and more-compacted soils. Soils with greater porosity means more water can be held because water is held in pores. Finer soils, soils with more micropores, have greater water holding capacity than coarser soils, with more macropores. But soils with a distribution of both pore soils are best for providing adequate moisture to plants because they have water available for plants both immediately and for a longer period of time in between rainfall or irrigation events.

Soil texture and structure are not the only factors controlling soil water content. Matric potential (matric suction) is a primary factor influencing the water content within a particular soil. Two identical soils with different matric potential levels will contain different amounts of water. The relationship between matric potential and soil water content is described by a soil water characteristic curve (Figure 11). As soil water content decreases (as soils dry) the matric potential increases and water becomes more strongly held to soil particles. Every soil has its own specific water characteristics.

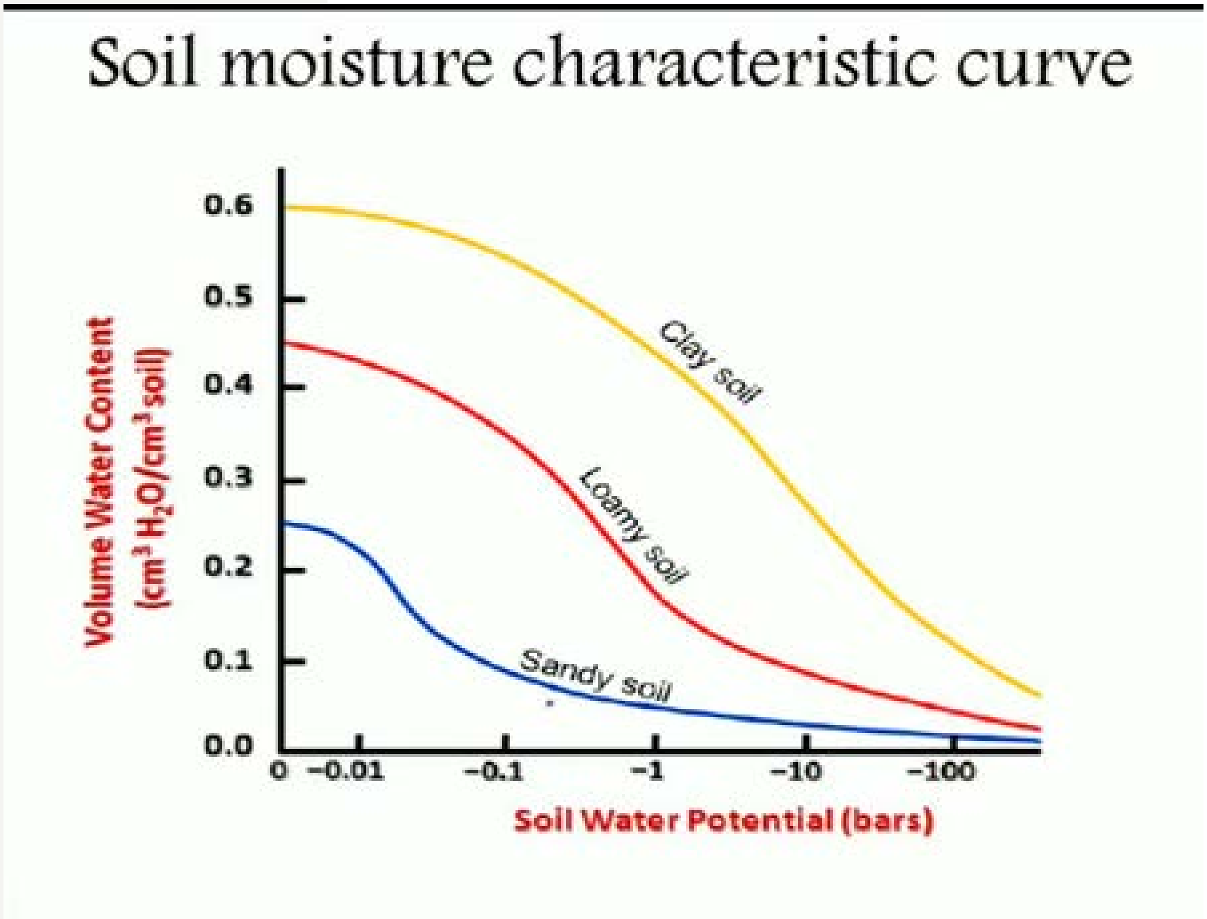


Figure 11 - Soil water characteristic curve.

Water that drains from macropores under the force of gravity is called gravitational water. Immediately after that gravitational water has drained away a soil is considered to be at field capacity. This typically occurs 2-3 days after a rainfall or irrigation event in pervious soils of uniform structure and texture. For container soils this may be after a few minutes or hours. The water that has not drained due to gravity is called capillary water and is held in soil micropores. A soil that has reach field capacity is then considered to either have available or unavailable water for plants. If plant roots can utilize (absorb) the water in the soil it is classified as available, if they cannot take it up and it is held too tightly to soil particles it is considered unavailable. A soil that is too depleted of water and there is no more available for plant uptake has reached its wilting point, and plants experience water stress, often visible as wilting leaves. The permanent wilting point has been reached if the water stress is sustained and even after a rainfall or irrigation event the plant is unable to recover. The water content between field capacity and wilting point is considered plant available water (Figure 12). Soil management practices that add organic matter to soil such as compost and mulch will over time increase a soils ability to hold more plant available water and decrease irrigation frequency.

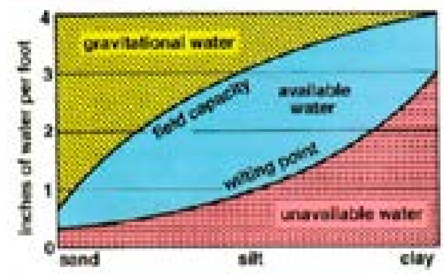


Figure 12 - Water Content

In summary, soil water retention depends greatly on soil texture and structure. The relationship between soil moisture content and potential is described by the soil water characteristic curve. Plant available water is the soil water content between field capacity and wilting point, this varies by soil. Various terms commonly used to describe soil moisture content are listed in Part B of the Glossary.

Soil Moisture Movement - How does water move through soils?

Only part of the water from rainfall or applied through irrigation stays in any single part of the soil; the rest infiltrates and percolates throughout the soil profile. The forces of gravity on water, pull it downward, mostly through the larger soil pores. The rate of water movement depends on both the distribution of different pore sizes (pore size distribution), and the total amount of soil pores (total pore volume). Infiltration into soil and drainage down through the soil profile is more rapid in coarser-textured and less-compacted soils (e.g. sandy soils). Movement of water retained in the soil matrix is called unsaturated or capillary water flow. Capillary or suction forces can pull water in any direction through adhered water films and water-filled pores. The initial distribution of water throughout the soil reservoir is via the flow of gravitational water immediately following a rainfall or irrigation event. Secondary or horizontal distribution of water throughout the soil occurs by capillary water movement. How water moves through a soil influences its availability to plants.

Soil Moisture Distribution - Where is water located in soils?

Water is not distributed uniformly throughout a soil following rainfall or irrigation. Soil texture plays a major role in water infiltration and percolation. Soil layers of varying textures impact water infiltration. For example, when a clay soil is overlaying a sandy soil the water must completely saturate (fill all pores) of the clay soil before it percolates downward into the sandy soil, however, the opposite is not true if the sandy soil is above the clay soil. This can have important implications for runoff, drainage, and soil aeration. Further, soils that are heavily compacted, such as urban soils, often have greater issues with ponding because there is little to no pore space for the water to infiltrate.

Summary

Water is essential for plant growth! Plant roots take up water from the soil solution. The most important aspect of soil moisture in relation to plant growth is its availability for plant use (plant available water). The availability of water is dependent on many factors including soil texture and porosity. Plant conditions also impact water availability such as nutrient concentrations, temperature, and pH.

Glossary A- Soil Moisture Terms

Available water holding capacity/Plant available water - the difference between field capacity and wilting point. Units are inches of water per inch of soil or metric equivalent.

Bar – a unit of pressure or suction equal to about one atmosphere (actually about .985 atmosphere).

Container capacity – the water content of a container soil following complete draining without any other water loss (an analogue of field capacity except it is a characteristic of both the soil and the container).

Field capacity – the water content water content of a soil after all gravitational water has drained. Typically occurs 2-3 days after a rainfall or irrigation event.

Infiltration - the rate that water enters the surface soil. This property varies depending on soil moisture content, slope of the soil, surface crusting, vegetation on the surface, and only recent management activities.

Soil water content - the amount of water in a soil (usually a percentage based on soil dry weight, soil wet weight or soil volume).

Soil water potential/suction – a measure of the difference between the free energy state of water and that of pure water. The total water potential consists of gravitation, matric, and osmotic potentials.

Soil solution – the liquid phase of the soil and its solutes. It consists of ions and other soluble materials.

Soil structure – the arrangement of soil particles into units or peds.

Saturation – a condition when all soil pores are filled with water

Unsaturated flow – movement of water in a soil that is not filled to capacity with water

Tensiometer – a device for measuring the negative pressure (or tension) of a soil

Percent pore saturation – the percentage of the soil pore volume that is filled with water

Permanent wilting point – the soil water content at which a plant can no longer recover their turgidity due to a lack of sufficient soil water.

Water-depth ratio – the volume of water contained per volume of soil.

Water table – a saturated zone in the soil or the upper surface of groundwater.

Soil Aeration

Introduction- Why is soil aeration important?

Soil aeration is critical for the growth of plants and activity of microorganisms. Plant roots and aerobic microorganisms respire just like us! In soils, inadequate aeration occurs when there is a deficient oxygen supply or an excessive carbon dioxide accumulation in the root zone, potentially reducing root growth and microbial activity of aerobic organisms. Without sufficient soil aeration, plant root and microbial activity are negatively affected. Lack of aeration also interferes with a soil organism's ability to respire and cycle nutrients. Plant growth typically becomes hindered when O_2 levels in the soil decrease below 0.1 L/L. This usually occurs when only 10-20% of the soil air space remains and 80-90% of the pores are filled with water.

Soil Aeration – What is soil aeration?

Soil aeration is the exchange of gases between the soil and atmosphere. Aeration normally involves an exchange of oxygen (O_2) into and carbon dioxide (CO_2) as well as other gases out of the soil. These gases move in the soil primarily through the soil atmosphere; this is the part of the soil volume not filled by solid or liquid phases. Aeration occurs primarily through partially filled or open soil pores. A microscopic view of the soil would show a network of interconnecting, irregular tubes or tunnels formed by soil pores honeycombing the soil structure. In a typical soil, the total volume is about 50% solids (approximately 45% soil particles and 5% organic matter), and about 50% pore space which are filled with air or water. A packed unstructured, single-particle-size soil, which may be representative of a manufactured soil, contains only about 27% pore space by volume. Gases, including O_2 and CO_2, move throughout the soil through this pore network, so fewer pores means less room for water and air to move. Adequate aeration requires sufficient open or unblocked tunnels in the network to permit free gas movement with the soil and exchange between the soil and atmosphere. Aeration tunnels (soil pores) can be blocked by solid particles or filled with water.

As previously discussed, most soils consist of a mixture of different-size particles which determine a soils texture. It is this soil texture that impacts soil pores, water content, and thus aeration. Soils with large pores generally have good drainage (less water) and aeration, while soils with small pores generally have poor drainage and aeration. Thus, sands generally have good drainage, while clays have poor drainage and are more likely to become anaerobic (deprived of oxygen) as microbes use oxygen more rapidly than it is replenished through diffusion. As soil water content increases, open pore space decreases; smallest pores tend to fill first followed by increasingly larger pores until all are filled. When all soil pores are filled or nearly filled a soil is saturated or waterlogged. In well-drained soils, saturated conditions are only temporary, occurring just following a heavy rainfall or excess irrigation. In general, aeration is greatest in uncompacted, well-structured, coarse textured and low water content soils.

Soil temperature, biological activity, irrigation, and atmospheric pressure changes also influence soil aeration. Temperature affects O_2 and CO_2 movement and an increase in biological activity occurs. The rate of biological activity determines O_2 utilization and CO_2 production rates. In general, the higher the rate of biological activity, the faster O_2 is utilized and CO_2 is produced. Soil O_2 and CO_2 concentrations can each range about 0 to 21% depending on aeration and biological activity. When a container soil (pot, planter, bench, etc.) is irrigated by flooding the surface, much of the existing soil atmosphere is purged or pushed from the soil by the water and replaced by atmosphere gases as the soil drains and dries. In some cases, a significant amount of aeration occurs by gases carried into and out of the soil by gases dissolved in irrigation water. Atmospheric pressure changes, for example those caused by turbulent air movement across the soil surface (wind pulses) tends to influence gas movement into and out of the soil. The relative importance of soil temperature, biological activity, irrigation and pressure changes to soil aeration varies from soil to soil and depends on plant and soil properties, and environmental conditions.

In summary, soil aeration is the exchange of oxygen and carbon dioxide between the soil and atmosphere. Soil air movement occurs through a network of interconnected, open soil pores. The efficiency of this aeration network is largely controlled by soil texture, structure, and moisture content, but soil temperature, biological activity, and atmospheric conditions play a role. Aeration is generally highest in uncompacted, coarse-textured, well-drained soils.

Soil Aeration and Plant Growth – How does soil aeration affect plant growth?

Soil aeration affects plant growth directly by affecting root respiration and thus growth and physiological activity (Figure 13).

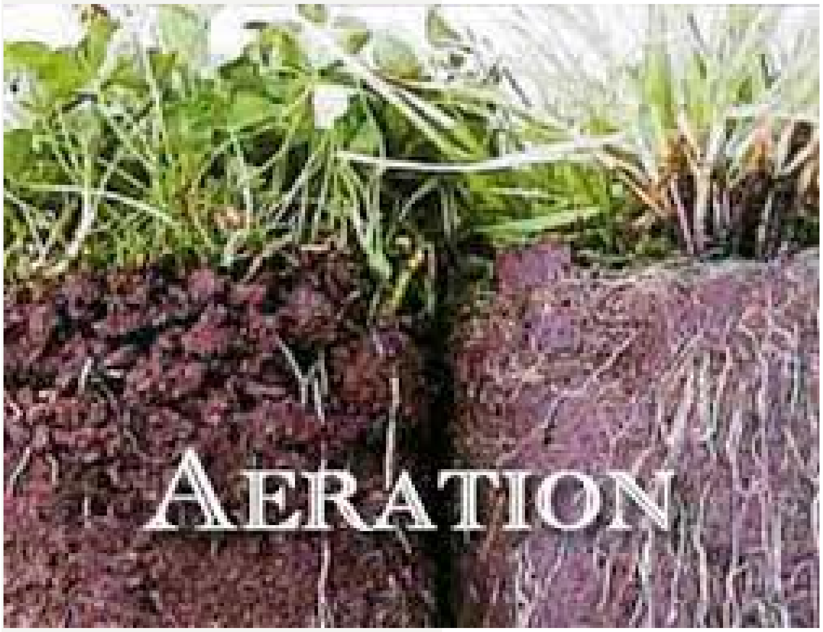


Figure 13 - Example of mechanical aeration.

Roots anchor the plant and extend through the soil connecting the plant to its water and nutrient reservoir, the soil pores. Roots absorb the nutrients and water required by the plant as well as produce exudates (sugar and other materials) that are a source of food for microorganisms. Growing roots allow plants to continuously access water and nutrients in the soil matrix and root physiological activity influences mineral and water absorption rates. Roots act as storage organs and synthesizers of specific substances essential for normal plant functions. Any factor affecting root growth and physiological activity ultimately affects the growth of the whole plant.

Roots require a constant supply of oxygen and good ventilation to prevent the accumulation of CO_2 and other gases. An oxygen deficiency retards respiration and root physiological activity. A high CO_2 concentration also retards respiration and may have a toxic effect on the roots depending on the duration. Some plants are capable of transporting sufficient oxygen for root respiration through the plant structure (leaves, stems, roots) from the aboveground atmosphere; however, in most cases soil aeration is the process responsible for oxygen supply and carbon dioxide removal from plant roots.

Poor aeration in any specific situation depends on plant, soil, and environmental factors. The severity of poor aeration damages to plant growth depend on the intensity, duration, and frequency of the lack of O_2 to roots as well as the plant species, growth stage, and other environmental conditions. Harm to plants is usually most severe when poor aeration occurs during the early stages of plant development and when it is frequent or prolonged.

Poor aeration symptoms (often due to compaction especially for urban soils) include:

1. Yellowing (chlorosis) on shoots,
2. Wilting, Abnormal, twisted shoot growth (epinasty) and eventual tissue browning and/or death,
3. Abnormal root anatomy and morphology,
4. Stunted shoot growth, and
5. Dead or injured roots.

The result of poor soil aeration may look different depending on the plant and the environment, but overall reduced growth and quality occur. Aeration may also influence plant growth by affecting soil chemical properties such as soil pH and by providing an environment unfavorable for beneficial soil microorganisms.
In summary, adequate soil aeration is critical for proper plant growth and development. Poor aeration can lead to numerous negative impacts on plant growth and, if sustained, plant death.

Summary and Conclusions

Soil aeration is the exchange of gases, primarily oxygen and carbon dioxide, between the soil and atmosphere. Soil aeration occurs through the network of interconnected open pores in the soil matrix. Soil texture, structure, moisture, temperature, biological activity, and atmospheric conditions all affect the efficiency of the aeration network. Good aeration usually occurs in uncompacted, well-structured and draining, coarse-textured soils.
Soil aeration affects plant growth by affecting root physiological activity and soil physical, chemical, and biological properties. Aeration requirements vary with plant species, soil type, and environment. Plant symptoms of poor aeration depend on the plant and the severity of the poor aeration, but in all cases the overall effect is reduced plant growth and yield. Adequate soil aeration in most agricultural and horticultural situations is guaranteed when best management practices are implemented. Plants require both good aeration and moisture and this is obtained by supporting a healthy soil system.

Soil Moisture, Texture, and Aeration Section - Updated

by Deborah Alher, PhD, Agricultural Stewardship Specialist, Cornell Cooperative Extension of Suffolk County. January 2021

Reference Material - Soils

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Glossary B - Soil Terminology *(common terms used when working with soils or soilless mixes)*

Acid Soil - A soil with a pH value <7.0.

Acidity – activity of the hydrogen ions in the liquid phase of soil. Measure and expressed as a pH value.

Adsorption - The attraction of ions or compounds to the surface of a solid. Soil colloids adsorb large amounts of ions and water.

Aeration - The process by which air in the soil is replaced by air from the atmosphere. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen than the atmosphere above the soil.

Aggregate - Many soil particles held in a single mass or cluster such as a clod, crumb, block, or prism.

Alkaline – A soil that has a pH value >7.

Artificial mix (soilless mix) - media used to grow plants. Contains no soil but may container amendments such as peat moss, shredded bark, compost, vermiculite or perlite.

Available water- The portion of water in a soil that can be readily absorbed by plant roots. Also, the amount of water between a soils field capacity and permanent wilting point

Bulk density – weight per unit volume of soil. It is related to the size of soil particles (texture) and the total pore space in a soil. Commonly measured in grams per cubic centimeter or pounds per cubic foot

Cation exchange capacity - The sum total of exchangeable cations that a soil can adsorb. Often expressed in milliequivalents per 100 grams of soil.

Chelate - A type of chemical compound in which a metallic ion is firmly combined with a molecule by means of multiple chemical bonds.

Class -A group of soils having a definite range in a particular property such as acidity, degree of slope, texture, structure, land-use capability, degree of erosion, or drainage.

Soil classification - The systematic arrangement of soils into groups or categories on the basis of their characteristics.

Clay - A soil separate consisting of particles <0.002 mm in equivalent diameter. Soil material containing more than 40% clay, less than 45% sand, and less than 40% silt.

Course texture - The texture exhibited by sands, loamy sands, and sandy foams except very fine sandy loam.

Cohesion - Holding together: force holding a solid or liquid together, owing to attraction between like molecules.

Crumb - A soft, porous, more or less rounded natural unit of structure from 1 to 5 mm in diameter.

Fertilizer - organic or inorganic nutrient material added to media and soil to insure good growth.

Field capacity - The percentage of water remaining in a soil two or three days after having been saturated and after free drainage has practically ceased. The upper limit of the plant available water range.

Fine texture - Consisting of or containing large quantities of the fine fractions, particularly of silt and clay.

Flocculate - To aggregate or dump together individual, tiny soil particles, especially fine clay, into small clumps or granules.

Friable - A soil consistency term pertaining to the ease of crumbling of soils.

Granular structure - Soil structure in which the individual grains are grouped into spherical aggregates with indistinct sides. Highly porous granules are commonly called crumbs.

Gravitational water - Water which moves into, though, or out of the soil under the influence of gravity.

Heavy soil - very fine-textured soil, one that is hard to work, does not refer to weight, Ex: clayey soil.

Humus - The stable fraction of soil organic matter that remains after the major portion of residues have decomposed. Humus provides nutrients, increases the water holding capacity of the soil, and provides food for microbial activity. Usually dark in color

Ions - Atoms, groups of atoms, or compounds, which are electrically charged. Cations are positively charged while anions are negatively charged.

Light soil -coarse textured soil, easy to work, ex: sandy soil.

Lime -a basic material (ground limestone) added to soils to control the acidity.

Loam- a soil that exhibits the best properties of both sand, silt and clay particles, considered very desirable. Loam soils contain 7-27% clay, 28-50% silt, and <52% sand

Mineral soil - A soil consisting predominantly of, and having its properties determined mainly by, mineral matter. Usually contains <20 % organic matter, but may contain an organic surface layer up to 30 cm thick

Organic matter- decayed or partially decayed plant and/or animal matter. Examples: peat moss, manure, compost material, grass clippings, sawdust, plant residues. Organic matter is added to soils for numerous benefits including for use as food for soil micro-organisms, increased soil's water holding capacity, and improved nutrient availability.

Organic soil -A soil which contains a high percentage (>20%) of organic matter throughout the upper part of the soil horizon.

Particle density - The mass per unit volume of the soil particles. In technical work, usually expressed as grams per cubic centimeter.

Peat moss - An organic material that was formed under wet swampy conditions. Peat moss holds moisture.

Perlite - Form of volcanic rock heated at 2000° temperatures causing it to expand. A component of some artificial or soilless mixes, it is used to promote drainage.

pH - a scale developed to indicate soil acidity (pH of 0-6.9), its neutrality 7.0 or its alkalinity

(7.1-14.0).

Plant nutrients - are elements needed by the plant. Carbon, hydrogen and oxygen are provided by air and water and are used by plants in large quantities. The macronutrients nitrogen, phosphorus, potassium, calcium, magnesium and sulfur are needed in relatively large amounts. The micronutrients Fe, B, Mn, Cu, Zn, Mo and Cl are needed by plants in smaller amounts.

Porosity - The volume percentage of the total bulk not occupied by solid particles.

Sand - A soil particle between 0.05 and 2.0 mm in diameter.

Silt - A soil separate consisting of particles between 0.05 and 0.002 mm in diameter.

Soil organisms - may be anything from bacteria, fungi to earthworms. Important to the soil because they conduct the biological activity needed to break down organic matter and nutrients into forms the plant can use.

Soil particles- sand, silt, and clay.

Soil solution - The aqueous liquid phase of the soil and its solutes consisting of ions dissociated from the surfaces of the soil particles and of other soluble materials.

Soil structure - refers to the arrangement or grouping of soil particles. A sandy soil contains large particles and because of this it has a loose structure, not much clumping together allows for good aeration and drainage. A clayey soil has fine particles that bind together tightly and holds lots of water. We can improve the structure of a soil. For example, the addition of organic matter will help hold moisture in a sandy soil. We can damage the structure by compaction, tillage, weathering.

Soil test – used to determine soil nutrient and pH levels that a accurate fertilizer and lime recommendations can be made. Recommended to test annually, but at least every 3 years.

Soil texture - refers to the size of the soil particles and is used to name a soil by the percent of these particles in a soil.

Tensiometer -A device for measuring the negative pressure (or tension) of water in soil in situ; a porous, permeable ceramic cup connected through a tube to a manometer or vacuum gauge.

Topsoil - The layer of soil moved in cultivation.

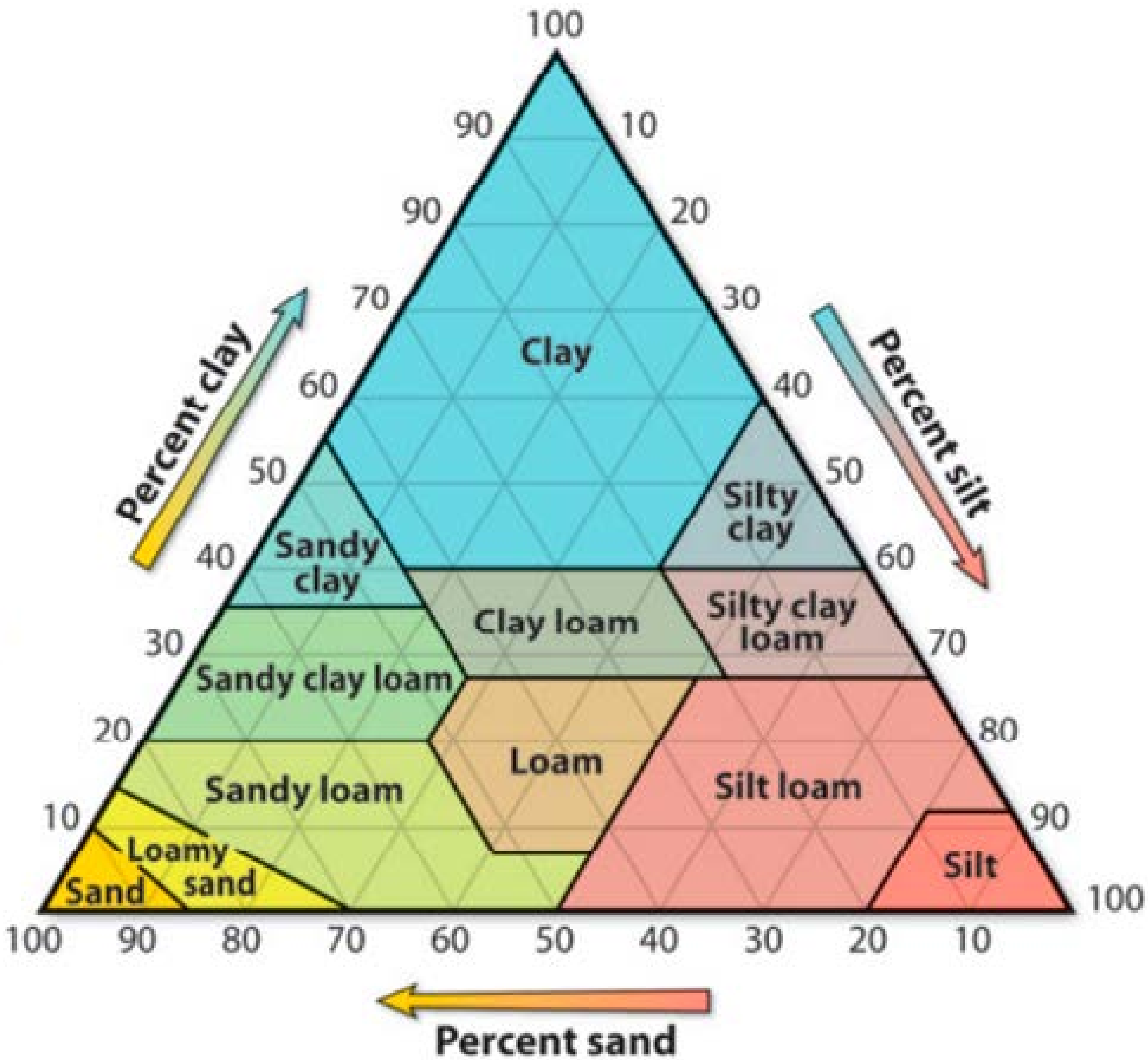
Wilting point - The moisture content of soil, on an oven-dry basis, at which plants wilt and fail to recover their turgidity when placed in a dark humid atmosphere.

Vermiculite - a mica mineral heated at a very high temperature causing the granules to expand greatly. Used to improve the air movement in fine-textured soils (clay), used to hold moisture in coarse-textured soils (sand and is a component of artificial mixes).

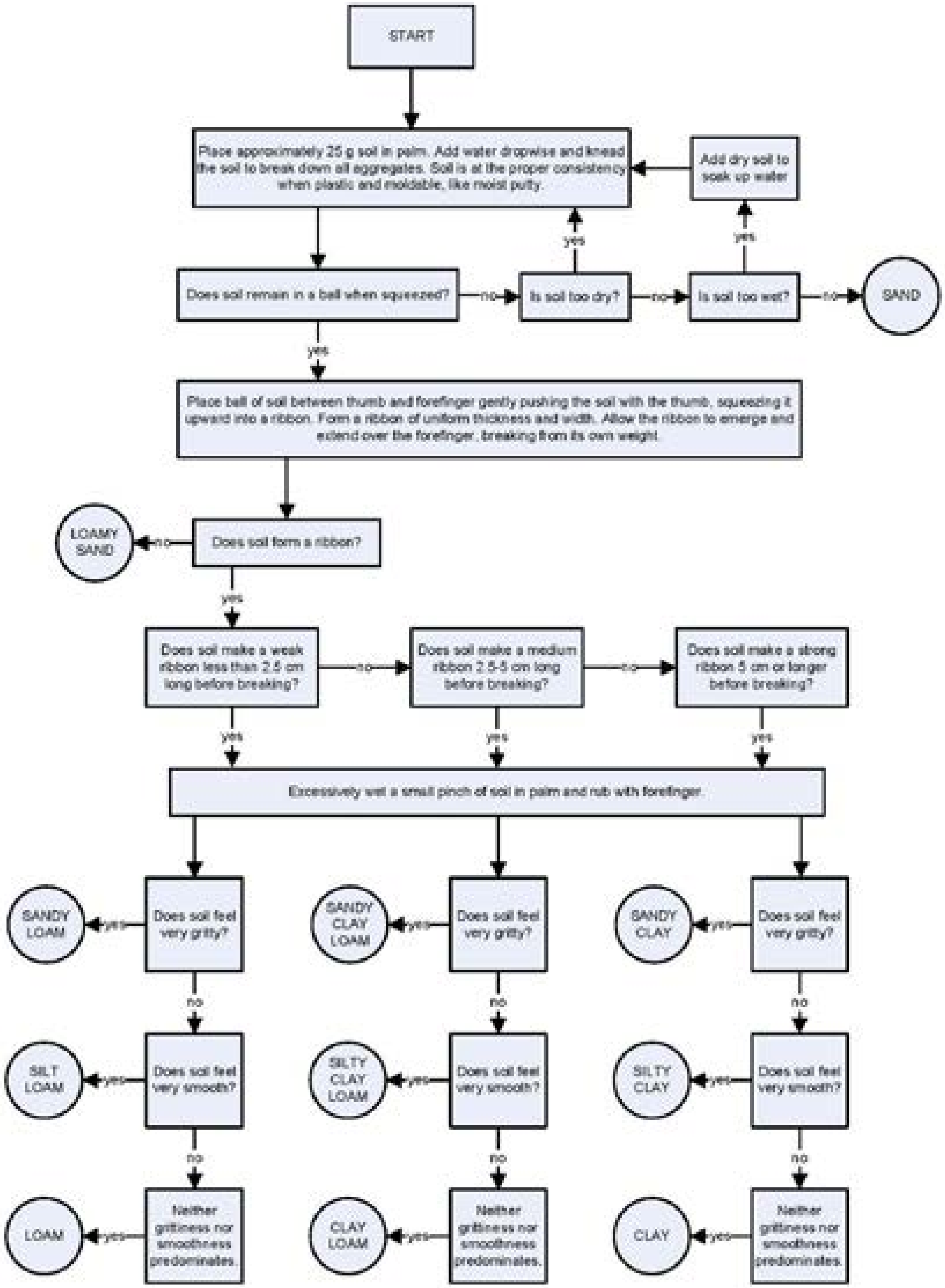
Review Questions - Soil Moisture, Texture, and Aeration

1. List the three phases of soil. Which phase is considered the backbone of soil? Why?
2. What is the basic relationship among the three phases of soil?
3. List three levels of soil moisture. Between which two levels is considered plant available water?
4. What is bulk density and how does it relate to soil pores and thus water/ nutrient retention?
5. What is soil moisture tension?
6. How much water makes up actively growing plant tissue and most herba ceous tissue?
7. Name three places where water is found in plants?
8. Define cohesion and describe how it affects water movement in plants
9. What part of the root is the most permeable to water?
10. In what direction does water move?
11. What are some functions of water in plants?
12. Where does all plant water come from?
13. What is soil bulk density and how does it relate to soil porosity and water retention in soil?
14. What is the soil solution?
15. What factors influence the amount of dissolved materials in the soil solu tion?
16. What is adhesion?
17. Define the following terms related to soil moisture: Bound or hygroscopic water, Capillary water, Gravitational water, Plant available water
18. What is soil aeration?
19. What happens under poor aeration?
20. What are three main factors that influence soil aeration?
21. What are three visible symptoms in plants possibly due to poor aeration?
22. What is soil texture?
23. What does the soil textural triangle tell us about soil?
24. What is an easy method to determine soil texture?
25. How does soil texture impact soil water retention and movement?
26. Familiarize yourself with the properties of different textured soils.
27. What is one major reason, particular in urban areas, for poor aeration and water infiltration in soil?

Soil Texture Triangle



Determining Soil Texture by Feel



A Video of this Method can be viewed HERE:

https://www.youtube.com/watch?v=GWZwbVJCNec

General Properties of Different Textured Soils

*depends on water content of the soil.

Soil Texture	Susceptibility To Compaction*	Water and Nutrient Holding Capacity	Available Water (%)	Infiltration Rate (inches/hr)	Drainage	Reaeration Time
sand	very little	limited	6.7%	2	.5	2
loamy sand	limited	limited	10.1	1.5	1	2
sandy loam	limited-moderate	moderate	12.3	1	2	2
loam	moderate	moderate-substantial	15.6	.5	3	3
silt loam	substantial	substantial	19.9	0.2	3	3
clay loam	substantial	substantial	12.0	0.1	3	3
clay	substantial	substantial	11.5	0.02	5	5

Soil Characteristics and Water Movement

As soil texture changes from having a greater % sand to a greater % clay this is the expected change in soil water for a given soil property.

Soil Property	**Expected change as % clay increases**
Soil surface area	Increase
Cation exchange capacity	Increase
Pore space	Increase
Moisture retention	Increase
Field capacity	Increase
Water infiltration rate	Decreases
Aggregation potential	Increases
Leaching loss potential	Decreases
Permeability	Decreases

Introduction

Plant Nutrition and Fertilization

Many people confuse plant nutrition with fertilization. Plant nutrition refers to the needs of the plant and how a plant uses the basic chemical elements. Fertilization is the term used when these elements are supplied to the soil as amendments. Adding fertilizer during unfavorable growing conditions will not enhance plant growth and may actually harm or kill plants.

To complete their life cycle, plants need 17 essential nutrients, each in varying amounts (Table 1). Of these nutrients, three are found in air and water: carbon (C), hydrogen (H), and oxygen (O). Combined, C, H, and O account for about 94% of a plant's weight. The other 6% of a plant's weight includes the remaining 14 nutrients, all of which must come from the soil. Of these, nitrogen (N), phosphorus (P), and potassium (K), the primary macronutrients, are the most needed. Magnesium (Mg), calcium (Ca), and sulfur (S), the secondary macronutrients, are next in the amount needed. The eight other elements—boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc—are called micronutrients because they are needed in much smaller amounts than the macronutrients.

Table 1 - Relative amounts of the essential nutrients required by most plants. (out of 100)	
Primary Nutrients	
Carbon (C)	45
Oxygen (O)	45
Hydrogen (H)	6
Nitrogen (N)	1.5
Potassium (K)	1
Phosphorus (P)	0.2
Secondary Nutrients	
Calcium (Ca)	0.5
Magnesium (Mg)	0.2
Sulfur (S)	0.1
Micronutrients	
Iron (Fe)	0.01
Chlorine (Cl)	0.01
Manganese (Mn)	0.005
Boron (B)	0.002
Zinc (Zn)	0.002
Copper (Cu)	0.0006
Molybdenum (Mo)	0.00001
Amounts unknown for Nickel (Ni) and Cobalt (Co)	

Soil Nutrients

For a plant to absorb an element, it must be in a chemical form used by the plant and dissolved in the soil water.

In addition to those nutrients already dissolved in soil water, nutrients can be present in the soil in these forms:

- Undissolved or granular form, as from newly applied fertilizer
- Chemicals bound to soil particles
- The chemical structure of soil organic matter released by microbial decomposition

Undissolved or granular nutrients, and those that are chemically bound to soil particles, are not immediately useful, although they have the potential to benefit the plant. For many plant nutrients, the soil acts as a bank. Withdrawals are made from the soil solution, much as you would withdraw money from a checking account. The undissolved pool of soil nutrients is like a savings account. When checking funds are low, transfers are made from the savings account to the checking account. When a checking account is flush with money, some can be moved to savings for long-term retention. In the same way, for many plant nutrients, when the soil solution has excess nutrients, some bind to the soil to become temporarily unavailable, and some react with other chemical elements to form insoluble minerals, which can dissolve again later.

Several factors improve a plant's ability to use nutrients:

- Type of soil: The more clay and organic matter a soil has, the higher its CEC will be, and the more cationic (positively charged) nutrients it will retain.
- Soil pH: The pH affects how tightly nutrients are bound to soil particles. If the soil pH is extremely high (basic) or very low (acidic), many nutrients become inaccessible to the plant because they are no longer dissolved in the soil water.
- Types of nutrients in the soil: Some nutrients affect the availability of other nutrients. In fact, an apparent deficiency of one nutrient may actually be caused by a large amount of another.
- Amount of soil water: Too much rain leaches nutrients from the soil. If there is too little water, the nutrients cannot dissolve and move into the plant.
- Anything that affects the plant's growth: If growing conditions are good, a plant will absorb nutrients from the soil. If the plant experiences extremes in temperature, incorrect light levels, or waterlogged or compacted soil, it will have a limited ability to absorb nutrients. Also, plants in dormant stages absorb few nutrients.

The presence or absence of nutrients can cause outward symptoms to appear on the plant. Table 2 reviews the essential nutrients for plant growth and symptoms that may appear if a plant is suffering a deficiency or an excess of that nutrient.

Table 2.

Essential nutrients for plant growth - Macronutrients

MACRONUTRIENTS			
Why Needed	Deficiency Symptoms	Excess Symptoms	Comments
Nitrogen (N)			
Responsible for rapid foliage growth and green color Easily leaches from soil Mobile in plant, moving to new growth	Reduced growth (Figure 1–30) Light-green to yellow foliage (chlorosis) Reds and purples may intensify with some plants Reduced lateral breaks Symptoms appear first on older growth	Succulent growth; leaves are dark green, thick, and brittle Poor fruit set Excess ammonia can induce calcium deficiency	High N under low light can cause leaf curl Uptake inhibited by high P levels

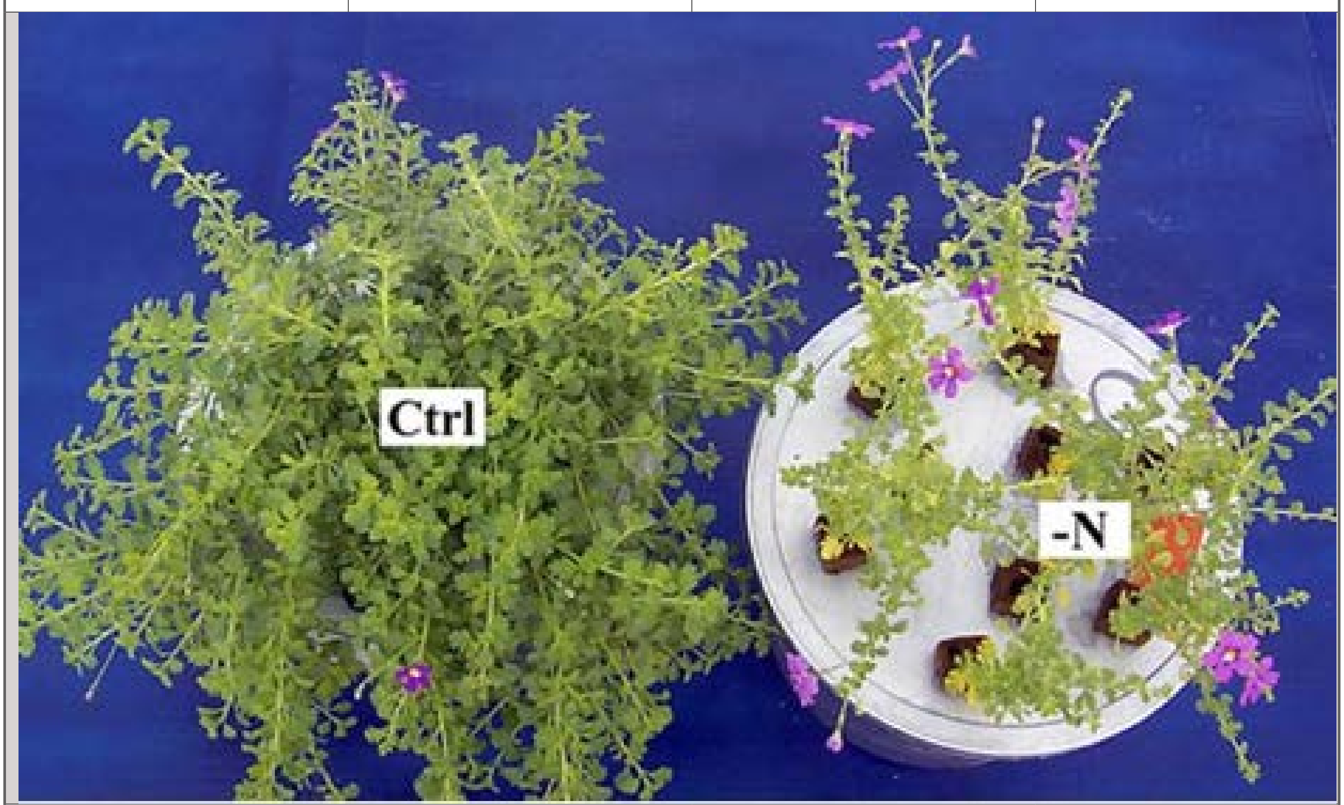


Figure 1–30. Nitrogen deficiency on in Bacopa. Note the severely reduced growth and light green-yellow leaves.
Paul Nelson

MACRONUTRIENTS continued			
Why Needed	Deficiency Symptoms	Excess Symptoms	Comments
Phosphorus (P)			
Promotes root formation and growth Affects quality of seed, fruit, and flower production Increased disease resistance Does not leach from soil readily Mobile in plant, moving to new growth.	Reduced growth Leaves dark-green; purple or red color in older leaves, especially on the underside of the leaf along the veins (Figure 1–31) Leaf shape may be distorted Thin stems Limited root growth	Shows up as micronutrient deficiency of Zn, Fe, or Co	Rapidly fixed on soil particles When applied under acid conditions, fixed with Fe, Mn, and Al High P interferes with micronutrient and N absorption Used in relatively small amounts when compared to N and K Availability is lowest in cold soils

Figure 1–31. Phosphorus deficiency exhibiting as purple leaves on this lettuce.

MACRONUTRIENTS continued			
Why Needed	Deficiency Symptoms	Excess Symptoms	Comments
Potassium (K)			
Helps plants overcome drought stress Improves winter hardiness Increases disease resistance Improves the rigidity of stalks Leaches from soil Mobile in plant	Reduced growth Shortened internodes Margins of older leaves become chlorotic and burned Necrotic (dead) spots on older leaves (Figure 1–32) Reduction of lateral breaks and tendency to wilt readily Poorly developed root systems Weak stalks	Causes N deficiency and may affect the uptake of other nutrients	High N/low K favors vegetative growth Low N/high K promotes reproductive growth (flower, fruit) Calcium excess impedes uptake of K

Figure 1–32. Potassium deficiency, chlorotic flecking and necrotic spots on older leaves. Scot Nelson, Flickr CC BY-NC-SA - 4.0

MACRONUTRIENTS continued			
Why Needed	Deficiency Symptoms	Excess Symptoms	Comments
Magnesium (Mg)			
Leaches from sandy soil Mobile in plant	Reduction in growth Yellowish, bronze, or reddish color of older leaves, while veins remain green (Figure 1–33) Leaf margins may curl downward or upward with a puckering effect	Interferes with Ca uptake Small necrotic spots in older leaves Smaller veins in older leaves may turn brown In advanced stage, young leaves may be spotted	Mg is commonly deficient in foliage plants because it is leached and not replaced Epsom salts at a rate of 1 teaspoon per gallon may be used two times a year Mg can be absorbed by leaves if sprayed in a weak solution Dolomitic limestone can be applied in outdoor situations to rectify a deficiency

Figure 1–33. Magnesium deficiency appears in first in older leaves. On this bean plant the veins remain green while the rest of the leaf turns yellow. Paul Nelson

MACRONUTRIENTS continued			
Why Needed	Deficiency Symptoms	Excess Symptoms	Comments
Calcium (Ca)			
Moderately leachable Limited mobility in plant Essential for growth of shoot and root tips	Inhibition of bud growth Roots can turn black and rot Young leaves are scalloped and abnormally green Leaf tips may stick together Cupping of maturing leaves Blossom end rot of many fruits (Figure 1–34) Pits on root vegetables; stem structure is weak Premature shedding of fruit and buds	Interferes with Mg absorption High Ca usually causes high pH	Ca is rarely deficient if the correct pH is maintained

Figure 1–34. Blossom end rot on a tomato is due to calcium deficiency. Scot Nelson, Flickr CC BY-SA - 4.0

MACRONUTRIENTS continued			
Why Needed	Deficiency Symptoms	Excess Symptoms	Comments
Sulfur (S)			
Leachable Not mobile Contributes to odor and taste of some vegeta-bles	Rarely deficient General yellowing of the young leaves, then the entire plant (Figure 1–35) Veins lighter in color than adjoining inter-veinal area Roots and stems are small, hard, and woody	Sulfur excess is usually in the form of air pollu-tion	Sulfur excess is dif-ficult to control, but rarely a problem

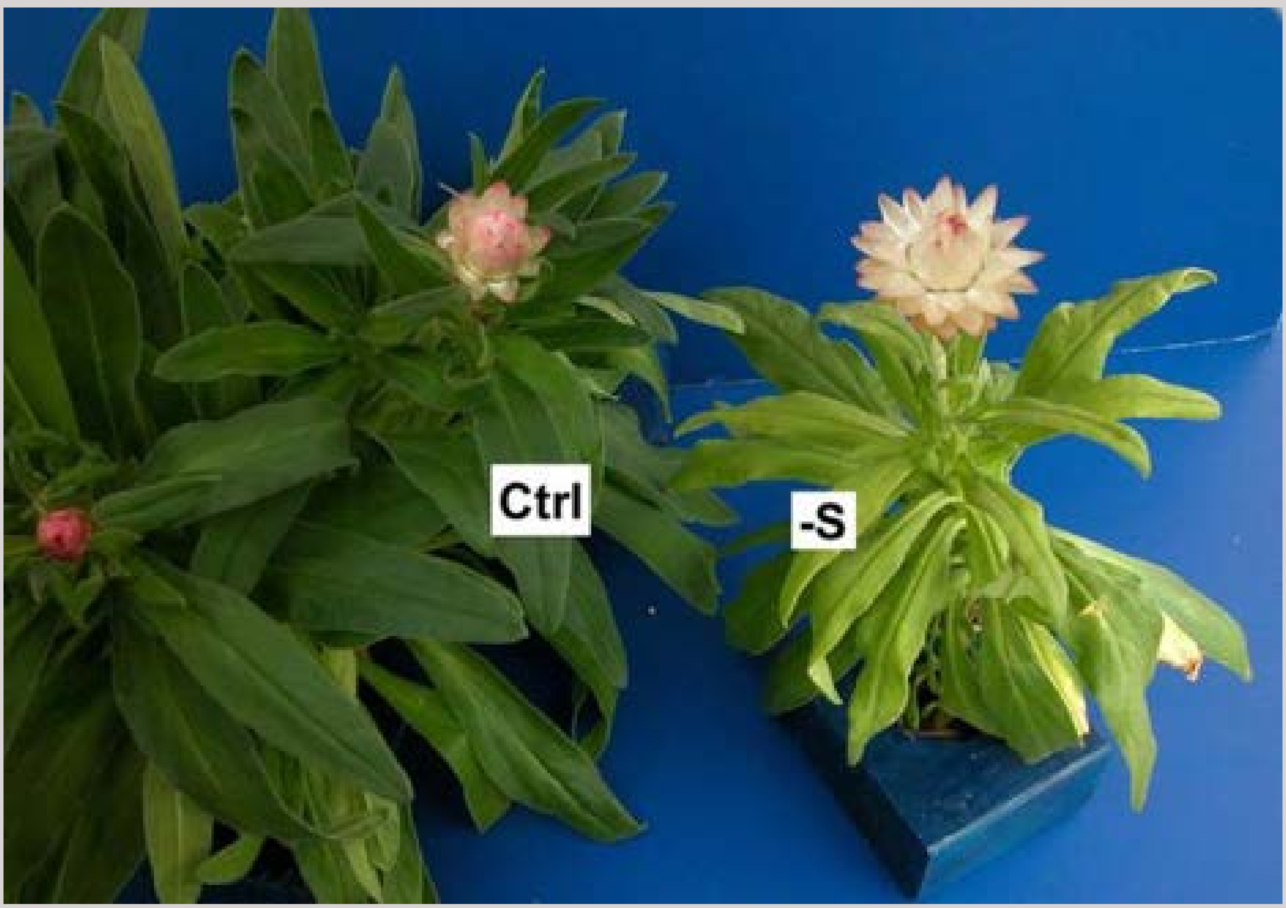


Figure 1–35. Sulfur deficiency rarely occurs but on this strawflower it has affected the shoot size and leaves with a yellowing of the veins. Paul Nelson

Essential nutrients for plant growth - Micronutrients

MICRONUTRIENTS		
Why Needed	Deficiency Symptoms	Comments
	Iron (Fe)	
Accumulates in the oldest leaves and is relatively immobile Necessary for the maintenance of chlorophyll	Interveinal chlorosis primarily on young tissue, which may become white (Figure 1–36) Fe deficiency may occur even if Fe is in the soil when: soil is high in Ca; soil is poorly drained; soil is oxygen deficient; nematodes attack roots; or soil is high in Mn, pH, or P Fe should be added in the chelate form; the type of chelate needed depends upon the soil pH Foliar fertilization will temporarily correct the deficiency May be deficient in centipede grass where pH and P are high	Rare except on flooded soils

Figure 1–36. Iron deficiency, interveinal chlorosis on young leaves. Scot Nelson, Flickr CC BY-NC-SA - 4.0

MICRONUTRIENTS continued		
Why Needed	Deficiency Symptoms	Excess Symptoms
Boron (B)		
Important in enabling photosynthetic transfer Very immobile in plants	Failure to set seed Internal breakdown of fruit or vegetable Death of apical buds, giving rise to witches' broom Failure of root tip to elongate normally Young leaves become thick, leathery, and chlorotic (Figure 1–37) Rust-colored cracks and corking on young stems, petioles, and flower stalks (such as heart rot of beets, stern crack of celery) Breakdown occurs at the base of the youngest shoots	Tips and edges of leaves exhibit necrotic spots coalescing into a marginal scorch (similar to high-soluble salts) (Figure 1–38) Oldest leaves are affected first • Can occur in low pH soils • Plants are easily damaged by excess application •Looks like Mg deficiency,green veins on a yellow leaf.

Figure 1–37. This geranium is deficient in boron which is evident by the thick leathery chlorotic younger leaves. Paul Nelson

Figure 1–38. Boron toxicity on a rose bush. Can look like the inverted "V" of green on a yellow leaf that is characteristic of magnesium deficiency but uptake of too much boron by the plant often occurs when pH is too low.
Malcolm Manners, Flickr CC BY - 2.0

MICRONUTRIENTS continued		
Why Needed	Deficiency Symptoms	Excess Symptoms
Zinc (Zn)		
Needed for enzyme activity	Young leaves are very small, sometimes missing leaf blades Short internodes Distorted or puckered leaf margins Interveinal chlorosis (Figure 1–39)	Severe stunting, reddening Poor germination Older leaves wilt Entire leaf is affected by chlorosis; edges and main vein often retain more color Can be caused by galvanized metal

Figure 1–39. Zinc deficiency shows very small young leaves and interveinal chlorosis .Scot Nelson, Flickr CC BY-NC-SA - 4.0

MICRONUTRIENTS continued		
Why Needed	Deficiency Symptoms	Excess Symptoms
Copper (Cu)		
Needed for enzyme activity	New growth small, misshapen, wilted (Figure 1–40) In some species, young leaves may show interveinal chlorosis while tips of older leaves remain green	Can occur at low pH Shows up as Fe deficiency

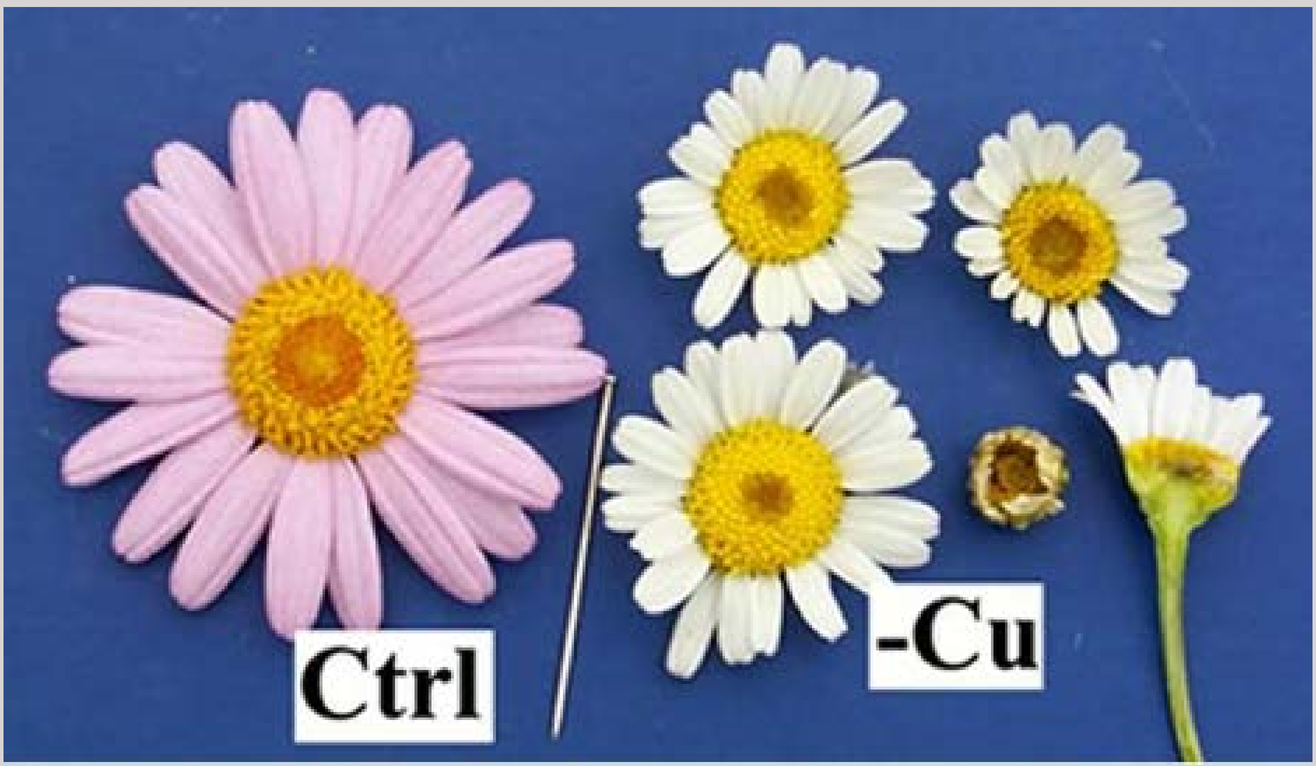


Figure 1–40. Copper deficiency in this daisy appears as small misshapen growth. Paul Nelson

MICRONUTRIENTS continued		
Why Needed	Deficiency Symptoms	Excess Symptoms
Manganese (Mn)		
Needed for enzyme activity	Interveinal chlorosis with smallest leaves remaining green, producing a checkered effect (Figure 1–41) Gray or tan spots usually develop in chlorotic areas Dead spots may drop out of the leaf Poor bloom size and color Induced by excessively high pH	Reduction in growth, brown spotting on leaves Shows up as Fe deficiency Found under strongly acidic conditions

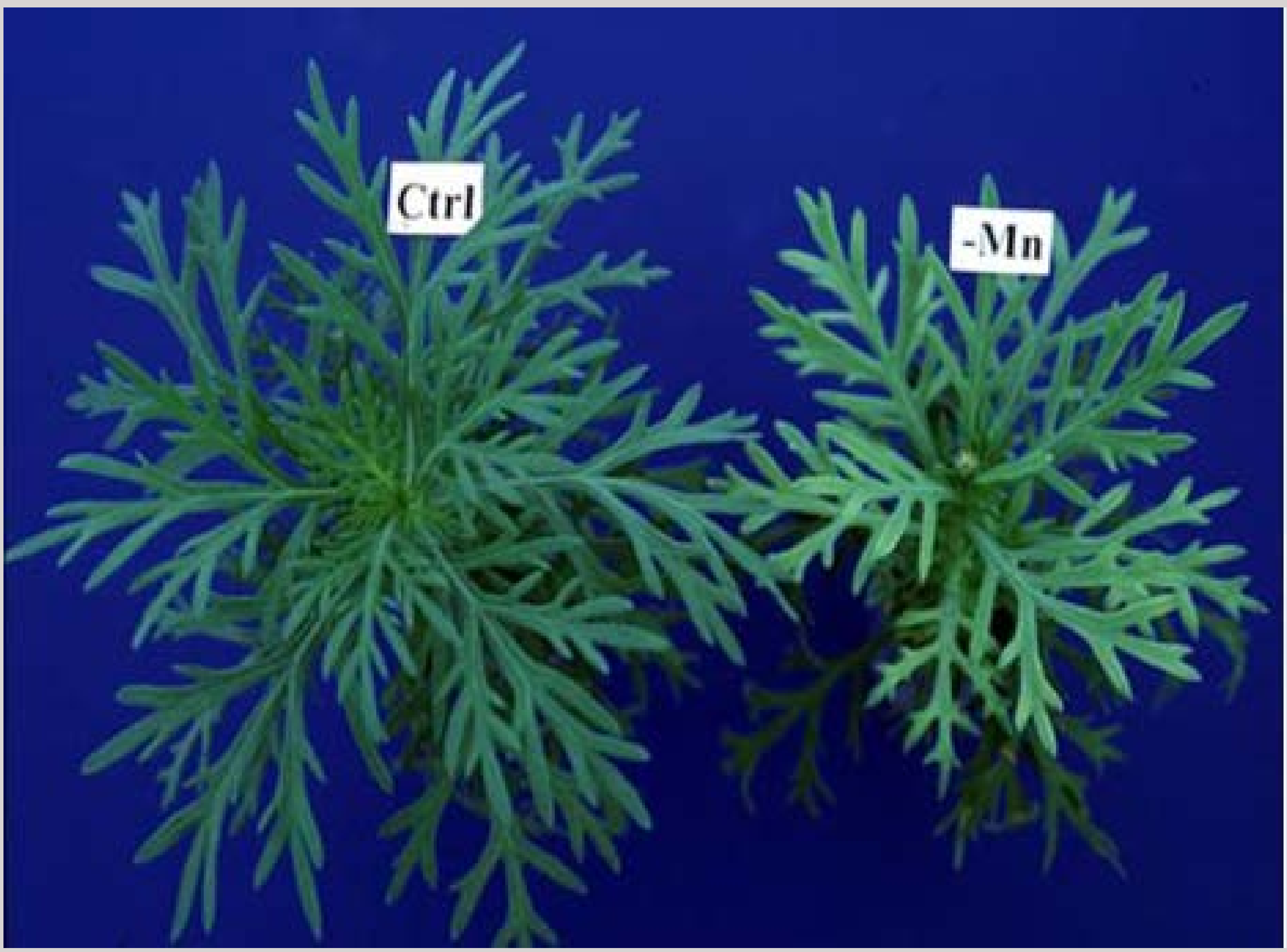


Figure 1–41. Manganese deficiency in a chrysanthemum exhibited as reduced growth while the youngest leaves remain green.
Paul Nelson

MICRONUTRIENTS continued		
Why Needed	Deficiency Symptoms	Excess Symptoms
Molybdenum (Mo)		
Needed for enzyme activity	Interveinal chlorosis on older or midstem leaves (Figure 1–42) Twisted leaves whiptail Marginal scorching and rolling or cupping of leaves Nitrogen deficiency symptoms may develop	Intense yellow or purple color in leaves Rarely observed

Figure 1–42. Molybdenum deficiency on poinsettia. Paul Nelson

MICRONUTRIENTS continued		
Chlorine (Cl)		
Needed for enzyme activity	Wilted leaves, which become bronze, then chlorotic, then die Club roots	Salt injury Leaf burn May increase succulence
Cobalt (Co)		
Needed by plants recently established Essential for nitrogen fixation	Little is known about its deficiency symptoms	Little is known about its deficiency symptoms
Nickel (Ni)		
Needed by plants recently established Essential for seed development	Little is known about its deficiency symptoms	Little is known about its toxicity symptoms

Soil Testing

A soil test is important for several reasons: to optimize crop production, to protect the environment from contamination by runoff and leaching of excess fertilizers, to aid in the diagnosis of plant culture problems, to improve the soil's nutritional balance, to save money and conserve energy by applying only the amount of fertilizer needed, and to identify soils contaminated with lead or other heavy metals.

Determining the pH and fertility level of a soil through a soil test is the first step in planning a sound lime and fertilization program. A soil test provides the means of monitoring the soil so deficiencies, excesses and imbalances can be avoided. Avoid sampling when the soil is very wet or has been recently limed or fertilized. Soils that look different or have been used differently should be sampled and tested separately. Areas where there is poor growth should also be tested separately.
The numerical results of a soil test reflect analytical procedures used by specific laboratories. For this reason, soil test results from different laboratories should not be compared.

Field Production

Soil samples from field nurseries can be taken any time during the year; however, midsummer to fall is the most desirable time to determine fertilizer needs for the following year. Soils should be dry enough to till when sampling, and fields are usually dry and easily accessible in the fall. The soil pH and nutrient levels will be at or near their lowest points during late summer and early fall. Therefore, samples collected in the fall are more representative of the actual fertility conditions during the growing season than samples collected in late winter or early spring. Fall sampling also allows sufficient time for results and recommendations to be received from the laboratory so any necessary limestone and fertilizer can be applied before planting.

Soil nutrient levels change during the year depending on the temperature and moisture content of the soils. It is important, therefore, that samples be taken at or near the same time each year, so results from year to year can be compared.

Container Production

Soil samples from soilless mixes are tested differently than samples from field soil. There are three commonly used methods of testing soilless media based on the use of water as an extracting solution: 1:2 dilution method, saturated media extract (SME), and leachate Pour Thru. The value representing the level of soluble salts from a soil test using a 1:2 dilution method will mean something different than results from SME or leachate Pour Thru. For example, 2.6 would be "extreme" (too high) for the 1:2 method, "normal" for SME, and "low" for leachate Pour Thru. Likewise, values for specific nutrients are likely to differ with testing methods. Always use the interpretative data for the specific soil testing method used to avoid incorrect interpretation of the results. For more details, see Appendix C, Interpretation of Soluble Salt and pH Measurements.

Most fertilizers (except urea) are salts and when placed in solution they conduct electricity. Thus, the electrical conductivity (EC or soluble salts) of a substrate solution is indicative of the amount of fertilizer available to plant roots. In addition to carrying out a complete soil test, container growers should routinely check the EC and pH of their container crops and irrigation water.
These checks can be done on site using portable testing meters, or samples can be sent to the University of Massachusetts soil test laboratory.
Growing media for long-term crops should be tested at least monthly, but biweekly monitoring during the summer may be necessary to track fluctuations in EC. Even when controlled-release fertilizers are used, substrate nutritional levels will gradually fall during the growing season to levels that may not support optimal growth.

Sending the leachate solution collected from the Pour Thru method for laboratory analysis at least once during the growing season is a good idea, so that actual nutrient levels in the container can be determined and corrected if needed. The accuracy of EC and pH meters can also be checked by sending a leachate sample to the laboratory at least once during the growing season.

Growers can plot or record average leachate EC and pH values from 3 to 5 containers scattered within a block of plants in an irrigation zone. Routinely sample leachates for EC and pH to obtain data on when fertilizer runs out, whether or not irrigation volume is appropriate, and whether or not irrigation distribution over the block is uniform. Sample containers diagonally across a growing block to help diagnose poor uniformity in irrigation patterns.

High temperatures in overwintering structures can result in nutrient release from controlled-release fertilizers. Monitor substrate EC two or three times during the winter to ensure levels are not toxic.

When plant foliage becomes chlorotic or off-color, analyzing container leachate and leaf tissue are the best diagnostic steps to determine nutritional disorders. A leaf tissue laboratory sample should include 20 to 100 (depending on the size of the leaves) of the most recently fully expanded leaves. Send a leachate sample with the leaf tissue sample to supply information about recent and current nutrient conditions in the container. Test results generally provide insight into problems related to nutritional imbalances in the plant or substrate.

> *See* RESOURCE Section *for sources and procedures for specific types of testing and specific labs.*

How to take a Cornell Assessment for Soil Health (C.A.S.H.) soil sample - Video

> *You can view this video in any browser by Clicking Here:*
>
> https://vimeo.com/166533578

Fertilizers

Fertilizers provide some elements that might be lacking in the soil and stimulate healthy, vigorous growth. How much and when to apply fertilizers should be based on observing plant performance, a reliable soil test, and an understanding of the factors that affect growth: light, water, temperature, pests, and nutrition. Simply applying fertilizer because a plant is not growing adequately will not solve many plant problems (insects, disease, or poor drainage, for example), and, in fact, excess nitrogen can often increase insect and disease infestation.

All fertilizers are labeled with three numbers, giving the percentage (by weight) of nitrogen (N), phosphorus (P), and potassium (K). This is referred to as the fertilizer grade.

A 100-pound bag of fertilizer labeled 0-20-10 has 0 pounds of N, 20 pounds of P (reported as P2O5), 10 pounds of K (reported as K2O), and 70 pounds of filler. Filler is added to make the fertilizer easier to spread and to reduce the likelihood of burning plants with too much fertilizer (the fertilizer salts can pull water out of the plant). A fertilizer may also contain secondary macronutrients or micronutrients not listed on the label because the manufacturer does not want to guarantee their exact amounts.

Fertilizers can be divided into two broad categories: natural and synthetic.

Natural fertilizers are commonly misnamed “organic.” “Natural fertilizers” is a more accurate description because these materials can be both complex chemical substances containing carbon (organic materials) or inorganic ores, such as rock phosphate, which are mined. Natural fertilizers containing organic materials include manures and composts, animal byproducts (such as bone meal, blood meal, feather meal), and seed meals. Natural fertilizers that are inorganic ores include potassium and lime.

Natural fertilizers typically release nutrients at a slower rate and over a longer period than synthetic fertilizers because microorganisms are involved in a breakdown and release cycle called mineralization. Moisture, temperature, and the microbial species and populations in the soil affect mineralization. Some water-soluble natural fertilizers, such as fish emulsion, are available when rapid nutrient delivery is desired.

When using natural fertilizers, it is helpful to incorporate them and provide adequate moisture for active microbial populations. When packaged as fertilizers, natural fertilizers will have the nutrient analysis stated on the labels. How much to use varies with the nutrient content of the material. The age of the material is also a factor. Producers are not required by law to state the nutrient content on bulk organic materials, such as compost, manure, and sludges. The source of these materials should be investigated and possible analysis performed at the Plant, Waste, Solution, and Media Lab at the NCDA&CS Agronomic Division before applying large amounts to a home garden. The age of the natural fertilizers is another important factor. When natural material decays and is rained on, it loses nutrients, especially potassium and, to some extent, nitrogen. Even natural sources of nutrients can be over applied and damage plants. Fresh manures, for example, may injure plants by adding excessive nitrogen or potassium, especially when applied in large quantities.

Natural fertilizers can be expensive if applied in amounts adequate to supply nutrients for good plant growth, but have the added benefit of improving soil structure and plant vigor. When applying natural fertilizers, calculate as closely as possible the amounts of nutrients being supplied. Always err on the low side of application rates, then test the soil and augment as recommended on the soil test report. The nutrient content may need to be supplemented with other natural or synthetic materials to achieve a balanced ratio of nutrients.

Synthetic fertilizers are made through industrial processes or mined from deposits in the earth. They are purified, mixed, blended, and altered for easy handling and application. Most are non-carbonaceous chemicals from nonliving sources and are usually cheaper than natural fertilizers. In general, nutrients are more rapidly available to plants because they are more water-soluble or in a form plants can use. The disadvantage is that it may be easier to over apply a synthetic fertilizer than a natural one, which may result in fertilizer burn. In addition, synthetic fertilizers may not support beneficial microbial populations to the same extent as natural fertilizers.

Special-purpose fertilizers are packaged for plants such as camellias, rhododendrons, and azaleas. Some of the compounds used in these fertilizers have an acid reaction that can be beneficial to acid-loving plants if the soil they are growing in is naturally neutral or alkaline.

Fertilizer spikes or pellets are fertilizers compressed into a form placed in the soil or pots. They are convenient, but are expensive per unit of fertilizer and do not provide uniform distribution. Nutrients are often concentrated around the spikes or pellets.

Liquid fertilizer can be purchased as a dry powder or as a concentrated liquid. Liquid fertilizers are frequently used for houseplants or as a starter solution for transplants. They tend to be more expensive per unit of fertilizer because they are made from refined chemicals.

Foliar fertilizers are dry powders or concentrated liquids that are mixed with water and sprayed on plants (Figure 14). Foliar feeding is used when insufficient fertilizer was applied before planting, when a quick growth response is wanted, when micronutrients are locked in the soil, or when the soil is too cold for the plant to use fertilizer in the soil. Foliar-applied nutrients are absorbed and used by the plant quite rapidly. They are expensive per unit of nutrient and only give short-term fertilization (completely absorbed within one to two days). Relying totally on foliar fertilization can be time consuming because the fertilizer must be applied regularly. Improper foliar application of fertilizers can also lead to plant tissue burn.

Figure 14 - Foliar application

Incomplete fertilizers can be used separately or combined to supply the needed nutrients, often at a reduced cost compared to using a complete fertilizer. For example, gardeners who have a soil with sufficient P and K can save money by applying a nitrogen-only fertilizer, such as ammonium nitrate (34-0-0). If a soil test indicates N and K are needed, but not P, use an appropriate amount of ammonium nitrate and muriate of potash (0-0-60), a naturally occurring material composed almost entirely of potassium, processed to remove impurities and concentrate the product. If a soil needs only P, use triple super phosphate (0-46-0), or for an organic nutrient source apply bone meal (approximately 3-15-0; note that this will add some N) or compost.

Regardless of the fertilizers used, be aware that excess fertilizer can damage plants and move into our stormwater systems, which can cause serious environmental problems.

Guidelines for Production Nurseries

Pour Thru Procedure for Collecting and Testing Leachate from Container Nursery Crops

In addition to collecting a soil sample to test, growers can collect leachate from container grown stock using the Pour Thru method. The leachate that is collected can be tested on site to determine EC and pH for container crops or it can be sent to a laboratory for a complete test.
Simply testing container leachate without adhering to the following procedure will lead to misinterpretation of results:

1. Irrigate nursery containers to container capacity (10% to 20 % leaching expected).
2. Wait 30 minutes to 2 hours for equilibration of nutrients in container solution.
3. Place containers to be tested in a shallow saucer to collect leachate. Pour 2.4 fl.oz. (80 milliliters (ml)) of water over the surface of a 1 gallon container, 2.9 fl. Oz. (86 ml) for 3 gallon container, 4.1 fl.oz. (122 ml) for 5 gallon container and 5.1 fl.oz. (151 ml) for 10 gallon container.
4. An alternative for nursery containers is to lift and tip containers to drain leachate into a collection vessel.
5. Calibrate the pH and EC test equipment using manufacturers' descriptions and appropriate standard solutions.
6. Read and record results.
7. Develop a log book for crops and irrigation zones for the season.

Make conductivity and pH equipment readily available to employees; keeping it in their vehicle or work area provides them with an opportunity to check EC and pH as part of the routine nursery scouting program. If equipment is kept in a truck cab, place it in an insulated cold drink cooler. This will reduce exposure of the equipment to extreme heat, cold, and evaporative conditions, thus extending its useful life. Train employees to use and calibrate the equipment using clean, fresh standards. Calibrate pH and EC equipment daily before use or each time before testing a group of solutions, and between samples, if critical decisions are going to be made based on results or if the readings seem questionable.

Soil pH

A fertility program for woody plants begins with obtaining an analysis of soil pH, or level of acidity. Soil pH is measured on a scale of 0 to 14. Soils with a pH below 7 are acidic while those above 7 are alkaline. Adjusting pH is important not only because specific plants grow best within a certain pH range, but also because soil pH affects the availability of both major and minor nutrient elements. Furthermore, soil pH influences the level of microbial activity in soils. Microbes involved in mineralization of organic matter are most active between a pH of 6 and 7. At extremes in pH, many nutrients occur in forms unavailable for uptake by plant roots. Analysis of soil pH should be routinely made prior to planting. Typically, limestone is required to adjust pH upward while sulfur is used to lower pH. These materials are best incorporated (in the field or in containers) prior to planting, since surface applications are slow to affect pH. In the field, most liming and sulfur recommendations are based on the assumption that the material will be worked in to a depth of 8 inches. Deeper incorporation of either limestone or sulfur will require adjustments in application rates to accommodate larger volumes of soil. In container production, pH adjustments are made during the potting mix preparation.

Fertilizer Choices

A distinction is necessary between field production and container production regarding plant nutrition. Field nurseries grow in soil and container nurseries grow in soilless potting mixes.

Basic plant nutrition involves the uptake of sixteen mineral elements essential to plant growth. In addition to carbon, hydrogen, and oxygen, which they obtain from air and water, plants require the elements nitrogen (N), phosphorus (P), and potassium (K) in greatest abundance.

Nutrition research on field grown woody plants has shown that N is the element that yields the greatest growth response in trees and shrubs. For this reason, high N fertilizers with N-P-K ratios of 4-1-1, 3-1-1, or 3-1-2 are generally used for feeding established woody plants. These include fertilizers with analyses such as 8-2-2, 15-5-5, 24-8-16 and similar formulations. The N-P-K analysis refers to %

N, % P (as P2O5) and % K (as K2O) in the fertilizer. Although a combination or complete (N,P, K) fertilizer is less expensive than applying straight (nutrient specific) fertilizers, if one of nutrient element is not needed or is needed in less amounts, potential negative environmental impacts may be greater. It is better to apply specific nutrient as recommended by a soil test. In field soils, P, K, and essential elements other than N are slow to be depleted. Provided these nutrients are at recommended levels, a fertilizer program for established woody plants can consist of applications of N sources alone. Under normal conditions, complete fertilizers as mentioned above may be used every 4 or 5 years to ensure a supply of the other essential nutrients.

Fertilizers are available as a granular, controlled- release, or water soluble formulations. Field nurseries use granular or controlled-release fertilizers (CRFs). Container nurseries use CRFs and water soluble fertilizers (fertigation). CRFs package nutrient salts in "capsules" with resin or polymer coating. The coating "controls" the release of nutrient salts according to moisture content or temperature of the substrate. The method of application also affects nutrient release..Research has shown that topdressing results in reduced nutrient losses compared to incorporation. CRFs are available in several formulations to suit the nutrient requirements of different plants, and also are available with different coatings to provide nutrient release over different time frames (e.g. 4-month versus 12- month formulations). These products generally provide more consistent nutrient availability to plants over time. Application of controlled-release forms of N provide the most efficient use of this nutrient because root growth and nutrient absorption can occur anytime soil temperatures are above 40°F. Research on some CRFs in New Jersey indicated that some CRFs are more responsive to temperature changes than others. Test CRFs new to you to find their performance under your particular growing conditions to adjust your fertilization management accordingly. The amount of N applied generally determines the rate used. Monitor the EC of the substrate regularly when using CRFs to check for soluble salts.

Nutrient Management Checklist - Field Nurseries

1. Test soils each year (midsummer to fall) to determine fertilizer needs for fields the following year. Have soil tested to indicate if other soil nutrients are required as pre-plant adjustments.

2. Incorporate nitrogen (N) fertilizer during field preparation based on soil test. Use soil test results to add other soil nutrients as required prior to planting.

3. After the first year, surface application of N is based on an amount of N per plant rather than pounds of N per acre. Place fertilizer within the root zone as a side dress at the rate of 0.25 to 0.5 ounce of N per plant.

4. If supplemental fertilizer is required the first year for fall-transplanted plants, each plant should receive 0.25 to 0.5 ounce of N before bud break. During the second year, each plant should receive 0.5 to 1.0 ounce distributed in split applications: the first two-thirds of the total amount should be applied before bud break, and the second application should be made by mid-June. During the third and following years, each plant should receive 1.0 to 2.0 ounces in split applications as described for the second year.

5. Slower-growing cultivars or species should be fertilized at the lower application rates, whereas vigorous plants will have increased growth if the higher application rate is used.

Best Management Practices

Best Management Practices (BMPs) for fertilizer applications focus on water quality and nutrient runoff as well as maximizing growth of nursery stock. Nutrient management should be a balance between optimizing plant growth and avoiding excess application of nutrients. Excess nutrients can be lost in the environment and become environmental pollutants. The two nutrient elements of most concern are phosphorus (P) and nitrogen (N). Phosphorus attaches to the cation exchange sites in the soil and can be moved off- site with eroded soil particles in runoff water and cause eutrophication and algae growth in surface water (rivers, lakes, and estuary). Nitrogen is very mobile and leaches through the soils into the ground water where it is considered a contaminant in drinking water.

Nutrient management and fertilizing decisions should be based on soil tests. Soil tests should be conducted prior to each crop cycle to evaluate pH (lime requirement), phosphorus (P), potassium (K) and micronutrients requirements.

Lime and phosphorus amendments should be incorporated well before the growing season and thoroughly mixed with the top 6 to 8 inches of soil during normal soil preparation practices. Potassium and micronutrients should be incorporated into the soil during cultivation before planting. Soil test results will indicate if other soil nutrients are required as pre-plant adjustments. In soils where phosphorus (P) and potash (potassium,K) tend to remain high once adequate levels are established, N may be the only required yearly addition. Currently, ammonium nitrate (33-0-0) and urea (46-0-0) are the most popular soluble fertilizers. Split nitrogen applications promote efficient use uptake of fertilizer and limits losses to the environment. Where yearly P application is also warranted, di-ammonium phosphate (18-46-0) has often been used as an N and P source. Although a combination or complete (N,P, K) fertilizer is less expensive than applying straight (nutrient specific) fertilizers, if one of nutrient element is not needed or is needed in less amounts, potential negative environmental impacts may be greater. Apply specific nutrient fertilizers such as triple super phosphate (0-46-0), muriate of potash (0-0-60), potassium sulfate (0-0-50) as recommended by a soil test.

Certain recommended fertilizer practices for field nurseries have been adopted in other states to reduce runoff while meeting the fertility needs of plants. For example, during field preparation, the practice of incorporating fertilizer at 50 pounds of N per acre reduces runoff potential and usually meets the N requirements of new plants during the first year. Other nutrients as recommended by soil tests should be incorporated before planting. In subsequent years, surface application of N is based on an amount of N per plant rather than pounds of N per acre. It is suggested that fertilizer be placed within the root zone as a side dress at the rate of 0.25 to 0.5 ounce of N per plant rather than applying previous recommendations of 100 to 200 pounds of N per acre. Doing so maximizes growth with a minimum amount of fertilizer. If supplemental fertilizer is required the first year for fall-transplanted plants, each plant should receive 0.25 to 0.5 ounce of N before bud break. During the second year, each plant should receive 0.5 to 1.0 ounce distributed in split applications: the first two-thirds of the total amount should be applied before bud break, and the second application should be made by mid-June. During the third and following years, each plant should receive 1.0 to 2.0 ounces in split applications as described for the second year. Slower-growing cultivars or species should be fertilized at the lower application rates, whereas vigorous plants will have increased growth if the higher application rate is used. Higher rates can contribute to nutrient runoff and water quality impacts.

Recently, slow-release fertilizers developed specifically for field use have been introduced. Although these fertilizers are more expensive, one application may last the entire growing season. Fertilizer application can also be done through irrigation (fertigation). In fertigation, fertilizers are injected into the irrigation water. It can be a good method of applying fertilizer in the nursery since it allows plants to be provided with nutrients as needed throughout the season. It can also be used effectively to quickly address nutrient deficiencies. Fertigation minimizes loses of nutrients into the environment. However care must be taken to avoid runoff during fertigation.

Base timing of fertilization on plant growth habit. For plants that have a single flush of growth, fertilize in the fall and early spring before growth begins. For plants that have multiple flushes, split recommended applications among fall, spring, and when the first flush begins to slow down.

Fall fertilization (late August through September) is effective because roots continue to absorb nutrients until soil temperatures approach freezing. N that is absorbed in fall will be stored and converted to forms used to support the spring flush of growth.
Nutritionally balanced plants have the best chance of withstanding winter conditions.

Note: N generally stimulates growth, and when applied late in the growing season (late summer) to plants that have multiple flushes of growth, it can prevent growth cessation and thus reduce the potential for cold hardiness in a woody plant. Avoid fertilizing field stock in late fall or early winter; fertilizer can easily run off frozen ground.

Nutrient Management Checklist - Container Nurseries

Mixing and Handling Growing Media

1. Test the media pH, electrical conductivity, and wettability before use.
2. Do not make changes to current growing media without experimenting first to see if changes may affect cultural practices.
3. When mixing, thoroughly mix components, but do not over-mix, especially if a medium contains vermiculite or controlled release fertilizer.
4. Do not store media that contains fertilizer especially if the media is moist.
5. Avoid contamination of components for finished media by keeping amendments in closed bags or by covering outdoor piles.
6. Do not allow mixes containing peat most to dry out.

Using Fertilizers

1. Use a backflow preventer to ensure that water containing fertilizer or pesticide is not mixed with water used for human consumption.
2. Apply fertilizer only when needed. Use a fertilizer nutrient ratio of approximately 3:1:2 N: P_20_5: K_20.
3. Use soil test results and product manufacturer guidelines to determine fertilizer rates.
4. Amend the growth substrate prior to potting with controlled-release fertilizer (CRF) rather than applying fertilizer to the substrate surface if containers are subject to blow over.
5. Mix CRFs uniformly throughout the growth substrate.
6. Do not add superphosphate to the container substrate.
7. Adjust application rates for fall and winter (after first frost) or when using subirrigation. Application rates are usually one-half the rates used in summer.

8. Apply supplemental fertilization or reapplication by injecting fertilizer into irrigation water or placing fertilizer on the surface of container substrate.
9. If injection is used with overhead irrigation systems, collect runoff or take steps to address nutrient runoff.
10. Inject an individual element or a combination of elements in concentrations slightly less than desirable levels to be maintained in the growth substrate.
11. Surface-applied fertilizer should be applied to small blocks or groups of plants to minimize nutrient runoff.
12. Avoid broadcast fertilizer applications unless containers are pot to pot.
13. Record fertilizer product name and analysis, date and location applied, and general notes about plant and environmental conditions. Use past records for troubleshooting current problems.
14. Group plants according to their fertilizer needs so supplemental fertilizer applications can be made only to plants requiring additional fertilizer. This is particularly important if fertilizer is injected in irrigation water.

Monitoring Nutrient Status

1. During the growing season, monitor container media every 2 to 4 weeks.
2. During the winter, monitor substrate electrical conductivity two or three times.
3. Collect several representative substrate samples to ensure that samples represent the growth substrate being considered.
4. Have irrigation water tested at least once each year.

Growing Media

The most common components in an outdoor container nursery mix are bark, sphagnum peat moss, and sand. Some alternative materials being used are shredded coconut husks (coir), composted yard wastes and animal wastes, composted hardwood bark, and other composted materials. Softwood bark typically comprises from 80 to 100% of a mix. Peat is often included to increase the water-holding capacity of a mix, while sand and soil are often added to increase the weight, which reduces container tip-over. Many growers use a recipe of 80% pine bark, 10% peat and 10% sand.

Use of Composts in Nursery Potting Media

Organic materials that have been properly composted can also be used in nursery potting mixes. For container use, be cautious and use approximately 10% compost by volume in pine bark mixes. The compost should be considered a substitute for peat moss and sand. Conduct a soil test before adding fertilizer. Addition of minor elements will probably be recommended. For container production, the use of slow-release fertilizers is also recommended. Dolomitic limestone should be omitted or reduced to no more than 3 pounds per cubic yard of potting mix. The soluble salts level and pH should be monitored during the growing season. Before using compost on any nursery crop, establish a small test area to determine the material's suitability for the particular ornamental species.

Mixing and Handling Growing Media

- Test the media pH, electrical conductivity and wettability before use.
- Do not make changes to your current growing media without experimenting first to see if changes may affect your cultural practices.
- If mixing your own media, thoroughly mix components, but do not over-mix, especially if a media contains vermiculite or controlled release fertilizer.
- Do not store media that contains fertilizer especially if the media is moist.
- Avoid contamination of components for finished media by keeping amendments in closed bags or by covering outdoor piles.
- Do not allow mixes containing peat most to dry out.

Fertilizing Container Nurseries

Container-grown plants are fertilized using water soluble fertilizers through an irrigation system or controlled-release fertilizers (CRFs). The amount of N applied generally determines the rate used.

When fertilizer is injected in the overhead irrigation system, steps need to be taken to address the irrigation water leaving the property, because much of the water from overhead irrigation systems falls between containers. Fertilizing through irrigation water is appropriate for low- volume irrigation systems in which irrigation water is delivered to the container such as drip irrigation. Even then, care needs to be taken to minimize leaching from the container to prevent nutrient runoff from entering surface or ground water.

When preparing a nutrient management plan for a container operation, a nutrient management consultant should conduct an environmental risk assessment. The purpose is to evaluate the potential risk to the environment of nutrient movement from container growing areas.

- Apply fertilizer only when needed. Use a fertilizer nutrient ratio of approximately 3:1:2 N: P_20_5: K_20.
- Use soil test results and product manufacturer guidelines to determine fertilizer rates.

CRFs supply essential plant nutrients for an extended period of time (months). Fertilizers are available that contain different mechanisms of nutrient release and different components.

- Amend the growing media prior to potting with CRF, rather than applying fertilizer to the surface, to prevent fertilizer being spilled if containers blow over. Also, surface- applied fertilizer encourages weed growth.
- Mix CRFs uniformly throughout the growth substrate.
- Do not broadcast fertilizer on spaced containers.

Nutrients in the growing media can be leached regardless of the type of fertilizer applied. Irrigation practices play an important role for preventing fertilizer runoff.

P leaches rapidly from a soilless growing media. Complete CRFs applied during the growing season should supply adequate P. Therefore, do not add superphosphate to the growing media.

CRF application rates vary from product to product, but also depend on plant species and container size. The goal of a fertilizer program is to apply the least amount of fertilizer for the desired growth so that nutrient leaching is minimized. Apply CRF at the manufacturer's recommended rate and reapply fertilizer when substrate solution status is below desirable levels. Application rates should be adjusted for fall and winter (after first frost) or when subirrigation is used since the rates used then are usually one half the rates used in summer.

When supplemental fertilization is needed, fertilizer is either injected into irrigation water or CFR is placed on the surface. If injection is used with overhead irrigation systems, runoff must be collected or steps taken to address nutrient runoff.

When CFR fertilizer is applied to the surface as a supplemental fertilizer it should be applied to small blocks or groups of plants to minimize nutrient loss and runoff. Surface applied fertilizer should not be broadcast unless containers are pot to pot.

Group plants according to their fertilizer needs so supplemental fertilizer applications can be made only to plants requiring additional fertilizer. This is particularly important if fertilizer is injected in irrigation water.

Record fertilizer product name and analysis, date and location applied, and general notes about plant and environmental conditions. Use past records for troubleshooting current problems.

Preventing Backflow

All potable water must be protected against backflow to ensure that water containing fertilizer or pesticides is not mixed with that used for human consumption. Backflow or backsiphoning occurs when a negative pressure develops in the water supply line, causing water that contains fertilizer or pesticides to be drawn back into the supply lines. The National Plumbing Code, which has been adopted in most states, requires that backflow preventers be installed on any supply fixture when the outlet may be submerged. Examples of this are hoses that fill spray tanks or barrels, fertilizer injectors, or equipment wash tubs.

Monitoring Nutrient Status for Container Production

The longevity of the release of CRFs is influenced by environmental factors. To ensure that adequate nutrient levels are maintained in the growing media, monitor the nutrient status and use the results to determine fertilizer reapplication frequency. Regular monitoring is important because plants may not show visible symptoms of excessive or inadequate nutritional levels, however growth may be reduced. High concentrations of nutrients can result from media components, inadequate irrigation frequency and duration, water source, and/or fertilizer materials and application methods. Nutrients may also accumulate during the overwintering of plants in polyhouses. Excessive nutrient concentrations injure roots, restricting water and nutrient uptake. Rainfall and excessive irrigation can leach nutrients from containers resulting in inadequate nutrient levels and runoff.

Growing media used for long-term crops should be tested at least monthly, but biweekly monitoring during the summer may be necessary to track fluctuations in electrical conductivity (EC), which is used as a relative indicator of the nutritional status of the container media. Even when CRFs are used, media nutritional levels will gradually fall during the growing season to levels that may not support optimal growth.

High temperatures in overwintering structures can result in nutrient release from CRFs. Monitor EC two or three times during the winter.

- During the growing season, monitor container media every two to four weeks.
- During the winter, monitor EC two or three times.
- Collect several representative media samples to ensure that samples represent the growing media being considered.

Irrigation Water Testing

In addition to monitoring the nutrient status of the growing media, irrigation water should be tested for pH, alkalinity, sodium (Na), chloride (Cl), and EC each year.

pH is a measure of the concentration of hydrogen ions (H+). In general, water for irrigation should have a pH between

5.0 and 7.0. Water with pH below 7.0 is termed “acidic” and water with pH above 7.0 is termed “basic;” pH 7.0 is “neutral”. Alkalinity is a measure of the water’s ability to neutralize acidity. An alkalinity test measures the level of bicarbonates, carbonates and hydroxides in water and test results are generally expressed as “parts per million (ppm) of calcium carbonate ($CaCO_3$)”. The desirable range for irrigation water is 0 to 100 ppm $CaCO_3$.
Levels between 30 and 60 ppm are considered optimum for most plants.

In most cases, irrigating with water having a “high pH” (7) causes no problems as long as the alkalinity is low. This water will have little effect on growing medium pH because it has little ability to neutralize acidity.

Na and Cl are naturally occurring elements in soils and water but their levels can become elevated due to road salt, water softeners, and some fertilizers. High levels of Na and Cl uptake can accumulate to toxic levels in plants and abundant amounts in water can raise the EC to levels undesirable for plant by inhibiting water uptake. Most often, these high levels are from private well or pond water but sometimes public water is the source. The solutions to the problem of high Na and Cl include regular water testing during the growing season (in borderline cases of excess Na and Cl) and avoidance of over-fertilization to prevent high growth medium EC; installation of water treatment systems to remove Na and Cl; efforts to protect wells and ponds from salt contamination by runoff; or finding new sources of water.

Table 3 - Ranges of EC, Na and Cl in irrigation water

Factor	Target Range	Acceptable Range
EC (mmho/cm)	0.2-0.8	0-1.5
Na (ppm)	0-20	Less than 50
Cl (ppm)	0-20	Less than 140

Table 3. Ranges for electrical conductivity (EC), sodium (Na), and chloride (Cl) in irrigation water

Resources

Interpretation of a Soil Test Report

Interpreting a soil test involves comparing the results of a test with the normal ranges of pH, soluble salts, and nutrient levels set by the testing laboratory. Normal ranges are specific to the lab and its method of testing. Some interpretation may be done for you, often by a computer program. Best interpretations take into account the crop, its age or stage of development, the growth media (soil or soilless media), the fertilizer program (specific fertilizer, rate, frequency of application) and if there is a problem, what the symptoms are.

pH or Soil Acidity—What action to take on pH depends on the specific requirements of the plants being grown and knowledge of the factors which interact to affect the pH of the media. Limestone (rate, type, neutralizing power, particle size), irrigation water pH and alkalinity, acid/basic nature of fertilizer, and effects of mix components (container plants) are major influences on pH.

Electrical conductivity (EC)—Measuring EC provides a general indication of nutrient deficiency or excess. A high EC reading generally results from too much fertilizer in relation to the plant's needs, but inadequate watering and leaching or poor drainage are other causes. Sometimes high EC levels occur when root function is impaired by disease or physical damage. Always check the condition of the root system when sampling soil for testing.

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The full text and other reference material can be found HERE:
https://ag.umass.edu/landscape/publications-resources/nutrient-management

Quick guide to taking a soil sample for the Cornell Soil Health Laboratory:

Identify 10 locations within the area you would like to test that are representative of the field or plot.	
	A – Remove surface debris.
	B– Use a spade to dig a small hole about 8” deep. From the side of the hole take a vertical slice of soil 6” deep and about 2” thick. Collect the same amount of soil from all soil depths so the sample is not biased with more soil from the top compared to the bottom.
	C1 – Manually remove any extra soil to ensure an even 6” x 2” slice of soil.
	C2 – Place in clean pail.
	D – At each sub-sample location collect soil hardness information with a penetrometer. Record maximum hardness from the 0-6” and the 6-18” depth on the Submission Form.
	E – Repeat steps A – C to collect the remainder of the sub-samples. Mix thoroughly and place 3-6 full cups of soil (one quart) into a clearly labeled Ziploc bag. Keep cool. Submit soil sample and submission form promptly.