Landscape Foundations: A Practical & Technical Guide to Landscape Maintenance

Marco Crosland

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Honors Thesis

LANDSCAPE FOUNDATIONS: A PRACTICAL & TECHNICAL
GUIDE TO LANDSCAPE MAINTENANCE

by
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Submitted to Brigham Young University in partial fulfillment
of graduation requirements for University Honors

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ABSTRACT

LANDSCAPE FOUNDATIONS: A PRACTICAL & TECHNICAL GUIDE TO LANDSCAPE MAINTENANCE

Marco Crosland
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Many homeowners struggle to maintain healthy landscapes. Often, they simply don’t understand basic principles that, if followed, would make a significant difference in the health and appearance of their landscape. The hope of Landscape Foundations is to help homeowners maintain healthy and excellent landscapes by teaching these “correct principles”.¹

What makes Landscape Foundations different than other landscape guides is that it brings in current research and explains it in a simple way. It is one thing to know what to do and another thing to know why it must be done. This guidebook provides pictures and additional resources to explain landscape maintenance principles. It teaches both the practical and technical sides.

Landscape Foundations is written for both beginners and experts. It presents modern research in a way that any homeowner can understand it.
Instead of being a comprehensive guide for all landscape needs, this guidebook is focused on the maintenance of a landscape. Principles for the design and the installation of landscapes are both needed and foundational to an understanding of landscapes. The design and installation of a landscape will greatly influence the future maintenance of the landscape. However, because most homeowners already have an existing landscape, the focus of Landscape Foundations is on best management practices for maintenance.

Please note that the recommendations in this guidebook are for *established plants* and NOT newly installed plants. In early growth stages or after transplanting, plants require different maintenance requirements.

Although this guide seeks to provide a basic, but more technical, overview of landscape maintenance, it doesn’t have information for all of the many possibilities that can occur in a specific landscape. The goal is to provide enough information for most situations and then direct the remaining few situations to more specific information elsewhere. In some cases, more expert advice is needed for certain landscape maintenance and application. For these needs, contact a certified landscape professional.

Landscape Foundations is broken down into two parts. The first part covers general practices that are performed for all plant material. The second part focuses on maintaining different types of plant material in a landscape including a lawn, trees and shrubs, and flowers and ornamental grasses.
ACKNOWLEDGEMENTS

I appreciate all of the help and mentorship from my professors. I have been blessed to be a part of the lives of those who see education as a means to truly transform the lives of their students. I sincerely thank my professors in the landscape management program as well as many of my other professors at Brigham Young University.

I also am grateful for the members of my thesis committee: Bryan Hopkins, Phil Allen, and Craig Coleman. Their contributions and suggestions have been very helpful in completing Landscape Foundations. I especially appreciate Hopkins for his great help. I appreciate the sacrifice of their time.

Lastly, I couldn’t do any of this without the support of my wonderful wife, Christina. She is an amazing wife, friend, and companion. She helps me to achieve my dreams, be diligent, and become the person I am capable of becoming. She has truly been supportive and I’m so grateful for her.
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Part One:
General Practices
0—Homeowner Mistakes

Many landscapes are designed poorly, leading to both difficult maintenance and resource waste. For example, many landscapes are made up of a large portion of unused turfgrass. Often, homeowners install plants that have high-water needs in an environment that doesn’t typically receive a lot of water. People also over-irrigate and waste water. In fact, EPA (Environmental Protection Agency) found that up to 50% of water used in landscapes is wasted from wind, evaporation, and runoff from inefficient irrigation methods and systems. As much as 50 percent of the water we use outdoors is lost due to wind, evaporation, and runoff caused by inefficient irrigation methods and systems.ii

The mistake doesn’t always reside with the homeowner. Sometimes landscape maintenance services “use a one-size-fits-all management approach with relatively high rates of fertilizer, insecticide, herbicide, and fungicide.”iii It is important to note that although many common problems exist in urban landscapes, each landscape is unique and must have a program that adapts to the specific site conditions.

Using a one-size-fits-all management approach or just having a lack of knowledge often leads to over-applying irrigation, fertilizer, and pesticides, which in turn, leads to environmental pollution. Droughts and water quality problems increase the pressure for proper design, installation, and maintenance of landscapes. However, instead of fixing the cause of the problem, some
communities have sought to fix the symptoms of environmental pollution by banning fertilizers and pesticides and restricting water use.

In fact, many communities have already banned the use of irrigation, fertilizers, and pesticides is an attempt to fix the symptoms instead of the cause. The problem with this solution is that it becomes very difficult to maintain a landscape without the use of these treatments. Instead of banning their use, a better way is to use them properly and teach homeowners how to correctly design, install, and maintain landscapes.

These treatments are essential to maintain healthy plants in the often harsh and unideal urban landscapes. Plants have many benefits, including:

- aesthetics
- mental health (The Nature Fix by Florence Williams shows this)
- physical health (people are more likely to exercise)
- sociality (people are more likely to gather)
- cleaner air
- cooling
- energy conservation (heating and cooling needs reduced)
- soil conservation (bare soil results in wind and water erosion)

The combination of improper design, poor installation, over-application of water, fertilizer, and pesticides, and lack of technical knowledge in landscape maintenance leads to inferior landscapes. It also increases maintenance and results in less-than optimal outcomes. The solution is to understand the foundational principles of landscape design, installation, and maintenance.
Ways Homeowners Can Make a Difference

Because the problem is that many people don’t understand foundational landscape principles, the purpose of Landscape Foundations is to teach and explain many of these principles. In this way, Landscape Foundations is unique because it shows common mistakes, explains the principle, and then uses technical data and research to offer solutions.

The following list is created by a soil and nutrient scientist, Bryan Hopkins. It explains specific solutions for common landscape mistakes that will help avoid environmental pollution.

**Design**
- Reduce the amount of turfgrass in a landscape. (Many homeowners have too much unused and unneeded turfgrass, especially because turfgrass is one of the more expensive plant materials to care for.)
- Increase the percentage of deeply rooted trees and shrubs. They require less water, fertilizer, and pesticides.
- Use deciduous trees (ones that lose their leaves in the fall) on the south side of buildings to provide shading during the summer, sunlight during the winter, and wind breaks year-round.
- Use water-efficient such as native plants or suitably adapted plants.
- Group plant material into areas with similar needs. To add variety to the landscape, specimen plants that require extra water and care can be added, but they should be grouped together. The majority of the landscape should focus on efficiency.

**Soil Management**
- Use soil testing to determine what actually needs to be applied to landscapes. Then, only apply nutrients that are needed based off of the
soil test results. Most landscapes that have been annually fertilized only need nitrogen (N) and possibly sulfur (S) for the near future.

- Stop using fertilizers and soil amendments that are high in phosphorus (P) if the soil test for the phosphorus level is too high. Compost materials are high in phosphorous.
- Use mulches over bare soil for water/soil conservation and weed control.

**Water Management**

- Train plant roots to grow deep by watering deeply and infrequently. Moisture-stress plants (especially turfgrass) a few times every spring.
- Avoid an irrigation controller that waters at both the same rate and the same timing for the entire year; rather, use an automatic controller or one that manually adjusts the system to account for differences in water need.
- Strive for good irrigation uniformity (> 75%) through proper design, installation, and regular maintenance of the irrigation system.
- Irrigate only when needed and avoid surface runoff.
- Ensure good air movement through plant material and avoid irrigating in the evening and at night to reduce the likelihood of disease.

**Fertilizer Management**

- Promote the deep rooting of turfgrass by ensuring adequate nutrition throughout the entire growing season and, especially, in the late fall when plants are still photosynthesizing, but where the photosynthates are being used primarily for root growth rather than shoot growth.
- Use enhanced efficiency fertilizers (such as polymer coated urea or compost and other control/slow-release fertilizers) at reduced rates (usually 50–75% of the normal rate) when applying twice annually (early spring and late summer/early fall).
- Spot spray herbicides only as needed to control weeds.
- Apply only insecticides and fungicides where needed and where a history of infestations is common.
1—Soil Care

Knowing both the soil type and the characteristics of it are critical in properly maintaining a landscape. Because plants grow in the soil, a knowledge of what will help plant growth and what will hinder it is important. One way to look at soil is comparing it to a kitchen pantry for plants. It keeps water, oxygen, and other nutrients for the plant to use later. A neglected soil pantry will cause common soil issues such as poor drainage, soil compaction, poor soil structure and lack of needed plant nutrients.

This section will first explain common soil characteristics, then soil testing, and finally ways to correct soil problems.

DO:
- Perform a soil test every 3–5 years
- Correct poor drainage
- Neutralize soil acidity if needed
- Add organic matter to soil to improve water & nutrient holding capacity

DON’T:
- Allow soil compaction to occur
- Lower the pH of alkaline soil levels with a high buffer capacity
Soil Characteristics

Soil Texture

The textural class of a soil is determined by the percentages of sand, silt, and clay. The textural class groups are separated from smallest to largest as clay, silt, and sand. See Figure 1.1 for size comparison of soil particles. Other components in a soil include organic matter and gravel/rocks, but these aren’t included in the textural classification. Understanding the textural class of soil is important because it can influence compaction, water and oxygen infiltration, nutrient holding capacity, and the overall health of plants.

Figure 1.1 Soil particle size comparison

A good soil for a homeowner typically has < 70% sand and < 30% clay.

This is an estimate and a soil may grow certain plant material in well at other
percentage amounts. Ideal soil textural classes are generally loam soils or soils that have similar amounts of clay, silt, and sand. These are located in the bottom-middle and bottom-right side of the soil classification chart (Figure 1.2).

![Soil classification chart](image)

**Figure 1.2 Soil classification chart**

A soil test can be performed to determine the soil texture through the use of a hydrometer. This must be specified to the soil testing lab. Another way to get an estimate of soil type, is through the Jar Test.iii This test is fairly simple and can be done by digging into the soil to the required depth (4 inches for turf, 8–12 inches for gardens, 2 ft for trees) and taking a section of the entire soil profile or
the layers of the soil. This soil is then placed into a clear container (such as a mason jar) with more water than soil, and a few drops of soap. The jar is then shaken vigorously and allowed to sit until all the soil has settled to the bottom. The height of the different layers is then measured to the total height of the soil. Divide each layer height by the total height to get a percentage for sand (bottom layer), silt (middle layer), and clay (top layer). Figure 1.3 gives a visual example of the jar test. These percentages are then compared to a soil classification chart (Figure 1.2).

![Figure 1.3 Jar test](image)

**CEC (Cation Exchange Capacity)**

The cation exchange capacity (CEC) is a measurement of the negative charge of a particular soil and, thus, its capacity to hold water and positively charged nutrients. Figure 1.4 visually represents this idea.
The soil is full of chemical elements. Some of these are essential or beneficial nutrients, others are toxins, and some are mostly inert or chemically inactive. These chemicals can have an electrical charge that is either positive or negative. A cation is a positively charged ion (e.g. K⁺, Ca²⁺, Mg²⁺, Na⁺, Al³⁺, H⁺, NH₄⁺, etc.). An anion is a negatively charged ion (e.g. NO₃⁻, SO₄²⁻, H₂PO₄⁻, H₂BO₃⁻, MoO₄²⁻, Cl⁻, etc.).

Soil particles are mostly negatively charged and essential nutrients are mostly positively charged. Because like charges repel each other and opposite charges attract each other, the negatively charged soil particles and the positively charged cations are attracted to each other. Although water does not have a net charge, it is a polar molecule so one end of it has a positive charge and the other
negative. As such, the positive end of water is attracted to the negatively charged soil particles.\textsuperscript{xii}

The higher the surface area of the soil particles, the higher the CEC and related water and nutrient holding capacity. The surface area and the CEC of soil particles differs. For example, the CEC of soil types is listed as follows:

- Organic matter > clay > silt > sand > gravel/rock

In addition to impacting plant nutrition, the CEC has a major impact on water interactions. Soils with a high CEC because of high organic matter levels will likely have high water holding capacity, adequate drainage, and sufficient oxygen concentration in the soil pores. However, soils with high CEC because of high clay levels will often have poorly drained and oxygen deficient soils. Very sandy soils with a low CEC are generally well-drained and have an ample supply of oxygen, but plants growing in these soils often suffer from lack of water. Please note that some sandy soils with silt and clay (e.g. sandy loam) are often compacted and have poor drainage and water relations due to the smaller silt and clay particles being compressed between the sand particles. Table 1.5 shows the CEC of common soil types.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>CEC (Cation Exchange Capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Organic Matter</td>
<td>150–500</td>
</tr>
<tr>
<td>Pure Clay</td>
<td>60–120</td>
</tr>
<tr>
<td>Clay Soil</td>
<td>24–35</td>
</tr>
<tr>
<td>Loam Soil</td>
<td>10–24</td>
</tr>
<tr>
<td>Sandy Soil</td>
<td>1–10</td>
</tr>
</tbody>
</table>

Table 1.5 CEC of different soil types
A good soil for a typical homeowner will have a CEC range of 16–28 mEq/100 g (milliequivalent per 100 grams) of soil. However, it is very possible to have healthy plants growing outside of this range. When correcting soils, it is not recommended to add sand to clay soils or to add clay to sandy soils without the help of a professional. Doing so can increase soil compaction. Instead, a better option is to add organic matter to improve drainage and water and nutrient holding capacity.xiii

**pH**

Soil pH (power of Hydrogen)xiv can greatly affect a plant’s ability to uptake nutrients from the soil. It is a measure of hydrogen ion (H⁺) activity. The pH scale ranges from 0–14 with most soils in the range of a 5–8 pH. A pH of 7 is neutral with values above it (7–14) being alkaline/basic and values below it (0–7) being acidic.

Generally, plants have an optimal pH range that is slightly acidic pH soils (6.3–6.9). However, plants are adapted to live well at a soil pH higher or lower than this range. As the pH levels become farther from the ideal the plants begin to reach their limit of tolerance and will be progressively less healthy. Therefore, understanding pH is important because of its creation of nutrient toxicities and its impact on the availability of nutrients (See Figure 1.6). Plants that are poorly adapted to the pH will not only experience nutrient deficiencies, but they will be weakened so they can’t withstand biotic and abiotic stresses.
Soils with an alkaline pH (especially pH > 8.5) have a reduced solubility of phosphorous (P), iron (Fe), manganese (Mn), boron (B), copper (Cu), and zinc (Zn). See Figure 1.5. In addition, nitrogen is more likely to be volatilized, or turned into a vapor, at an alkaline pH. Many high alkaline soils are also calcareous which means that the soil has free excess limestone. This can negatively add to the severity of nutrient deficiency problems.

Soils with an acidic pH (typically pH < 5.5) have a reduced solubility of phosphorous (P) and molybdenum (Mb). In addition, acidic soils, especially
sandy soils, are more likely to be depleted of potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Acidic soils also have less nitrogen fixed into the soil from the atmosphere by free-living, nitrogen-fixing microbes and by legumes with associated microbes. The reason for this is because microbial activity thrives best at pH levels between 6–7. Finally, acidic soils can be toxic to plants due to aluminum (Al) and manganese (Mn) toxicity.

A good soil for a typical homeowner will generally have a pH between 6–7.5. However, a pH higher or lower than this may be fine too. As stated before, most plants are tolerant at pH levels outside of the 6–7.5 range.

**Salinity (Salts)**

Electrical conductivity is a measure of the amount of salt in the soil. All nutrients are salts that plants need to survive. However, excessive salts can cause desiccation which is where water uptake is prevented by plants. Soils with an EC of > 4 dS/m (deciSiemens per meter) are considered saline and need to be corrected. Saline soils are often caused by water that is high in salts. If salinity is a problem, it is recommended to have a water test performed.

A good soil for a typical homeowner will have an EC < 4 dS/m, yet some plants may suffer at levels in this range. Generally, levels between 0.1–1 dS/m are considered safe. For more information, see *Managing Salt-Affected Soils:*

https://eal.byu.edu/Portals/100/docs/Additional%20Resources/Managing%20Salt-Affected%20Soils%20for%20Crop%20Production.pdf
**Sodicity**

Sodic soils have a higher ratio of sodium (Na) in relation to calcium (Ca) and magnesium (Mg). When this occurs, soil aggregates or clods can deflocculate (aggregates breaking apart from *clay particles* detaching from one another). This leads to poor water infiltration into the soil and poor percolation through the soil. Sodic soils are generally alkaline with a pH greater than 8.4. To be classified as a sodic soil, a soil must have an ESP (Exchangeable Sodium Percentage) > 15% and/or a SAR (Sodium Absorption Ratio) > 13. The ESP is commonly included on a soil test report. If the ESP is greater than 5%, it indicates that a problem may be developing and preventative action should be taken by requesting an SAR analysis on the soil water to monitor it so it doesn’t become a future problem.

**Bulk Density (BD)**

Soil is made up of both solid particles (sand, silt, clay, and organic matter) and pore space (water and air). These two types of space make up the density and porosity of a soil. An ideal soil will have about 50% solid particles and 50% pore space. Compacted soils have a pore space area that is less than the solid particle area. Figure 1.7 compares a soil with low BD on the left and one with high BD on the right. Compaction is very common in urban soils due to construction, tillage, and foot/vehicle traffic. Severe compaction will negatively affect root growth and water infiltration.
Bulk density is the tool to measure the balance of solid space and pore space. It measures the mass of the soil in grams per unit of volume in cubic centimeters (g/cm$^3$).

A good soil for a typical homeowner will have a bulk density between 1.3–1.5 g/cm$^3$. This number can’t be obtained from the soil test, so the best way to achieve a soil with 50% solid particles and 50% pore space is by preventing compaction. If shallow compaction is present, it can be fixed through aeration. However, because aerators usually only penetrate 2 inches deep, a serious compaction issue may require more than aerating the soil.

**Infiltration Rate**

Infiltration is a measure of how quickly water moves into the soil. These rates are used to determine accurate irrigation rates (the frequency and amount). Water that cannot enter into the soil quickly enough will be lost to runoff if the
irrigation application rate is higher than the infiltration rate. Infiltration in regards to water management will be discussed later.

The saturated infiltration rate of a soil can be found by using a clear container with both an open top and bottom to place on the ground. Pour water onto the surface of the test area (larger than the size of the container) and let it soak in for a few minutes. Then, place the clear container firmly into the ground. Next, pour water into the container and start a timer. After 15 minutes, record the water level drop in fractions of an inch. Multiply this fraction by 4 to convert to inches per hour.

For example, a homeowner will place a clear container on the soil, fill it with water, and then start a timer. The starting water height is 2 inches. After 15 minutes, the ending water height is $1 \frac{7}{8}$ inches. The infiltration rate is calculated by finding the height change in inches and the time in hours. Subtract the start and end height ($2 - 1 \frac{7}{8}$ inch). Then multiply the height change ($\frac{1}{8}$) by 4 to convert to inches per hour.

$\frac{1}{8} \times \frac{4}{1} = \frac{4}{8}$ OR $\frac{1}{2}$ in/hr. The infiltration rate for this soil is $\frac{1}{2}$ in/hr.

A good soil for a typical homeowner will have an infiltration rate $> 1$ in/hr. A rate lower than 0.5 in/hr would need to be corrected with aeration (turfgrass) or the addition of organic matter (planting beds).
Performing a Soil Test

Many types of soil tests are available. Generally, a textural soil test is only needed initially or after large soil amending. Other tests are only needed if a problem is present with the soil. For example, a sodic soil would need a SAR (Sodium Absorption Ratio) test performed.

One practice that a homeowner should implement is to conduct a soil test at least every 3–5 years. This soil test should measure the main nutrients in a soil especially the macronutrients. This can help determine the soil pH, salinity, organic matter content, nutrient levels, and estimates of CEC. These soil characteristics are explained in more depth earlier in this section.

A soil test involves collecting cores, or tubes of soil, and submitting them to a soil lab. Over-the-counter soil test kits are generally unreliable because the information is generalized and not as accurate. Often, state extension services offer help in doing a soil test, so it may be helpful to contact them. Remember that a soil test is only as good as the collected sample. If a representative sample isn’t collected correctly or it gets contaminated, a false reading will result. For directions on taking a soil sample, view Soil Sampling Instructions for Homeowners: http://eal.byu.edu/Portals/100/Soil%20Sampling%20Instructions%20for%20Homeowners.pdf.

The best tool to take a soil sample is a clean soil probe (Figure 1.8). It is specially designed to take soil cores from the soil. Often, soil probes can be borrowed from a state extension service or through a landscape supply...
company. Inexpensive probes can also be purchased. Although a shovel is not recommended (it is usually contaminated and it is difficult to get a representative sample), it can be used if the soil sampling directions are followed.

![Soil probe](image)

**Figure 1.8 Soil probe**

Different plant material requires different depths when taking soil cores. Refer to Table 1.9 for guidance in taking the correct sampling depth for the specific type of plant material.

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Sampling Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turf, Pasture, and Other Permanent Sod Areas</td>
<td>4–6 in.</td>
</tr>
<tr>
<td>Vegetable, Shrub,</td>
<td>Tillage Depth (8–12 in.)</td>
</tr>
<tr>
<td>and Flower Gardens</td>
<td></td>
</tr>
<tr>
<td>Tree (current or future)</td>
<td>2–3 ft. along drip line OR 2–3 ft. in the root zone</td>
</tr>
</tbody>
</table>

Table 1.9 Sampling depth for different plant material

For information on interpreting soil tests, see *Appendix 3: Fundamental Soil Test Interpretation for the Urban Landscape*. 
Correcting Soil Problems

**Correcting pH (Acid/Alkaline)**

Acid soil is corrected by adding a material that will neutralize the hydrogen ions (H\(^+\)). The most commonly used material is lime. The amount of lime to apply is based upon the buffer pH test compared with calibration data for the soil type. Buffer refers to the soil resisting a change in pH levels. The buffer pH test is listed on a soil test report.xxii

A good example to compare a high buffered soil with a low buffered soil is the difference between a tractor tire and a bicycle tire. If air is let out of each tire for 10 seconds, the change in air pressure will be small in the tractor tire and large in the bike tire. Now compare this to soil with the tractor tire being a high-buffered soil and the bicycle tire being the low-buffered soil. The high-buffered soil will require large amounts of lime to neutralize the soil whereas the low-buffered soil will require less.xxiii

The pH of lowly-buffered alkaline soils can be improved by applying a form of elemental sulfur or of strong acids. The amount will depend on the soil’s buffering capacity which is determined mainly by the CEC and the concentration of basic minerals, with lime being the most common.xxiv Refer to BYU’s EAL resource *Acidifying Soil*:

https://eal.byu.edu/Portals/100/docs/Additional%20Resources/Acidifying%20Soil.pdf
Correcting a highly-buffered alkaline soil is generally not recommended because the lime content in most irrigation waters and in alkaline soils can be so high that the costs to lower the pH wouldn’t be practical. A better solution is to manage nutrient deficiencies. This is done by ensuring an adequate nutrient supply in the soil and by selecting appropriate plant material.

**Correcting Saline Soil**

Correcting a saline soil is done by ensuring adequate drainage and leaching the salts out of the soil with water that is low in salts. If a salinity problem occurs, the irrigation water may be high in salts. Perform a water test to ensure that the water is low in salt so the problem can be fixed.xxv

In climates that experience winters, salts can build up in areas where snow melt or salt is applied to melt the ice/snow. These areas are typically around sidewalks and driveways. If this is a problem, correct it by adding a buffer area (such as mulch, rock mulch, etc.) or by leaching the soil of the salt by applying higher rates of water.

**Correcting Sodic Soil**

The best way to remediate a sodic soil is to prevent it. The cost to fix it takes many years and it is expensive. Just as with saline soils, water can cause soil to become sodic. If a sodicity problem occurs, perform a water test. To remediate sodic soils, first ensure the soil has good drainage. Next, apply gypsum (CaSO₄) or anything that will increase the concentration of calcium relative to the concentration of sodium. Lastly, leach the sodium from the soil.xxvi
Correcting Drainage

Drainage is important because it allows for oxygen to get to the roots. Drainage solutions usually fall under one of three categories: improving irrigation rates, enhancing water movement over the surface, or increasing drainage through the soil. Often this should be done in the given order because the cost and difficulty rises with each solution.

Excess water must have a place to go. It is much faster, easier, and cheaper to move water across the surface of the ground than through it. Landscapes must be carefully designed so surface drainage will move water to an appropriate collection place. Before attempting a sub-surface drainage solution, always seek to correct the problem first through proper grading of the surface to let water drain naturally.

Surface drainage refers to water moving over the surface of an area from gravity. This solution is generally preferred to others, like installing a sub-surface drainage, because it allows gravity to do the work and generally needs little maintenance once initially corrected. Surface water is best fixed in the initial construction of a landscape because soil must be formed to channel water to a desired location.

For those who have established landscapes, some drainage issues can be alleviated by reducing compaction through aerating (turfgrass). Aerating is generally useful only for shallow-rooted species like turfgrass. Aeration tines
penetrate to a depth of about 2 inches, so serious compaction issues may need more than aeration. If soils are compacted, they will have poor percolation meaning the movement of water through the soil. This means poor drainage. Prevention, through avoiding compaction, is the best recommendation to maintain good drainage. Never let the problem occur and it won’t be a problem.

Other drainage issues can be fixed by adding organic matter and tilling the soil (planting beds and gardens). Soil under trees & shrubs can also be corrected through air tillage. This method uses special tools and compressed air to loosen the soil without damaging the roots."
2—Water Care

The purpose of an irrigation system, or of irrigating, is to provide plants with water so they can thrive in their environment. Just as it is for people, water is essential for plant growth and survival.

This section will review the parts of an irrigation system, review common irrigation principles, and then determine irrigation timing and rates.

DO:
- Create head-to-head spacing on sprinkler systems
- Promote a homogenous, uniform soil for better water uniformity
- Separate zones by plant material and group similar plants together
- Water deeply and infrequently
- Add water-efficient parts like smart controllers, rain sensors, weather stations, pressure-regulated heads, multi-stream nozzles, drip lines, etc.
- Adjust water needs throughout the season
- Seek for uniform distribution of water across each zone
- Apply only as much water as the landscape is using
- Inspect the irrigation system every month
- Winterize the irrigation system in winter for freezing climates

DON’T:
- Water frequent and shallow
- Keep the same water schedule throughout the season
- Put different heads on the same zone
- Overwater resulting in wasted water from runoff
- Expect a non-uniform soil to have equal distribution uniformity
Irrigation System

Understanding how an irrigation system works is necessary to know how to manage it well. The basic components of an irrigation system will be listed with a brief description of what they are used for. Figure 2.1 visually shows the main irrigation components in a landscape.

- Water Meter: When the house main line comes off of the city main line a water meter is placed to track water usage in gallons.
- Culinary/House Line: The main line transfers water from the city main line to both the house and the landscape irrigation.
- Master Valve/Shutoff Valve: A shutoff valve is typically installed right after the landscape irrigation line comes off of the house main line. This allows water to be turned off to all the irrigation.
- Backflow Preventer: Because the irrigation line is attached to the house main line, a backflow preventer must be used to prevent backflow. This part acts as a safety device to prevent irrigation water from flowing back into drinking water.
- Controller: A controller programs the scheduling and turn on times of all zones. It has electrical wires that go to each valve to turn on irrigation zones. The controller allows an irrigation system to run automatically.
- Irrigation Main Line: This pipe runs from the house/culinary line to each of the valves.
- Valve: A valve allows water into a zone so water can be distributed through heads or rotors.
- Zone: A zone is all of the heads and pipe attached with a valve. Zones have the same irrigation heads and water similar plant material.
• Lateral Line: This pipe runs between the valve and the heads/rotors in a zone. Once the valve is turned on, water passes through the lateral line to the heads.

• Head or Rotor: This is the visible part of an irrigation system when it is running. Water comes out of the head or rotor to provide water to the landscape.

• Nozzle: Nozzles go on heads and can adjust how water is distributed. It is located where the water comes out of the head.

Figure 2.1 The ten basic irrigation system components
View a short video by Rain Bird to better understand the basic parts of an irrigation system. *How an Irrigation System Works* (www.youtube.com/watch?v=UADXcEJTcso).

**Irrigation Inspection**

An irrigation inspection should be regularly done to make sure the irrigation system is functioning properly, especially if irrigation is scheduled to run during nighttime hours when problems won’t be readily noticed. These should be performed at the beginning of the season and at least once a month throughout the growing season. This will ensure that there are no broken components to the irrigation system and that it is watering efficiently.

For an example of an irrigation inspection and what a homeowner should look for during each inspection see *Appendix 4: Irrigation Inspection*.

**System Improvement**

Many homeowner systems are outdated with old equipment. New technology has made irrigation parts more efficient. Some parts that can incorporated into an irrigation system are listed below with an explanation of how they improve an irrigation system.

- Smart Controllers
  - Allow for an irrigation system to adjust itself for a more hands-off approach. Needed for weather stations and rain sensors.
- Weather Stations/Rain Sensors
  - Rain sensors prevent an irrigation system from watering when it rains. Weather stations can adjust water timing and rates according to the local conditions.
• **Pressure-regulated Heads**
  
  o High pressure causes misting and water loss. On the other hand, low pressure causes uneven watering and brown spots. A pressure-regulated head fixes high pressure only by regulating the psi at each head.
  
  o Average needed psi for different head types:
      - Spray heads: 30 psi
      - Rotary heads: 45 psi
      - Rotors: 30–100 psi depending on rotor size. 45 psi for 3/4” rotors and 70 psi for 1” rotors.

• **Nozzles**
  
  o Create larger water droplets so less water is lost to misting.
  
  o Types:
      - High-efficiency nozzles
      - Multi-stream nozzles

• **Drip line**
  
  o Deliver water directly to the ground, preventing water loss.

## Water Principles

*Even Distribution Uniformity (DU)*

Seek to have uniform watering distribution across the landscape. This means that water is distributed reasonably evenly across the irrigated area. Figure 2.2 shows the difference between uniform distribution and poor uniform distribution. Water needs to be applied down just below the root depth, which will differ based on plant material. Poor uniformity happens either with overwatering or underwatering an area. Distribution uniformity (DU) is written
as a percentage between 0-100% with a higher number having greater uniformity. A distribution uniformity of 100% is not possible due to irrigation inefficiencies. A DU of < 70% is considered poor, 70-90% good, and > 90% excellent. More information about DU can be found on Rain Bird’s Distribution Uniformity for Sprinkler Irrigation:


Figure 2.2 Different types of distribution uniformity

It is common for some areas of a landscape to receive relatively less water than other areas, forming dry spots. The typical approach to fix this is to increase the water being applied everywhere—thus over-irrigating the rest of the area. However, it is better to improve the distribution uniformity. This can be done through the following:
• a professionally designed and installed irrigation system,
• head to head coverage,
• identical types of heads,
• appropriately sized nozzles,
• adequate water pressure,
• proper maintenance (fix leaks, straighten heads, etc.), and
• homogenous soil, or where it is not possible/practical, annual aeration over the lawn to improve infiltration uniformity.

Never mix different heads (rotors, spray heads, emitters, bubblers, drip, etc.) onto the same zone. This will negatively affect the distribution uniformity and prevent plant material from receiving their needed water requirements.

**Different Zones for Different Plant Material**

Separate plant material into different zones. Different plant materials have different water requirements. Ensure that they are on different zones so water can be adjusted to their needs. Common categories to separate plant material include turf, trees, color/flowers, shrubs, and natives.

**Additional Water-Saving Tips**


Also see Water Conservation Tips from Rain Bird:

Know the Soil Type

Soil type will affect water management, specifically infiltration of water into the soil. For example, with heavy clay soils, water enters into the soil slowly and then remains in the soil for a longer period of time requiring the landscape to be irrigated less frequently. On the other hand, sandy soils allow water to enter in quickly, but retain water only for a short time. Therefore, they should be irrigated with less water each time, but more frequently.

When to Water

Time

The best time to water plants is in the early morning hours because less water is lost from evaporation. This time also reduces the chances of leaves/blades being infected with diseases because the amount of time that the leaves are wet is shortened compared to watering at night. Watering in the early morning also allows more water to get to the plants because it is not lost to wind drift. Although wind can blow during any part of the day, research in Agricultural Water Management showed that the wind is generally calmer in the mornings compared to during the day. Therefore, watering in the morning will lead to less water loss.

Evapotranspiration is water lost through evaporation and transpiration, or water lost from the soil and from plants. Evapotranspiration rates are highest
between the approximate times of 10 am–4 pm. During this time, up to 20–30% of applied water can be lost due to the hot temperatures. If plants are irrigated during the day with spray or rotor heads, more water will be lost from evaporation and from wind drift. This will result in water being both wasted and distributed unevenly. Drip lines can be run anytime because the water is delivered directly to the ground.

**Irrigation Schedule**

Water should only be applied when it is needed. However, some communities impose restrictions on when irrigation systems can be run. This can complicate watering applications, but it is still possible to follow an appropriate watering schedule. Remember that water is only needed to the depth of the plant roots. Both too much water and not enough water can be detrimental to plant health. Knowing when to apply depends on a variety of factors including:

- species,
- plant size,
- rooting depth & efficiency,
- plant stage of growth,
- soil water holding capacity,
- air temperature,
- humidity,
- light levels, and
- wind movement.

In general, plants require less water in the spring and fall and more water during the summer. Typically, irrigation frequency is 7–21 days apart in the spring and fall. In the summer, the frequency is closer together at about every 2–
7 days. Shallow-rooted plants, like turfgrass, need more frequent irrigation compared to deep-rooted plants, like most established trees, which can often be watered only once a month, and in some cases, only 3–5 times a year. Native plants growing under similar conditions to their native habitat may not require any irrigation following establishment.

A practical way to determine the time between watering is to use a soil probe and irrigate once the top 1 inch is dry (for shallow rooted species).

Although more complicated, a more specific way to determine the time between watering is through calculating the evapotranspiration rates (ET). To do this, the ET₀ number of the plant material and the daily ET rate of the local area are needed. These will give a fairly accurate rate of how much water is being lost from the soil and plants and therefore how much needs to be replaced. For more information on ET calculations view Irrigation Scheduling — Use "ET" to Save Water: http://www.rainbird.com/landscape/resources/articles/Irrigation-Scheduling.htm

How Much Water to Apply

Just as water frequency varies according to the factors mentioned previously, the amount of water needed for plants also varies according to these same factors. The next section headings discuss important principles to know how much water to apply.
**Water Deep & Infrequently**

The main rule to watering is to water deep and infrequently according to the needs of the plant. This encourages roots to extend deeper into the soil so plants will become more drought tolerant. Deep and infrequent watering also allows for more oxygen to get back into the soil before the next watering so plants can use the oxygen for important plant processes. This type of watering will leave several-day gaps between watering. Watering time will also be done for a longer period of time depending on how well the soil can absorb water.

In contrast, shallow and frequent watering will promote shallow surface roots, compacted soils, slower infiltration, and less healthy plants. Watering every day for 5 minutes would be considered shallow and frequent watering.

Use a soil probe to visually see how deep the water is moving into the soil.

**Cycle & Soak**

Irrigation water should be applied only as fast as it can move into the soil. Depending on the soil type, the time to run each zone or area will vary. If water is applied too fast for the soil, it will lead to run-off which causes waste and potential nutrient pollution. Therefore, watering duration is largely determined by the soil’s infiltration conditions. (See Infiltration Rate under Soil Management to determine how to find the infiltration rate.) Soils that are high in clay will have a shorter watering duration to prevent runoff, whereas soils with better structure may have a longer duration.
If the soil type doesn’t allow for long run times (e.g., steeply sloped turfgrass, heavy clay soils, poor infiltration, etc.), the way to still allow water to soak deep into the soil is through a cycle and soak method. This is done by running the irrigation system until the soil can no longer absorb the water being applied. At this point, the irrigation system should progress to the next zone. After a certain wait period, — dependent upon the soil type and slope — the irrigation system will again run all the zones to allow for more water to be absorbed into the soil. As an example, a system that usually runs for 15 minutes on each zone would be broken up to instead run the entire system three times with 5 min on each zone. For more information, see Rain Bird’s Avoid Runoff with Cycle & Soak Watering:


**Seasonal Adjustment**

Plants generally require more water when the temperature is hotter. Because of this, water application rates will need to be adjusted throughout the growing season. The spring and fall months will require less water for plants than the summer months. A frequent mistake that people make is keeping the same irrigation schedule throughout the entire season. This will result in wasted water, higher water bills, and overwatering.
Winterization

For climates that experience freezing temperatures during the winter, it is important to prepare an irrigation system to successfully withstand freezing. If water freezes in the irrigation pipes it can expand and break irrigation parts. Hunter has published an article that explains in more detail how to winterize your irrigation system: *Winterizing Your Irrigation System*

https://www.hunterindustries.com/winterizing-your-irrigation-system.

Drainage

Drainage issues can greatly affect water infiltration, which will then affect water rates and scheduling time. Drainage is further explained in *Infiltration Rate* and *Correcting Drainage* under Soil Management.
3—Fertilizer Care

People need a constant supply of nutrients to stay alive. They store food in pantries, fridges, and cupboards. When hungry, food is just a few minutes away. When food is low, a trip to the grocery store is made and shelves are restocked. Plants are similar to people in that they also need a constant supply of nutrients. They receive their food from the sun, air, water, and soil. A plant’s pantry is the soil. It stores the nutrients and water that a plant needs. Once these are used up the soil must be restocked so the plant can continue growing. This restocking is done by fertilizing.

This section will give an overview of essential plant nutrients and then explain how to properly choose a fertilizer and apply it.

DO:
- Apply only the amount of fertilizer needed based on a soil test and a nutrient program
- Use a slow- or controlled-release fertilizer
- Fertilize during times when nutrients will be most available to plant roots

DON’T:
- Over-fertilize, causing excessive growth, more maintenance, and lower plant quality
- Add a fertilizer that supplies an unneeded nutrient or would lead to excessive amounts of a nutrient
- Over-irrigate causing nutrients to be leached from the soil
• Continuously apply complete fertilizers, those that contain all the primary macronutrients of N, P, & K, unless needed
• Apply very heavy rates of nitrogen fertilizer when plants are attempting to enter dormancy in the fall

Necessary Plant Nutrients

Nutrients are critical for plants to survive and perform their proper functions. Seventeen essential nutrients are necessary for a plant to survive (some sources say 16 or 18 as Co and Ni are still debated). These nutrients are grouped into categories known as non-mineral nutrients and mineral nutrients. Mineral nutrients are further broken down into macronutrients (those most commonly deficient) and micronutrients. A plant obtains non-mineral elements [Carbon (C), Oxygen (O), and Hydrogen (H)] from water and the air absorbed through the roots and leaf stomata respectively. The mineral elements are absorbed by the roots of the plant. The macronutrients make up about 1%–6% of plant’s dry weight whereas the micronutrients make up less than 1% of the plant’s dry weight.

The nutrients are listed in Appendix 2: Essential Plant Elements. This table includes each nutrient listed as the element, the form it is available to plants, the function of each element, and the deficiency symptoms. Please note that some deficiency symptoms may be similar between several nutrients, and that some plant varieties (cultivars) will be much more susceptible to nutrient deficiencies than other varieties of the same species. Symptoms are not a guarantee that a
specific nutrient is low or unavailable. Before taking correction, perform a soil
test, and in some cases a tissue analysis, to get accurate results. For most
homeowners, landscapes generally only experience a deficiency in the primary
and secondary macronutrients, micronutrient deficiencies being rare. Appendix
2: Essential Plant Elements serves as a brief guide. Consult a certified landscape
professional or soil scientist before making corrections.

Nitrogen is the nutrient most likely to be deficient, largely because
significant amounts are lost from soil through leaching and volatilization.
Leaching occurs when nitrate (NO$_2^-$) passes through the soil out of reach from
plant roots. Volatilization is when ammonium (NH$_4^+$) is turned into a gas called
ammonia (NH$_3$) which is lost to the atmosphere. Since nitrogen is an important
component of the chlorophyll molecule, nitrogen-deficient plants turn yellowish-
green, a condition known as chlorosis. Thus, a light green color may indicate a
nitrogen deficiency. Shortly after nitrogen-containing fertilizers are applied,
plants turn a darker green color and vertical shoot growth increases.

**Fertilizer Recommendations**

Table 3.1 gives the average industry standards for different plant
materials in the United States. Please note that crop production, including small
gardens, requires more sophisticated fertilization requirements not covered in
this guide.
<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Turfgrass</th>
<th>Trees, shrubs, &amp; ground covers</th>
<th>Annual &amp; perennial flower beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>3–5 (cool season) 4-6 (warm season; 1 per month of growth)</td>
<td>2–4</td>
<td>2–4</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>2–4</td>
<td>1–2</td>
<td>2–3</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>3–5</td>
<td>1–2</td>
<td>2–4</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.3–0.5</td>
<td>0.1–0.2</td>
<td>0.2–0.4</td>
</tr>
<tr>
<td>Calcium (Ca) &amp; Magnesium (Mg)</td>
<td>Rarely deficient if pH is managed correctly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micronutrients</td>
<td>Follow label directions of various fertilizers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are in pounds of actual nutrient per thousand square feet annually, lbs X/1000 ft²

Table 3.1 Average fertilizer recommendations

### Determine Current Nutrient Amount—Soil Testing

In order to know how much fertilizer to apply, it is important to know how much is already in the landscape. This is one by performing a soil test.

Based off of the soil test results and compared with the industry standards from Table 3.2, homeowners will know how much nutrients to apply to the landscape. For more information on interpreting soil tests, see Appendix 3: Fundamental Soil Test Interpretation for the Urban Landscape. It is important to only apply what is needed. Too much fertilizer or too much of any one nutrient is not good and can negatively affect plant health, plus, it will cost more money.
Choosing a Fertilizer

Fertilizers are categorized according to their source or to their release rate. Their source can be inorganic or organic and their release rate can be quick-release or slow-release.

Inorganic vs. Organic

People debate over whether organic or inorganic fertilizers are best for plants. Plants don’t care what type of fertilizer they get, they only care that they get the needed nutrients. Both inorganic and organic fertilizers provide the needed nutrients for a plant. The differences between the two are mostly cost, release rates, and soil structure improvement.

Inorganic fertilizers are synthetic or man-made. They are beneficial because they have a more concentrated amount of fertilizer or a higher percentage of nutrient per pound of fertilizer. They are also cheaper and more readily available. A down side is that a misapplication can result in fertilizer burn due to the concentration being higher. Some inorganic fertilizers have been engineered to release nutrients more slowly like polymer coated urea (PCU).

Organic fertilizers come from plants or animals. These are typically natural with common examples including manure, yard waste, leaves, and ground-up parts of animals or plants. Their benefit is that they release nutrients slowly and add organic matter which can improve the structure of the soil. A disadvantage is that they may be contaminated with weed seeds and harmful
pathogens. Organic fertilizers have an NPK rating that varies and is not consistent between similar products.

**Slow-Release vs. Quick-Release**

Slow-release fertilizers release nutrients in small amounts over a longer period of time. Although more expensive, their slow release of nutrients allows for more even plant growth. These types of fertilizers are most beneficial for nitrogen because it is a highly mobile nutrient, meaning that it can move through the soil easily by leaching with water or it can be lost to the atmosphere as a gas by volatilization.

Using slow-release nitrogen fertilizer allows for better absorption of nitrogen with minimal loss to the environment. Because nitrogen is made available slowly, it allows for more uniform growth instead of bursts of quick, weak growth. Slow-release nitrogen fertilizers also more accurately match nutrient supply with plant need. One of the best performing inorganic slow-release nitrogen fertilizers is polymer coated urea (PCU).

A slow-release fertilizer is represented on fertilizer labels as WIN (Water Insoluble Nitrogen). In order for a fertilizer to be considered slow-release, the WIN amount must be 50% or more of the total nitrogen.\(^xli\)

Quick-release fertilizers release nutrients in larger amounts over a shorter period of time. They are usually cheaper, but if applied incorrectly can more easily cause fertilizer burn. Because fertilizer is a salt, if too much is applied it can pull water out of plants.
Understanding Nutrient Analysis

Reading the Fertilizer Container

On every fertilizer bag a nutrient analysis is listed that gives the weight of the three primary macronutrients (See Figure 3.2). The primary macronutrients are nitrogen (N), phosphorous (P), and potassium (K). These elements that are most commonly deficient in plants, so fertilizers are required to list their percentage amounts. They are always listed as a percentage of the total weight in the order of nitrogen (N), phosphorous as phosphate (P₂O₅), and potassium as potash (K₂O).

<table>
<thead>
<tr>
<th>Brand Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10-10-10 (Grade)</strong></td>
</tr>
<tr>
<td>Guaranteed Analysis</td>
</tr>
<tr>
<td>Total N..........................................._____%</td>
</tr>
<tr>
<td>_____% Nitrate</td>
</tr>
<tr>
<td>_____% Ammoniacal N</td>
</tr>
<tr>
<td>_____% Water soluble organic N</td>
</tr>
<tr>
<td>_____% Water insoluble N</td>
</tr>
<tr>
<td>Available phosphate (P₂O₅)..._____%</td>
</tr>
<tr>
<td>Soluble potassium (K₂O)......._____%</td>
</tr>
</tbody>
</table>

Derived from: (Actual source for primary plant nutrients, e.g. urea, ammonium phosphate, etc.)

| Manufacturer Name |
| Address |
| Net Weight _____lgs |

Figure 3.2 Fertilizer guaranteed analysis example
Finding the Actual Element Amount

It is really important to distinguish between the pounds of fertilizer being applied and the pounds of an actual element being applied. Failure to do so can result in over-application of a fertilizer which can lead to desiccation of plants. Desiccation is the drying out of a plant from removing the moisture in it. Because fertilizer is a salt, when it is over applied the salts will draw water from the plant.

The fertilizer analysis always lists N, P, and K as a percent weight of the molecule. N is listed as the actual amount of N. P and K, on the other hand, are in a molecule form (P₂O₅ and K₂O), meaning they are combined with other elements. For this reason, their percentages on the bag are listed for the entire molecule, NOT the actual element. (A common mistake is that people don’t take this into account when calculating fertilizer requirements). To know the amount of actual element being applied for each pound of fertilizer, it will need to be calculated. The following example will demonstrate how to determine the amount of actual P or K in a bag of fertilizer.

A 50 lb bag of fertilizer with a fertilizer analysis of 24–12–6 will have 24% of 50 lbs or 12 lbs N, 12% of 50 lbs or 6 lbs P₂O₅, and 6% of 50 lbs or 3 lbs K₂O. The percentages align with the fertilizer analysis of 24–12–6. To find the specific amount of P in the P₂O₅ and the K in the K₂O, the molecule must be multiplied by the conversion factor listed in Table 3.3.
Element/ Molecule | Conversion Factor
---|---
P₂O₅ | 0.44 or 44% of P₂O₅ weight is P. 
P | 2.3 P₂O₅ 
K₂O | 0.83 or 83% of K₂O weight is K. 
K | 1.2 K₂O

Table 3.3 Conversion factors for P₂O₅ ↔ P and K₂O ↔ K

6 lbs P₂O₅ * 0.44 = 2.64 lbs P

3 lbs K₂O * 0.83 = 2.49 lbs K

A 50 lb bag of 24–12–6 would supply 12 lbs N, 2.64 lbs P, and 2.49 lbs K.

**Common Fertilizers**

<table>
<thead>
<tr>
<th>Product</th>
<th>Analysis (N–P₂O₅–K₂O)</th>
<th>Release Rate</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Nitrogen Fertilizers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>46–0–0</td>
<td>Fast</td>
<td>Solid</td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>21–0–0–24S</td>
<td>Fast</td>
<td>Solid</td>
</tr>
<tr>
<td>Urea ammonium nitrate</td>
<td>28–0–0</td>
<td>Fast</td>
<td>Liquid</td>
</tr>
<tr>
<td></td>
<td>32–0–0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polymer Coated Urea</td>
<td>44–0–0</td>
<td>Slow (Control)</td>
<td>Solid</td>
</tr>
<tr>
<td><strong>Common Phosphorous Fertilizers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monoammonium phosphate</td>
<td>11–52–0</td>
<td>Fast</td>
<td>Solid</td>
</tr>
<tr>
<td>Diammonium phosphate</td>
<td>18–46–0</td>
<td>Fast</td>
<td>Solid</td>
</tr>
<tr>
<td>Ammonium polyphosphate</td>
<td>10–34–0</td>
<td>Fast</td>
<td>Liquid</td>
</tr>
<tr>
<td><strong>Common Potassium Fertilizers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>0–0–60</td>
<td>Fast</td>
<td>Solid</td>
</tr>
<tr>
<td>Potassium sulfate</td>
<td>0–0–50–18S</td>
<td>Medium</td>
<td>Solid</td>
</tr>
<tr>
<td><strong>Organic Fertilizers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manure</td>
<td>(2–3)–(1)–(1–2)</td>
<td>Slow</td>
<td>Solid</td>
</tr>
<tr>
<td>Yard Waste</td>
<td>(1–1.5)–(0.2–0.5)– (0.5–1.5)</td>
<td>Slow</td>
<td>Solid</td>
</tr>
<tr>
<td>Compost</td>
<td>(2–5)–(1–4)–(0–0.5)</td>
<td>Slow</td>
<td>Solid</td>
</tr>
</tbody>
</table>

Table 3.4 Common fertilizers for N, P, & K.
Applying Fertilizer

Time (When)

Depending on the climate and region, the terms spring and fall can have different meanings. Spring occurs when temperatures begin to warm up (usually March-May). Fall occurs when temperatures begin to cool down (Sep-Nov). Generally, apply a lighter amount of fertilizer in the spring (compared to fall) when new growth is highest. For turfgrass and some garden crops, timing is relatively more important than most other urban landscape plants. Because turfgrass has small root systems, it needs a steady supply of nitrogen for consistent growth and health through the entire season. However, for fruiting plants, too much nitrogen will result in excessive vegetative growth and smaller and less fruit production.

Applying fertilizer in fall may also be the most appropriate depending on plant type. During this time, conditions allow for greater nutrient absorption and accumulation for next year’s growth. (For warm-season grasses this time is during the summer.) During the fall, roots are growing more so the extra nutrients allow the roots to grow deeper for a healthier and more drought tolerant plant in the spring. This is critical because early shoot growth of plants depends upon dormant-stored nutrients.

Plants must have adequate water to best absorb nutrients. Fertilizer application, then, is not recommended during drought conditions.\textsuperscript{xliv}
**Location (Where)**

Fertilizer must be applied where it is needed. Often this is at the roots of plants. For established trees, roots often extend at least 1.5 times the size of the crown or the upper structure of branches.

Spread fertilizer pellets when the grass does not have moisture on it or else leaves may get salt burn. After applying fertilizer, irrigate the area so the fertilizer can get down into the soil and be accessed by the roots.

**Rate (How Much)**

Figure 3.4 earlier in this section gives general fertilizer recommendations for different plant types. In urban environments, most nutrients (other than N) often have a large residual supply in the soil from previous fertilization and rich natural supplies. This means that the nutrients are slow to be used up in the soil. If most of the nutrients are at a recommended level, nitrogen is commonly the only needed nutrient. Basically, complete fertilizers (ones that have nitrogen, phosphorous, and potassium) are generally not needed and should only be used if a soil or tissue test suggests the use of them. In some states phosphorous can only be applied by prescription (as indicated by soil test).\textsuperscript{xlv}

Fertilizer is a salt. When it is over applied it can result in the soil having a lower water potential than plant roots. Water potential refers to water moving from one area to another, like areas of high water concentration to areas of low water concentration. If a water is purer it will have a higher water concentration compared to a water that contains salts and other elements. If the soil has a lower
water potential than the roots, water will be pulled out of plant roots due to the imbalances of salt content, resulting in plants becoming drought stressed.\(^{xlvi}\)

A tradeoff exists between plant growth and plant resistance to biotic (insects, disease, pests, etc.) and abiotic (wind, drought, excessive sunlight, etc.) factors. More growth means a plant cannot designate as much energy and resources to building up its defenses. More growth also means more maintenance by mowing or pruning. Slower growth may help increase plant resistance to diseases, insects, and other pests. To avoid excessive growth, use lower rates of fertilizer.

**Method**

The two main ways to distribute fertilizer are through a liquid form or a solid form. The solid form is generally preferred because it is easier and cheaper. Solid fertilizer is typically distributed through broadcasting. Push broadcasters have a rotating disk that spreads the fertilizer outwards. It is best to pass over a lawn at a half rate in one direction and then place the other half rate perpendicular to the first direction. This will provide a more even distribution of the fertilizer.
Part Two: 
Plant Care
4—Lawn Care

Proper lawn care principles will equip turfgrass with the right tools it needs to grow well and out-compete diseases, weeds, and pests.\textsuperscript{xlvii}

One key element in creating healthy grass is to promote adequate root growth so the plant can have access to more nutrients and water. Poor maintenance practices that will negatively affect root growth include large applications of water and nitrogen, high temperatures (especially for cool-season grasses), low mowing, nutrient deficiencies, highly shaded areas, and certain insects and pathogens.\textsuperscript{xlviii}

This section will first explain more specific principles to watering and fertilizing turfgrass. Then other maintenance practices such as mowing, edging, trimming, and aerating will be discussed.

DO:
- Water according to plant need and ET rates
- Use a slow-release or controlled-release nitrogen fertilizer
- Aerate with a clean aerator if soil compaction is an issue

DON’T:
- Remove more than 1/3 of the blade height when mowing
Watering

Turfgrass requires more frequent watering, especially compared with trees, because it has more shallow roots. As mentioned previously under General Practices, watering rates vary throughout the year. In the spring and fall, lawns may need to be watered every 7–10 days; whereas in the summer, they may need to be watered every 2–5 days. See Water Management under Part One: General Practices for more detail in understanding water rates.

In general, turfgrass requires 1–1.5 inches of water each week during the growing season. However, specific water rates will need to be adjusted according to the specific turfgrass species and soil type. Throughout the growing season (spring to fall) temporary adjustments will need to be made because of differences in rooting depth and environmental conditions (temperature, humidity, wind, and canopy resistance).xl

The amount of water applied at one time should be determined by the soil type and the rooting depth of the turfgrass. A simple way that a soil type can be determined is by doing a jar test (see Soil Texture under 1—Soil Care). Rooting depth can be determined by cutting out a small section of sod to view the depth of the soil roots. A tool specifically designed for checking root depth is a Mascaro profile sampler.

Ideally, irrigation should fill the soil with water to the depth of rooting (avoid pushing water below roots) and not be repeated until the turfgrass comes under moderate moisture stress (indicated when the turfgrass takes on a gray-
green hue and is slow to spring back from traffic). Roots need oxygen. If excess water saturates the root zone for extended periods, oxygen will be unavailable and result in a decline in turfgrass health.¹

**Fertilizing**

As mentioned earlier, doing a soil sample every 3–5 years is necessary to accurately determine the quantity of fertilizer and nutrients needed for a lawn. Turfgrass is usually most deficient in nitrogen (N), followed by sulfur (S) (more in the East with acidic soils) and potassium (K) (more in the West with alkaline soils), and then phosphorous (P).

Generally, nitrogen needs to be applied every year and phosphorous and potassium need to be applied only once every 3–5 years. Table 4.1 explains average amounts of nutrients needed annually for lawn areas.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Turfgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>3–5 (cool season)</td>
</tr>
<tr>
<td></td>
<td>4-6 (warm season; 1 per month of growth)</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>2-4</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>3–5</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.3–0.5</td>
</tr>
<tr>
<td>Calcium (Ca) &amp; Magnesium (Mg)</td>
<td>Rarely deficient if pH is managed correctly</td>
</tr>
<tr>
<td>Micronutrients</td>
<td>Follow label directions of various fertilizers</td>
</tr>
</tbody>
</table>

*Values are in pounds of actual nutrient per thousand square feet annually, lbs X/1000 ft²*

Table 4.1 Fertilizer recommendations for turfgrass
Nitrogen Fertilizer

Nitrogen is the key nutrient in a turfgrass fertility program because turfgrass plants require more nitrogen than any other essential element. Nitrogen is the nutrient most likely to be deficient, largely because significant amounts are lost from soil through leaching and volatilization. Density of turfgrass also varies with nitrogen availability.

A test performed in Provo, Utah on Kentucky Bluegrass (a cool-season grass) sought to determine how often fertilizer needed to be applied to maintain a healthy lawn. The studies showed that grass would be healthy when a mixture of ammonium sulfate (AS) and polymer coated urea (PCU) was applied twice a year with a heavier application in fall and a lighter one in spring.

For cool-season grasses, a general recommendation for nitrogen fertilizer is a mix of 1/3 AS (ammonium sulfate) and 2/3 PCU (polymer coated urea). This mix is applied at different rates, but generally with a higher rate in the fall (1 lb N/1000 ft²) and a lower rate in the spring (2 lb N/1000 ft²).

For warm-season grasses, a general recommendation for nitrogen fertilizer is 1 lb N/1000 ft² per month during the growing season. Warm-season grasses are best fertilized during the summer.

After a fertilizer is applied, it must be watered in to prevent nutrient loss and fertilizer burn. Also, ensure that any fertilizers on hard surfaces are blown off onto the grass to prevent nutrient waste and pollution.
Mowing

Mowing is the number one labor cost for landscapes and it is one of the most common turfgrass maintenance practices. The whole purpose of mowing is mainly for two reasons: 1) to create a clean appearance and 2) to increase the density of the lawn so the lawn can compete with weeds. As a general overview, the main principles of mowing are listed below.

DO:
- Manage mowing with fertilizer
- Adjust mowing frequency according to the 1/3 rule
- Change the mowing direction pattern
- Always cut with sharp blades
- Mow turfgrass when it is dry
- Return grass clippings to the lawn

DON’T
- Scalp or remove more than 1/3 of turfgrass blade height
- Over fertilize or overwater

Manage Fertilization

Manage mowing by managing fertilizer application. Fertilizer should be applied only when needed to prevent excessive grass growth and more mowing. It is helpful to apply a slow-release fertilizer because it will lead to more consistent growth instead of bursts of growth. If applied incorrectly, quick-release fertilizers can lead to rapid and excessive growth leading to more mowing.
**Mowing Height**

Never remove more than 1/3 of the grass blades when mowing. Removing more than 1/3 or cutting turfgrass too low can cause scalping. Scalping places shock on turfgrass and can cause shallow rooting, low turf density, weed infestation, and a decline in plant health.

Following the 1/3 rule allows for greater photosynthetic ability, more vigorous turfgrass, less weeds, and lower water need.

The depth of turf roots has a direct relationship with the cutting height. A higher blade height equates to deeper roots, whereas a lower blade height leads to more shallow roots (Figure 4.2) For this reason, it is better to side on a higher-cut lawn because the grass will have more stress tolerance, deeper roots to absorb water and nutrients, and lower upkeep requirements.

![Figure 4.2 Effect of mowing height on turfgrass roots](image)

It is also important to understand that mowing height changes throughout the season. Depending on different factors, grass will grow more or less quickly. Figure 4.3 shows that a cool-season turf grows more quickly in the spring and...
fall. When a cool-season turf is stressed, such as in drought conditions or in the middle of the summer, it is beneficial to mow it higher.

![Cool-season turfgrass growth throughout the year](image)

During stress periods, using the higher mowing height range will help the lawn stay healthy and strong.

For most homeowners, a typical mowing height ranges between 2–3 inches with grass needing to be cut before it is 3–4.5 inches tall respectively. Be aware that this height will change with different turfgrass species. Table 4.4 shows the mowing heights for several cool-season and warm-season grasses with the height of when the grass needs to be cut.

<table>
<thead>
<tr>
<th>Grass Climate</th>
<th>Grass Type</th>
<th>After-Mowing Height (inches)</th>
<th>Before-Mowing Height (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool-season</td>
<td>Bentgrass</td>
<td>0.5–1</td>
<td>0.75–1.5</td>
</tr>
<tr>
<td></td>
<td>Bluegrass</td>
<td>2–3</td>
<td>3–4.5</td>
</tr>
<tr>
<td></td>
<td>Perennial Ryegrass</td>
<td>2–3</td>
<td>3–4.5</td>
</tr>
<tr>
<td></td>
<td>Fescue</td>
<td>2–3</td>
<td>3–4.5</td>
</tr>
<tr>
<td>Warm-season</td>
<td>Bahia</td>
<td>2–2.5</td>
<td>3–3.75</td>
</tr>
<tr>
<td></td>
<td>Bermuda</td>
<td>1.5–2</td>
<td>2.25–3</td>
</tr>
</tbody>
</table>
Table 4.4 Mowing heights for different grass species

<table>
<thead>
<tr>
<th>Grass Species</th>
<th>1.5–2</th>
<th>2.25–3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centipede</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Augustine</td>
<td>2–3</td>
<td>3–4.5</td>
</tr>
<tr>
<td>Zoysia</td>
<td>1–2</td>
<td>1.5–3</td>
</tr>
</tbody>
</table>

**Mowing Frequency (1/3 Rule)**

How frequently a homeowner mows depends on the 1/3 mowing height rule (See Figure 4.5). During different times of the year, grass may grow more or less quick. This means that mowing frequency will be proportional to mowing height. Instead of basing a mowing schedule on a certain day of the week, it is better to base it on the growth rate of the grass.

![The ONE-THIRD Rule](image)

Figure 4.5 The one-third rule for mowing frequency and height

Mow frequently so no more than 1/3 of grass blades are removed. Scalping or removing more than 1/3 of the shoot can drastically reduce root growth for 6–14 days. This will cause turfgrass to be stressed and have poor health. Scalped grass will also be more vulnerable to pests and diseases.

Mowing frequency will need to be adjusted during periods of higher and lower growth. Several factors that influence growth include weather conditions,
the season/time of year, moisture conditions/irrigation, turf species growth rate, and fertilizer applications.

During dry and hot weather, reduce mowing frequency and raise the mowing height for cool-season grasses because the temperature slows their growth rate. For warm-season grasses, growth is fastest during the summer.

Turfgrass experiences periods of faster growth after fertilizer application, rain events, and in the turfgrasses’ main growing period (spring and fall for cool-season grass and summer for warm-season grass). During dormant periods (summer for cool-season and spring/fall for warm-season), lawns experience slower growth. The rule is to mow frequently enough so less than 1/3 of the blade height is cut off. A general rule is that if grass clippings aren’t clumping, then the cutting frequency is correct.

If turfgrass grows really tall, only remove 1/3 by raising the height of the mowing deck. Over a period of a couple of weeks, gradually bring the turf height down to the desired height while always removing less than 1/3.

**Mowing Pattern**

Routinely change the mowing direction to prevent a turf grain. A grain occurs when the blades all lean one way causing a striping effect in mowed lawns. Changing the mowing direction also prevents ruts from forming.

Each time the lawn is mowed, change the mowing direction. As Figure 4.6 demonstrates, on the first mowing mow N-S, then NE-SW, then E-W, etc.

For steep and hazardous areas, mow in the direction that is the safest.
Figure 4.6 Mowing direction

**Keep Sharp Blades**

Consistently sharpen lawn mower blades. Dull blades can increase the risk of pests and diseases. They also can cause discoloration, bruise the leaf tips, and allow water loss.

Sharp blades give a clean cut and a high-quality appearance, whereas dull blades result in a frayed grass blade tip (Figure 4.7). It is a great idea to have 1–2 extra mowing blades so a sharp blade will always be ready for the mower.

Figure 4.7 Clean cut vs dull cut grass leaf blades

**Mow Dry Turf**

The best time to mow a lawn is when it is dry (different regions may require mowing when it is wet, but the ideal time is when it is dry). This allows for a consistent cut because grass is standing up instead of laying down. It can
also reduce clogging the mower, provide a better look, and take less time.

Mowing when the soil is wet can lead to trenches and damage to the lawn.

**Return Grass Clippings**

Leave clippings on the lawn when mowing. Many people bag their clippings, but leaving them returns nutrients and organic matter to the soil, plus it reduces landfill waste.

If a homeowner is mowing properly (following the 1/3 rule), then clippings will easily decompose in the lawn. Contrary to popular belief, grass clippings don’t contribute to thatch buildup because they decompose quickly. Leaving clippings will allow nutrients to be returned back to the soil, resulting in a lower fertilizer demand and a healthier turf. lx

**Edging, Trimming, & Blowing**

Edging, trimming, and blowing are final touches to make a lawn look clean and professional. Edging is done to touch up around areas that can’t be reached by a mower. Two types of edging are used; one around hardscapes and the other around softscapes (trimming).

An edging machine or tool is used to create straight lines on hardscapes or hard surfaces. It includes using a hand-held machine or a tool to run along hard straight edges like sidewalks and driveways. The purpose for edging is to prevent grass from spreading over the hard surface. It allows for a clean straight edge to be visible between a lawn and the hard surface.
The other type of edging is done around softscapes or plant material. A line trimmer is used for touching up in places where the mower can’t reach. The line trimmer acts as a mini lawnmower to trim grass around fences, rocks, pond edges, and plant material. When trimming around trees, never cut into the bark of the tree because it can damage the health of the tree by cutting into the phloem or the layer that transports sugars and nutrients. One practice to prevent this is to have mulch areas around trees.

Blowing is the last task done after a mowing session. Its purpose is to remove any grass clippings from hard surfaces such as sidewalks and driveways. It is the final touch that allows for the landscape to look its best.

**Thatch**

Thatch and soil compaction can be a major problem with turfgrass. Thatch is a layer of tightly woven shoots, roots, stems. Although having some thatch is good, too much is a problem because it inhibits water, oxygen, and nutrients from reaching the soil. Thatch levels are dependent upon the grass type because some grass species produce more thatch than others. Bad maintenance practices such as over-applying fertilizer or watering shallow and frequently can increase the amount of thatch buildup.
Compaction & Aerating

Compaction is likely the greatest problem that most homeowners face. With the installation of many urban landscapes, the weight and use of heavy construction equipment will compact the soil. Wet clay soils are also more likely to become compacted. Situations like these can severely compact soils, often deeper than the 2 inches that an aerator will penetrate. When compaction occurs, soil particles are compressed together preventing the movement of water, oxygen, nutrients, and plant roots into the soil.

Aerating is a great way to reduce low to moderate soil compaction. This process is completed by a machine with hollow tines that removes soil cores from the lawn and deposits pellets onto the surface. Figure 4.8 shows the benefits of aerating a lawn. The pellets will decompose back into the soil within a couple weeks. Aerification helps loosen the soil to allow more oxygen into it.\textsuperscript{xiii}

\textbf{Figure 4.8 Benefits of aerating turfgrass}
Most aerator machines only penetrate about 2 inches into the soil. If a lawn has serious soil compaction issues, aerating the soil may not be sufficient. In these cases, contact a certified landscape professional for more help.

Aerating should only be done when it is necessary, meaning when the soil is compacted. Although aerating can only help a lawn, it is generally not worth the time and money unless there is a need. For cool-season grasses, aerate in the early fall to avoid weed seed germination. For warm-season grasses, aerate in the late spring.
5—Tree & Shrub Care

DO:

• Make pruning cuts outside of the branch collar so the tree/shrub can seal off the wound properly
• Improve the soil through mulching and avoiding compaction

DON’T:

• Top trees
• Make flush cuts by cutting into the branch collar
• Remove more than 25% of the living branches when pruning
• Bury the root flare under the soil or under mulch

Watering

Trees and shrubs have deeper roots than turf so they access water for greater periods of time before they need to be replenished with water. A common problem in urban environments is that trees are over-irrigated. Because trees often have roots that reach 6–18 inches deep, they don’t need to be watered as frequently as turf with roots 2–6 inches deep.

Typically trees with lower volumes of soil (sidewalk median, tree grate, etc.) or trees next to windy hot areas (next to a building or parking lot) will show drought stress sooner. Trees and shrubs in these situations may need to be watered more frequently.\textsuperscript{lxi}
A general time between watering is 10–30 days. This number will change depending on soil type, climate, temperature, plant size, plant species, etc.

Although tree roots are deeper than turfgrass, most tree roots are located in the upper one foot of soil. Remember to water trees and shrubs deeply and infrequently.

Trees need 1–1.5 inches of water every 7–10 days. This suggestion will vary according to the site conditions, size of the tree, and water requirements for the particular plant.

Fertilizing

Trees and shrubs generally require less maintenance than lawns. Because they grow slower, they can usually be watered and fertilized less frequently.

When tree roots grow beneath a lawn, the tree may get enough nutrients from lawn fertilizer applications. Table 5.1 gives general fertilizer recommendations.

What

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Trees, shrubs, &amp; ground covers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>2–4</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>1–2</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>1–2</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.1–0.2</td>
</tr>
<tr>
<td>Calcium (Ca) &amp; Magnesium (Mg)</td>
<td>Rarely deficient if pH is managed correctly</td>
</tr>
<tr>
<td>Micronutrients</td>
<td>Follow label directions of various fertilizers</td>
</tr>
</tbody>
</table>

Values are in pounds of actual nutrient per thousand square feet annually, lbs X/1000 ft²

Table 5.1 Fertilizer recommendations for trees and shrubs
When

Trees and shrubs can generally be fertilized anytime during the growing season. What limits nutrient uptake is usually root activity and available water. Depending on the region, root activity is higher during early spring. If adequate amounts of water are available, early spring is the best time to fertilize trees and shrubs to support spring growth.\textsuperscript{lxviii}

Depending on the age and health of a tree, fertilizer applications may vary between 1–3 years. Some trees and shrubs are low maintenance, and others are able to get enough nutrients from the mulch around their base or from fertilizer applications applied to the lawn.

Where

Trees and shrubs have most of their feeder roots in the top 6 inches of the soil (See Figure 5.2). These feeder roots are primarily responsible for absorbing water and nutrients. To get nutrients to the roots, a fertilizer is used. It can be distributed in multiple ways, but the most common is applying fertilizer to the surface through a granular form. Applying fertilizer in this way is usually inexpensive, quick, and easy. It is important to note that when a tree is growing in a lawn, additional fertilizer may not be required if the lawn is regularly fertilized.\textsuperscript{lxix}
Most trees and shrubs should have fertilizer placed from around the trunk to just beyond the drip line. The drip line is the edge of the canopy as can be seen in Figure 5.2. For trees that have branches that grow more upright, the area to apply fertilizer can be calculated. Measure the diameter of the tree (in inches) at a height of 4.5 feet above the ground. This diameter measurement is then multiplied by 1 or 1.5 to get the radius of the tree. The area of a circle is then calculated for total application area.

For example, if a tree had a diameter of 12 inches at 4.5 feet up the trunk, then the radius would be 12–18 feet (12*1 or 1.5). By using the area of a circle ($A=\pi r^2$), the total fertilizer application is determined to be 75.4 ft$^2$–113.01 ft$^2$ ($2\pi r^2$ or 18).
In calculating the fertilizer area for trees, measure the radius of the canopy or from the trunk to the farthest out branches. Then use the area of a circle to calculate the square footage of the tree’s main growth area. It is important to note that the roots extend beyond the drip line of a tree usually to at least 1.5 times the distance and often farther. This is one reason why trees between streets and sidewalks are often stressed because the nearby sidewalks and pavement interfere with roots absorbing needed water, oxygen, and nutrients.

**How Much**

Fertilizer recommendations should be based off of the soil test results. In general, trees and shrubs need fertilizers with lower rates of P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O, nitrogen being needed the most often. The rate for slow-release nitrogen fertilizers should generally be 2–4 lbs of *actual nitrogen* per 1000 ft\textsuperscript{2} of root area per application. During a year, the amount of *actual nitrogen* applied shouldn’t exceed 6 lbs per 1000 ft\textsuperscript{2}.\textsuperscript{lxii} When applying fertilizers, a slow-release fertilizer that has a minimum 50% WIN (Water Insoluble Nitrogen) is recommend in order to disperse nutrients more consistently.\textsuperscript{lxiii}

If necessary, a quick-release fertilizer can be used, but application rates should be lower to avoid excessive salt accumulation and fertilizer burn. Rates per application range between 1–2 lbs of *actual nitrogen* per 1000 ft\textsuperscript{2} and total *actual nitrogen* per year shouldn’t exceed 4 lbs.\textsuperscript{lxiv}
Pruning

Why We Prune

Pruning is one of the most common practices performed on trees and shrubs. Its purpose is to shape the plant, reduce shade/wind resistance, encourage better structure, remove hazardous branches (dead, diseased, weak), improve flower/fruit production, and enhance visual appeal.\textsuperscript{lxxv}

How Trees Seal: CODIT

Trees don’t heal, they seal. Trees are different than people in that they don’t repair damage. Instead, trees repair wounds by sealing them off through the CODIT process. In fact, any cut on a tree, whether through weed trimming, pruning, or wear from ropes, is an injury to the tree.

Alex Shigo, a well-known tree biologist, created the CODIT model that explains the process that trees experience to compartmentalize or seal off decay in trees. CODIT stands for Compartmentalization Of Decay In Trees. It consists of trees using four types of walls to compartmentalize decay. Another biologist, Dirk Dujesiefken further expands CODIT by applying it to all damage on trees (Compartmentalization Of Damage In Trees).\textsuperscript{lxxvi}

To fight off damage, trees employ four types of walls (See Figure 5.3):

- Wall 1: Resists vertical spread through clogging xylem vessels. Weakest.
- Wall 2: Resists inward spread through chemicals in latewood cells.
- Wall 3: Resists radial spread of decay through ray cells.
- Wall 4: Resists outward spread with a barrier to seal wound. Strongest.
When

Although trees can generally be pruned year around, often the best time to prune is when the plant is dormant (some trees and shrubs don't go dormant, especially in warmer climates). Pruning when the tree is dormant allows for less sugars to be lost, less stress caused to the tree, and pruning cuts to seal over more quickly. Usually early spring before buds swell and late fall are the best times to prune. Some trees are susceptible to certain diseases that are prevalent only during certain times of the year (oak wilt, fire blight, etc.) These typically occur during spring when flowers are blooming or when buds have broken out. Avoid pruning certain tree species during this time. 
Pruning Cuts

All pruning cuts are permanent and cause damage to the tree. Luckily, trees are often forgiving. The goal is to minimize damage caused to the tree/shrub and encourage them to grow healthy and properly. Several types of pruning cuts are used to achieve this goal.

Thinning Cuts

Thinning cuts are used to cut branches back to a large main branch or to the trunk (Figure 5.4). These cuts are used to increase light penetration and wind circulation.

Figure 5.4 Thinning cut made back to the trunk
**Reduction Cut**

Reduction cuts are used to reduce the length of a limb by cutting it back to a lateral branch that can assume the terminal role. Trees can’t seal these cuts off as quickly, so it is best to avoid large reduction cuts and instead use it for smaller branches. When making a reduction cut, prune the branch back to a lateral branch that is at least 1/3 the size of the branch being removed. Figure 5.5 shows, on the right, how this cut is made and, on the left, what it looks like on a tree. If the lateral branch is smaller water sprouts will likely emerge.

![Figure 5.5 Reduction cut made to a lateral branch](image)

**Heading Cut**

Heading cuts reduce branches back to a bud, stub, or lateral branch that isn’t large enough to assume the terminal role (Figure 5.6). This type of cut is generally discouraged on trees because it results in topping conditions which will negatively affect the tree health. Heading cuts are used mainly with shearing.
small plants and shrubs. However, using a thinning cut or reduction cut is preferred.\textsuperscript{xxxiv}

Figure 5.6 Heading cuts

**Pruning Types**

Pruning is not always done for the same reasons. Because of this, different types of pruning are needed to improve the health and safety of a tree. One way to remember the different types is through the CT3R method.\textsuperscript{xxxvi}

- Cleaning: remove dead, diseased, damaged, or weakly attached branches
- Thinning: remove some inner branches to increase penetration of light and air and to improve structure
- Raising: remove lower branches for clearance
- Reduction: reduce height or spread and done only when necessary
- Restoration: improve structure and safety from storm-damage and topping
What to Look For

Understanding what constitutes poor tree structure and growth will help a homeowner know what to look for and what to prune in trees. Figure 5.7 shows many of these common problems. Some main issues that will being fixed with proper pruning include removing crossing or rubbing branches, codominant stems, water sprouts, suckers, branches spaced too closely together, and weak branch crotches with a narrow angle.

A. Suckers (base) & water sprouts (branches)
B. Stubs or broken branches
C. Downward growing branches
D. Rubbing/crossing branches
E. Shaded interior branches
F. Codominant stems
G. Narrow crotches

Figure 5.7 Common problems in an unpruned tree

lxxxvii
- **Codominant stems**: These occur when two equally sized branches split into a “Y” shape. They are weak branches because they lack a branch bark ridge, they don’t have a branch protection zone, they don’t have a branch collar, and they often have included bark (bark between the stems). Figure 5.8 shows included bark. For these reasons, codominant stems are weak and can lead to future branches failing. Branches with a narrow angle have similar symptoms.

![Figure 5.8 Included bark in a codominant stem](image)

- **Crossing or rubbing branches**: Whenever branches cross or rub they can slightly damage the other branch. When they grow larger they can hinder the movement of sugars through the phloem of the branch.

- **Water sprouts and suckers**: Water sprouts are weakly attached branches that grow quickly and straight up. They typically have few buds and the tree produces them to provide sugars to damaged areas so it can seal over wounds. They are often a result from over pruning. Suckers are similar to
water sprouts except they grow only at the base of the tree. They are likely to occur in fruit trees that were grafted.

- Branches spaced closely together: Good structure for trees includes having branches spaced well vertically and radially. For trees that grow large, branches should be spaced out 18 inches vertically. Trees that grow small should have branches spaced out 12 inches vertically.

**How to Prune Right**

**3 Steps of Pruning**

1. Base: it is important to assess the base of the tree to make sure the tree is healthy. Ensure that the root flare is visible. The root flare is the base of the trunk that angles outward. Figure 5.9 shows a correctly planted tree with a visible root flare. Figure 5.10 shows a tree that was planted too low because the root flare isn’t visible. This will cause the root flare to stay moist inviting disease and potentially leading to decay.

Figure 5.9 Tree with a properly exposed root flare
Assess roots for girdling root, roots that wrap around the base of the tree, and remove them to prevent trunk growth restriction (See Figure 5.11). Look for damage or decay at the base of the tree. Sometimes rodents will chew the bark during the winter which is detrimental because it removes the phloem layer which transports sugars and starches which the tree uses for energy.
2. Main: Remove rubbing/crossing branches, weak crotches, and low branches to raise the canopy. Also remove damaged, dead, and diseased branches. These branches can cause future injury to both the tree and to people. If a branch is diseased, disinfect pruning tools after each cut to make sure the disease doesn’t spread. A solution of water and 10% bleach will work well to disinfect tools. An example is 1 gallon of water to 1 tablespoon of bleach.

3. Improve: Prune branches for proper structure and shaping. Branches should be spaced correctly (18 inches vertically for large-growing trees and 12 inches vertically for small-growing trees).

How Much

During a year, don’t remove more than 25% of the tree canopy. Removing more than this amount can cause stress to the tree, promote the growth of weak water sprouts, and slow tree growth. The goal is to properly prune trees when they are young so they need minimal pruning when they are mature. Young trees can generally handle more heavy pruning than mature trees.xciv

Additional Pruning Tips

Smaller cuts seal faster than larger cuts. It is best to train trees when they are young so smaller cuts are made. If a homeowner “train[s] up a [tree] in the way [it] should go: when [it] is old, [it] will not depart from it.xcv

When any pruning cut is made, cut about \( \frac{1}{4} \) inch above a lateral bud with the lateral bud pointing outward. The \( \frac{1}{4} \) inch gap allows for the bud to survive and a bud facing outward will create better structure. When a branch is cut back to the bud, the bud will now become the new growing direction for the branch.

- Make planned cuts at the right location.
• Always cut outside of the branch collar.
• Remove no more than 1/4 of the tree’s branches.

**Branch Attachment**

An understanding of branch structure is helpful to know where to make pruning cuts. At the base of every branch consists a branch collar and a branch bark ridge as shown in Figure 5.12. The branch collar is the swollen base that wraps around the entire branch. It contains chemicals that help in the CODIT process or in sealing off wounds. Line one shows where the branch collar ends. The branch bark ridge is where the growth of the branch and the trunk meet. Pruning cuts should only be made outside of the branch collar and the branch bark ridge. These two structures serve as guides to know where to make a pruning cut.

Figure 5.12 Branch collar and location of a proper pruning cut
(Line 1 shows the location of the branch collar with a correct cut always being made outside of this line. Line 2 shows where an incorrect and damaging flush cut would be made.)

**Three-Point Cut for Larger Branches**

For branches that are larger than one inch a three-point reduction cut is used to prevent bark from ripping. Figure 5.13 demonstrates the three steps — undercut, overcut, and final cut.

1. **Undercut:** Make an undercut. This is made one or two feet from the parent branch or trunk. This cut will prevent the bark from ripping when the branch is cut.
2. **Overcut:** Make a complete cut just outside of the undercut. If using a chain saw, make the cut right on top of the undercut to allow the limb to drop as smooth as possible when the weight is released.
3. **Final cut:** Remove the entire stub (what is still left)

![Three-point cut diagram](image)
What to Avoid

Stub Cuts

When a cut is not made up next to the branch collar it will leave a short stub (Figure 5.14). This requires the tree to take a longer period of time to completely seal the wound.

Flush Cuts

Flush cuts occur when a cut is made into the branch collar (Figure 5.15). This slows the CODIT process and can sometimes prevent it from occurring. If this happens decay and disease can easily enter into the tree.
Figure 5.15 Flush cut

Topping

Topping is a damaging, yet common practice with those who are inexperienced in pruning. It looks like the tree received a haircut with all of the top branches being cut back to stubs (Figure 5.16). This practice is very harmful to trees and can lead to their future death. Bluntly, topping is malpractice on trees. The better way to prune is through pruning early on and consistently and through making heading cuts.
Figure 5.16 Topped trees with too much mulch

Below are eight reasons why topping trees is damaging:

- **Starvation**: Good pruning rarely removes more than $\frac{1}{4}$ of the crown. Topping removes more of the crown which upsets the crown-root ratio and cuts off its food making ability.
- **Weak Limbs**: Wood of new limb that sprouts after the larger limb is truncated is more weakly attached.
- **Insects & Disease**: Stubs are highly vulnerable to insect invasion and the spores of decay.
- **Tree Death**: Reduced foliage can result in the death of the tree.
- **Rapid New Growth**: Results in many water sprouts that makes the tree return to its original height in a very short amount of time.
- **Ugliness**: Topped tree is disfigured.
- **Cost**: Topping is cheaper than pruning in short run but the costs are more in the long run.
- **Shock**: Suddenly removing this shield protection from the sun results in scalding. This can have an effect on the trees around it that thrive in shade.
Lion Tailing by Over-Thinning the Center

Lion tailing is caused by removing large amounts of inner foliage from a tree so the only remaining foliage is on the edge of the crown (Figure 5.17). This can cause sun scalding, stress the tree, and increase the likelihood of a branch breaking.\textsuperscript{cv}

Figure 5.17 Lion-tailing
Not Making Undercuts on Large Branches

Ripped bark usually occurs when the Three-Point Cut is not used on larger branches. The weight of the branch causes the branch and bark to rip off, damaging the trunk or branch of the tree (Figure 5.18). Always make an undercut before making the overcut when cutting large branches with a saw.

![Figure 5.18 Ripped bark from not following the 3-point cut method](image)

Applying Wound Dressing

Don’t apply wound dressing to a pruning cut. Research doesn’t support its use of aiding in sealing off cuts. In most cases it inhibits the tree from naturally closing the wound and it can keep the cut moist which will invite disease. For large trunk damage, a better solution is to cover the damaged area with a thick opaque plastic wrap. This will aid in the trunk forming a callus to seal the wound.
Pruning More Than 25% of the Canopy

For most cases, more than 25% of the canopy should not be removed during pruning. If more than 25% of branches are removed, the tree will become stressed and respond by sending up weakly attached water sprouts (Figure 5.19).

Figure 5.19 Water sprouts growing off a branch

When to Hire a Professional

In some situations, a homeowner should hire a certified landscape professional or a certified arborist. The main reasons, not all, are when trees are growing into utility lines, when a tree needs to be removed, and when pruning requires specialized gear and skills (climbing into a tree with climbing gear to remove branches).
Shrub Pruning

Shrub pruning follows the basic principles as pruning a tree, just at a smaller scale. Generally, shearing a shrub is not recommended because it causes growth to occur only on the outside of the plant, forming a shell of leaves on the outside and no growth on the inside. To avoid this issue, open up the shrubs by making selective thinning cuts to allow for sun to penetrate into the middle of the shrub (See Figure 5.20).

Figure 5.20 What to do when pruning shrubs and what not to do

When pruning hedges make sure the base of the hedge is wider than the top. This will let light get to all the leaves, including at the bottom, so the shrub can grow full and healthy (See Figure 5.21). Avoid making the top wider or even having a straight edge box shape. The ideal shape is one that is narrower at the top and wider at the base as shown in Figure 5.22.
Fruit Pruning

Pruning trees, shrubs, and vines to produce fruit differs from pruning ornamental trees. For specific direction on fruit pruning as well as how to prune specific types of fruit trees see the following resources:

- Utah State University: *Pruning the Orchard*  
  https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1724&context=extension_histall

- University of California–Davis: *Fruit Trees: Training and Pruning Deciduous Trees*  

- University of California: *Pruning & Training*  
  http://homeorchard.ucanr.edu/The_Big_Picture/Pruning_&_Training/

- Penn State: *Fruit Tree Pruning - Basic Principles*  
  https://extension.psu.edu/pruning-basics
Mulching

What

Mulch is a material that is placed around trees and shrubs. It can be an inorganic mulch like stones or an organic mulch like shredded bark, wood chips, pine needles, ground-up organic material, etc. Some benefits of mulches include reducing weed competition, limiting damage from mowers and weed trimmers, and providing visual appeal. Because organic mulches are decomposable, they improve the soil compared to inorganic mulches.

Organic mulches are spread around a plant to help improve the quality of the soil. It is used typically to hold in more water and nutrients, as well as improve soil structure by alleviating compaction and adding organic matter. Typically, a mulch with aggregates of about 1–2 inches are preferred because fine mulches can compact and prevent the movement of water, oxygen and nutrients to the soil.

Where

A general recommendation is to mulch from the trunk to the drip line of the tree. A more specific recommendation is to have a minimum 3-foot radius of protected mulch for young or small trees and a minimum radius of at least three times the diameter of the trunk for large trees. This means that a tree with a 2-foot trunk diameter would have at least a 6-foot radius mulch area.

When mulch is applied it must not be placed against the trunk of the tree to cover the root flare. The root flare needs to stay dry and exposed in order to
avoid pathogens and pests. At all times, the root flare must be visible. Keep mulch at least 4 inches away from the trunk. Figure 5.23 shows the proper techniques of mulching and compares these to improper mulching.

*Figure 5.23 Bad and good mulch rings around trees*

**How Much**

When applying and maintaining mulch it should reach a depth of 2–4 inches. It is better to apply mulch wider than deeper. Mulch will naturally decompose and add nutrients to the soil so it must be replaced periodically.

Never use anything that will prevent water and air from moving into the soil such as plastic sheeting or a tarp. This will cut off much needed oxygen, water, and nutrients, prevent organic matter from being incorporated into the soil, cancel out the benefits of using mulch, and even hinder tree growth.
Flowers add color and excitement to the landscape. They bring a rich diversity of aesthetics to the landscape, but this comes at a cost. Maintaining flowers can often take a lot of time and care. The main practices in promoting healthy flowers include proper watering, fertilizing, and weeding.

**DO**
- Dead-head flowers to make their bloom period last longer

**DON’T**
- Plant the wrong flower in a garden that is not adapted to the local environment

**Annuals & Perennials**

Flowers are generally grouped into two main categories: annuals and perennials. The difference between the two is their life cycle in one year. Figure 6.1 shows the difference between the two. Annuals complete their entire life cycle from seed to flower in one year. After their flowering the plant will die. Perennials, on the other hand, complete their life cycle each year, but they don’t die at the end of each year. Instead they go into dormancy and store energy in their roots or root-like structures. The next year they will send out new growth from the roots.
Figure 6.1 Annual and perennial life cycles

In flowering time, perennials bloom for a few weeks during a certain time of the year. After that period, the plant loses its flowers. Annuals will stay in bloom for a long time providing color throughout the season.

Most annuals do best in slightly acidic soils with a pH of 5.8–6.8.

**Watering**

Generally, perennial flowers need at least 1 inch of water each week during the growing season. Make sure to water deeply so water can get down to the roots. Flowers generally require more water than other landscape plants.
Fertilizing

Flowers generally require less nitrogen (used in green, leafy growth) and more phosphorous (used in flower and root growth). Table 6.2 gives general fertilizer recommendations for flowers.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Annual &amp; perennial flower beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>2–4</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>2–3</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>2–4</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.2–0.4</td>
</tr>
<tr>
<td>Calcium (Ca) &amp; Magnesium (Mg)</td>
<td>Rarely deficient if pH is managed correctly</td>
</tr>
<tr>
<td>Micronutrients</td>
<td>Follow label directions of various fertilizers</td>
</tr>
</tbody>
</table>

Values are in pounds of actual nutrient per thousand square feet annually, lbs X/1000 ft²

Table 6.2 Fertilizer recommendations for flowers

For perennials, a good fertilizer mix is 5–10–5 which contains 5% nitrogen, 10% P₂O₅, and 5% K₂O. This is applied around the perimeter of the plant in a circle, a technique called side-dressing. Fertilizer should be applied in the spring and also in the early summer. When fertilizer is applied, water it into the soil to prevent nutrient loss and to make it available for flower growth.

Many annuals will bloom throughout the summer without additional fertilizer. A good fertilizer mix for annuals is 5–10–10. This is best applied when the annual flowers are planted because fertilizer can be worked into the soil. For regions that have longer and hotter growing periods a second application may be needed to promote flower growth and health.
Mulching

Mulching is also a helpful practice because it enriches the soil, prevents weed growth, conserves water, and adds nutrients. Add a layer of 1–2 inches for annuals and 2–3 inches for perennials throughout the flower bed.\textsuperscript{cxxvi}

Weeding

Weeds compete with flowers for nutrients, water, sunlight, and space. In the early spring, remove any weeds to prevent them from competing with flowers and producing weed seeds.

Dead-Heading, Pinching, Disbudding

Pinching encourages some annuals and perennials to grow more flowers. Pinching will force plants to produce more growth to create more blooms. Plants will become bushier and flowers will be smaller, but with more blooms. Pinching is done by pinching off stem tip growth in the spring (Figure 6.3).\textsuperscript{cxxvii}
Dead-heading is a practice that removes flowers that are dead or dying by cutting off the dead flowers (Figure 6.4). This is done to remove flowers that don’t look good and to encourage new flower growth. It also prevents the flower from going to seed. This is important because plant will stop creating flowers once they go to seed. By dead-heading flowers, the plant will often continue blooming which will extend the length of flower blooms. When dead-heading, cut down the stem below the flower.
For flowers that have many small stems, the effects of dead-heading can be achieved by shearing. Shearing cuts back the small flowering plants and encourages new flower growth.\textsuperscript{cxxxix}

A practice opposite to pinching is disbudding. Instead of promoting many small flowers, disbudding encourages fewer, but larger flowers. This is best used to create a focal point. It can only be done on flowers that grow in groups. Disbud plants by removing side buds (Figure 6.5) so the plant can put energy into creating a large central flower.\textsuperscript{cxxx}
Winter Preparation

Because perennials grow back from their roots each year, the roots must be protected for a winter season. In locations where temperatures drop below 20°F, it is beneficial to cover perennial flowers with mulch. This will insulate the roots and protect them from damaging frost and soil heaving. (Heaving happens when the soil freezes and thaws and freezes, causing soil to move and break plant roots.)

To prepare perennials for winter, wait until the first killing frost has occurred. After this frost, cut back all perennial stalks to 3–4 inches above the ground. Then remove and clean the flower bed to remove plant material which may contribute to insects and disease. After the soil is frozen, it must be
insulated. Snow typically performs this task very well if average snow depths will stay at about 4 inches throughout the winter. In places where snow won’t be present throughout the winter, it is helpful to add 2–3 inches of mulch to the bed. (Tree leaves are often useful for this purpose because they are readily available from existing trees in the yard.) Wait until the ground is frozen before adding mulch. If mulch is applied before the ground is frozen it can invite rodents.\textsuperscript{cxxxii}

Annuals complete their life cycle every year so they die during the winter. In the fall, remove all annual plants to discourage diseases.

**Ornamental Grasses**

Although not flowers, the practices for maintaining ornamental grasses is similar to perennials except that they require less maintenance. During the spring, cut the stalks back to about 6 inches. This will promote new growth and remove last year’s growth. Follow the watering and fertilizing practices mentioned above. Please note that some ornamental grasses are more drought tolerant and may not require as much water and fertilizer. Follow directions for specific ornamental grass maintenance on plant labels.\textsuperscript{cxxxiii}
Appendix

Appendix 1: Additional Resources

National Associations

Most of these associations have information that can be purchased at their store or they have an education, resource, training, or media tab that offers free information.

- Landscaping
  - NALP (National Association of Landscape Professionals)
    https://www.landscapeprofessionals.org
- Soils
  - SSSA (Soil Science Society of America) https://www.soils.org
- Irrigation/Water Management
  - IA (Irrigation Association) https://www.irrigation.org
- Pest Management
  - NPMA (National Pest Management Association)
    https://npmapestworld.org
  - Pest World https://www.pestworld.org
- Tree Care
  - TCIA (Tree Care Industry Association) https://tcia.org
  - ISA (International Society of Arboriculture) http://www.isa-arbor.com
- Trees Are Good [https://www.treesaregood.org](https://www.treesaregood.org)
- Flower Care
  - SAF (Society of American Florists) [https://safnow.org](https://safnow.org)
- Gardening
  - AHS (American Horticultural Society) [http://ahsgardening.org](http://ahsgardening.org)
  - NGA (National Gardening Association) [https://garden.org](https://garden.org)
  - APGA (American Public Gardens Association) [https://publicgardens.org](https://publicgardens.org)
  - ACGA (American Community Gardening Association) [https://communitygarden.org](https://communitygarden.org)
- Snow Removal
  - SIMA (Snow & Ice Management Association) [https://www.sima.org](https://www.sima.org)

**State Extension Services**

State extension sites are run by agricultural universities in each state. Although the quality between state extensions can differ, they often offer more specific information about how to care for landscape plants and materials in a region. To find a local state extension, search the internet with: “(Current state) extension service.”
# Appendix 2: Essential Plant Elements

## Non-mineral Elements

<table>
<thead>
<tr>
<th>Essential Element</th>
<th>Plant Available Form</th>
<th>Function</th>
<th>Deficiency Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-Mineral Elements</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>Carbon dioxide (CO₂)</td>
<td>Basic building block of plant life</td>
<td>NA</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>Air (O₂), Water (H₂O)</td>
<td>Used in respiration or the production or energy, used in many compounds that are used for plant-growth processes.</td>
<td>NA</td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td>Water (H₂O)</td>
<td>Used in many compounds needed for plant growth.</td>
<td>NA</td>
</tr>
</tbody>
</table>

## Mineral Primary Macronutrients

<table>
<thead>
<tr>
<th>Essential Element</th>
<th>Plant Available Form</th>
<th>Function</th>
<th>Deficiency Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>Nitrate (NO₃⁻), Ammonium (NH₄⁺), Urea [CO(NH₂)₂]</td>
<td>Increases green leafy growth and gives darker color for leaves. Used to create amino acids which create proteins, needed for chlorophyll, nucleic acids, &amp; enzymes.</td>
<td>Leaves/Needles are yellow-green, small &amp; thin, and drop early in fall. Slow growth &amp; stunted plants. Death of the edges of leaves starting on mature leaves.</td>
</tr>
<tr>
<td>Phosphorous (P)</td>
<td>Phosphate (H₂PO₄⁻), Hydrogen Phosphate (HPO₄²⁻)</td>
<td>Stimulates seedling development and root formation.</td>
<td>Leaves are very dark green or a purplish color. Plant growth is slow. Delayed</td>
</tr>
<tr>
<td>Mineral Secondary Macronutrients</td>
<td>Secondary Macronutrients</td>
<td>Macronutrients</td>
<td>Macronutrients</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>Potassium ion (K⁺)</td>
<td>Increases root growth and improves disease resistance. Improves fruit size &amp; quality and winter hardiness. Moves sugars and creates starch. Controls stomata on leaves. Creates larger xylem vessels in the root system.</td>
<td>Leaves have chlorosis (yellowing) on the edges and between the veins. Slow plant growth. Weak stems and small fruit &amp; seeds.</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>Calcium ion (Ca²⁺)</td>
<td>Used in cell walls, cell membranes, and creation of new cells.</td>
<td>Young/new leaves have dead tips. Growing points die (terminal buds, root tips). Dark green foliage. Blossoms and buds shed early.</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Magnesium ion (Mg²⁺)</td>
<td>Used in photosynthesis in the chlorophyll molecule. Activator for plant enzymes.</td>
<td>Older leaves yellow between veins, are thin, and drop early. Leaves curl up along the margin. Margins yellow.</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>Sulfate (SO₄²⁻)</td>
<td>Used in amino acids so necessary for protein creation.</td>
<td>Slow growth rate and late maturity. Young leaves are light green-yellow. Plant growth is spindly and small.</td>
</tr>
</tbody>
</table>

*Mineral Micronutrients*
<table>
<thead>
<tr>
<th>Element</th>
<th>Ion Form</th>
<th>Uses</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc (Zn)</td>
<td>Zinc ion (Zn(^{2+}))</td>
<td>Used in enzymes and indoleacetic acid which is a plant growth regulator.</td>
<td>Terminal growth area decreases. Fruit bud formation is reduced. Twigs dieback after 1(^{st}) year. Leaves are uniformly yellow. (Seen in alkaline and calcareous soils.)</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>Iron ion (Fe(^{3+}))</td>
<td>Used in chlorophyll. Activator for processes such as respiration, photosynthesis, &amp; N fixation.</td>
<td>(Most common micronutrient deficiency.) Common in areas with high levels of Mn or lime and in high pH soils. Young leaves have interveinal chlorosis with green veins. Older leaves remain green. Twigs dieback.</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>Manganese ion (Mn(^{2+}))</td>
<td>Activator for enzymes. Used in chlorophyll creation.</td>
<td>Interverinal chlorosis of young leaves. Common in calcareous soils.</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>Copper ion (Cu(^{2+}) or Cu(^{+}))</td>
<td>Activator of enzymes. Vitamin A production.</td>
<td>Stunted growth. Terminal shoots dieback. Wilting and death of leaf tips.</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>Borate (H(_2)BO(_3)^-) or Boric acid (H(_3)BO(_3))</td>
<td>Used in the differentiation of meristematic cells. Regulates metabolism in carbohydrates.</td>
<td>Death of terminal growth. Thickened, curled, wilted, and chlorotic leaves. New growth is bushy &amp; thick. Reduced flowering.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Formula</th>
<th>Function</th>
<th>Sign of Deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molybdenum (Mo)</td>
<td>Molybdate (MoO₄⁻)</td>
<td>Used in the utilization of N.</td>
<td>Light green leaves. Stunted growth and lack of vigor. Cupping, rolling, and burning of leaf edges.</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>Chloride ion (Cl⁻)</td>
<td>Used in photosynthetic reactions. Regulates cell turgor.</td>
<td>Small leaves with tip and margin burn.</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>Nickel ion (Ni²⁺)</td>
<td>Used in enzyme urease to convert urea to ammonia. Helps N metabolism.</td>
<td>Young leaves yellow. Meristem dies.</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td>Cobalt ion (Co²⁺)</td>
<td>Used in enzymes. Affects growth and metabolism.</td>
<td>Uniform pale green color on leaves.</td>
</tr>
</tbody>
</table>

*Please note that micronutrients are rarely deficient and generally only need a small amount to correct the issue.*

cxxiv cxxv
Appendix 3: Fundamental Soil Test Interpretation

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Brigham Young University

Soil testing is a valuable tool that can help guide fertilizer decisions and aid in soil management. The following is a guide to help interpret soil tests.

1) Take a **good soil sample**. Decide on the number of samples to take. Each sampling area should be unique. Do not combine unique areas, as this will make the sample results invalid. For example, do not combine the garden area with the lawn, or the fairways with the greens for golf courses. Sample problem areas separately for diagnostic purposes if the problem is related to soil chemistry. Insert the probe into the soil to the depth of primary rooting (usually 4–6 inches for turf, 8–10 inches for the depth of tillage in gardens, etc.). See **Soil Sampling Instructions for Home Owners**. Samples cost between $20 and $50 each, plus shipping.

2) Evaluate **pH**: Ideally the pH should be between 6.5 and 7.0. If the pH is highly acidic (less than 6.2), apply finely ground limestone or other material that will raise pH (unless the species prefers acid soil). Limestone generally contains calcium and magnesium combined with carbonate. The carbonate raises the pH and the calcium and magnesium displace the acid causing hydrogen ions in the soil. Calcium and magnesium are rarely deficient, but are most likely to be so in acidic soils (especially sands) — adding lime (CaO) generally corrects deficiency of these nutrients. If establishing turf, it is important to apply the entire amount of recommended lime (CaO), which is based on a separate buffer pH test done by the lab. For established turf, apply no more than 50 lb-lime per
1000 ft² during the cool part of the season, twice a year until the problem is corrected. It may take several years to correct the problem, especially on soils with high clay and/or organic matter content. High nitrogen and water application rates tend to lower the pH over time, so it is not unusual to have to continually treat acid soils over time.

a. Alkaline or high soil pH can be corrected by adding acid or acid forming materials. It is very important not to add high rates of these materials to established turf. The most common method of lowering pH is to apply elemental sulfur, which oxidizes through microbial activity and generates sulfuric acid in the process. Unlike raising soil pH, lowering it can be next to impossible due to the quantity of pH buffering minerals commonly present in the soil and irrigation water. The cost of lowering pH is generally prohibitive and, instead, the problems with alkaline soil can generally be solved by dealing with the nutritional problems caused by the high pH (particularly iron, phosphorus, manganese, zinc, and copper) through adding additional nutrients in proper forms and planting species/cultivars adapted to alkaline soil. Calcium carbonate (CaCO₃) is not very soluble at a high pH. High amounts of carbonate make a soil calcareous. Usually if the soil has a high amount of lime than it will be calcareous because the lime (CaO) contains calcium and carbonate.

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>pH range</th>
<th>Nutrient Deficiencies</th>
<th>How to Fix</th>
<th>Commonly Found</th>
<th>Applying Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic Soil</td>
<td>0–6.2 pH</td>
<td>Calcium (Ca), Magnesium (Mg)</td>
<td>Apply limestone or calcium carbonate (CaCO₃)</td>
<td>High rainfall areas, sandy soils. No more than 50 lb lime (CaO) per 1000 ft² twice a year in the cool season.</td>
<td>High nitrogen and water application rates lower pH.</td>
</tr>
</tbody>
</table>

CaCO₃
3) Evaluate **salts**: Salt problems are generally found in alkaline soils common in the western US. Ideally the soil EC (Electrical Conductivity), which is a measure of salt content, is less than about 1 mmho/cm, with plant desiccation occurring as the salt content increases. A soil is considered “saline” if it has an EC greater than 4 mmho/cm or dS/m. Generally salt problems are due to poor irrigation water with high salt content. If the soil salt concentration is high, the irrigation water should be tested. Mild problems can be managed through leaching of the salts through the soil with excess irrigation water and/or planting of salt tolerant species/cultivars. Drainage problems can prevent leaching and may need to be corrected prior to leaching. Severe salt problems in the irrigation water may need to be solved through mixing with a high quality water source.

4) Evaluate **sodium (Na)**: As with salts, sodium problems are found almost exclusively in alkaline soils. The ESP (Exchangeable Sodium Percentage) is an indicator of potential sodium problems. ESP values greater than 15% are generally associated with severe destruction of the soil structure, causing water infiltration problems. However, it is essential to not let the soil reach this point. If the ESP is greater than about 5%, more in-depth analysis should be performed by laboratory personnel skilled in dealing with sodic (sodium affected) soils. These technicians will perform a Sodium Absorption Ratio (SAR) test and, potentially, other tests that will aid the diagnoses of the severity of the problem (the ESP test is only an
indicator test). If the SAR value is high (greater than 12 is considered “sodic soil”), a recommendation for gypsum (CaSO₄) or another soluble calcium source will be needed. The calcium will displace sodium on the soil exchange complex, thus lowering the percentage of sodium. Another method is to add acidic materials to the soil or water to convert carbonate to carbon dioxide, thus increasing the soluble calcium content. As with salt problems, the source of sodium problem is generally related to poor irrigation water and drainage issues.

a. Steps to Fix:
   i. Determine source of sodicity and correct if possible.
   ii. Take action (tillage, add drainage pipes, etc.) to make certain that the soil will take in water and be able to drain.
   iii. Add a soluble calcium (Ca) source, such as gypsum (CaSO₄).
   iv. Leach the soil to replace the sodium (Na) with Ca.
   v. Retest the soil and water periodically for monitoring purposes.

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Measure</th>
<th>Cause</th>
<th>How to Fix</th>
<th>Commonly Found</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline Soil</td>
<td>EC (Electrical conductivity) &gt; 4</td>
<td>Poor irrigation water high in salts</td>
<td>Improve drainage, leach soil with excess water, improve water quality, use salt tolerant plants</td>
<td>Alkaline soils, western USA</td>
<td>Desiccation of plants</td>
</tr>
<tr>
<td>Sodic Soil</td>
<td>ESP (Exchangeable Sodium)</td>
<td>Poor irrigation water and</td>
<td>Add gypsum (CaSO₄) or soluble</td>
<td>Alkaline soils</td>
<td>Soil structure destroyed causing</td>
</tr>
</tbody>
</table>
5) Evaluate **nitrogen (N)**: There are many forms of N in the soil, but nitrate (NO$_3^-$) is the form most commonly utilized by plants and, therefore, is most commonly used in soil test evaluations. Unlike most other nutrients, basing a fertilizer recommendation off of the nitrogen soil test value is generally not useful due to the transient nature of nitrate. Instead, the nitrate test can be used to monitor whether excess N is being applied (assuming that excessive irrigation isn’t moving it out of the rooting zone). Values for nitrate are commonly between 5 and 15 ppm (parts per million). Values much higher than this likely indicate excessive application due to fertilization and/or high nitrate-containing irrigation water. Irrigation water should be tested for nitrate with suitable adjustments in the fertilizer plan if it is suspected that the water has high concentrations of nitrate. High soil nitrate values in problem areas may also indicate that plants are not growing actively and, thus, not taking up nutrients. In general, it is best to develop an N fertilization program and follow it, using soil testing periodically to monitor for excess. Ideally, N should be spoon fed throughout the season. For warm season grasses, about 1 lb-N per 1000 ft$^2$ should be applied for each month of active growth. Cool season grasses need about 1 lb-N per 1000 ft$^2$ during the spring green up and another 1 lb-N per 1000 ft$^2$ during the late spring/summer. An additional 3 lb-N per 1000 ft$^2$ should be applied through the fall (minimum of 2 separate applications), with a slightly higher rate applied after air temperatures have lowered and shoot growth has nearly ceased, but while photosynthesis and root growth is still
occurring, Slow- or controlled-release fertilizers can be used to give a steadier supply of N to the plants.

6) Evaluate **phosphorus (P):** The P soil test should be used to monitor levels of this nutrient over time. Ideally, this nutrient should be built up to medium levels and then maintained at that level over time. The target values for the three most common P soil tests for most species are: 16–22 ppm Mehlich III, 15–20 ppm Bray P1, and 10–12 ppm Olsen (bicarbonate) (Bray P1 should only be used on non-calcareous soils—i.e. those lacking the presence of free excess lime.) Building the P concentration in the soil well above these values represents a potential environmental hazard, a waste of natural resources and favors annual bluegrass and other weeds over turfgrass. For turfgrass establishment, apply 2–5 lb-P₂O₅ per 1000 ft², with higher rates required for the lowest soil test concentrations. For established turf, apply 1–3 lb-P₂O₅ per 1000 ft² until the target range is met and then apply just enough to maintain this value (relatively more required if clippings are removed and/or if the soil pH is very acidic or very alkaline). In the case of alkaline soils that also are calcareous, relatively higher rates of P fertilizer will need to be applied to maintain P nutrition (approximately 1 lb-P₂O₅ per 1000 ft² additional will have to be applied for every 4% lime content in the soil). Phosphorus can be spoon fed over the course of the season, but the best time for high soil P availability is during the time prior to dormancy. The rates listed here are based on aesthetics for high value landscapes. Much lower rates can be used for low maintenance situations. Fertilizer rates for sod production are also different and should be based on locally developed soil test calibration.

7) Evaluate **potassium (K):** As with P, the K soil test should be used to monitor levels of this nutrient. Unlike P, excessively high levels of soil K are generally not detrimental to turfgrass or the environment. However, application of K when it is not needed is a waste of resources. In very rare
cases of acidic sands with very low CEC, extremely high K levels can inhibit calcium and magnesium uptake. As with P, there are differing soil tests available for K, but the differences in interpretation can be mostly ignored for most circumstances (not sod production). In general, potassium fertilizer should be applied at 2-5 lb-K₂O per 1000 ft² until the soil test concentration reaches 200-250 ppm.

8) Evaluate sulfur (S): The soil test for sulfur is not well correlated to uptake. A better measure of whether or not S fertilizer is needed is the organic matter percentage (OM) and the cation exchange capacity (CEC) and/or soil texture. Soils with high OM and/or CEC rarely show dramatic response to S fertilizer, but sandy, low OM soils often require S for optimum color in turfgrass. Some irrigation water sources can be high in S and negate the need to apply S fertilizer. Turf grown downwind from industrial areas has been shown to receive adequate S from air pollution deposition (acid rain) in the past, although air quality standards have resulted in less deposition from these sources. Some soils are naturally high in S from minerals containing this nutrient. The value of the S soil test is that it can show when additional S fertilizer is not needed (generally none needed if the value is greater than 25 ppm), however, low soil test S does not necessary mean a response will be observed.

9) Evaluate iron (Fe): As with S, the Fe soil test is not the only standard of measure to use when deciding whether or not to apply Fe fertilizer. Values above 5 ppm are generally considered adequate, but it is common to get a visual response on turfgrass to Fe fertilization at soil test concentrations above this value. And, it is also common to not see a visual response to values below this value. The soil pH is a much better indicator of Fe status. Soils with alkaline pH have almost no plant available Fe, although plants adapted to growing in these soils have developed physiological mechanisms to assist with extraction of Fe from the soil. High maintenance turfgrass grown at high soil pH almost always has
repeated (every week or two) applications of foliar Fe or application of chelated Fe periodically (every month or two). Application of Fe impregnated with elemental S is another strategy that can make Fe available to plants. Regular mineral sources of Fe fertilizer are not generally very effective, because the Fe precipitates dissolve almost immediately after applying. Rates of Fe fertilizer are generally found on the fertilizer label.

10) Evaluate zinc (Zn), manganese (Mn), copper (Cu), boron (B), and chloride (Cl): Deficiencies of these nutrients are rarely documented in turfgrass and application is not warranted by soil test alone. Other species, especially annuals, are more likely to be deficient. As with Fe, deficiencies of all of these nutrients (except Cl) are more common on alkaline soil. Concentrations below 1.0–1.5 ppm Zn, 4.0–8.0 ppm Mn, 0.3–0.5 ppm Cu, and 0.5–1.0 ppm B are generally warning levels for when deficiencies may occur. Chloride deficiencies are rare because many potassium fertilizers contain Cl, as well as many irrigation water sources. Some managers have been convinced that Cl containing K fertilizers are bad due to salts. Switching to other sources completely can eventually result in a Cl deficiency if the irrigation water does not contain adequate amounts.

11) Evaluate calcium (Ca) and magnesium (Mg): See pH discussion above. Most Ca and Mg deficiencies occur in sandy acidic soils and liming to raise pH generally supplies enough of these nutrients to meet plant needs. In rare cases, non-acidic soils are deficient and need fertilizer application of these nutrients when Ca values are less than about 400 ppm and Mg values are less than 100 ppm.

These guidelines are general in nature and do not apply to all circumstances. Consulting with an expert in soil chemistry and turfgrass nutrition may be necessary in specialized circumstances.
Appendix 4: Irrigation Inspection

The following two pages contain an example of an irrigation inspection form and an irrigation system performance checklist.
# Irrigation System Inspection Form

<table>
<thead>
<tr>
<th>STATION</th>
<th>FACILITY:</th>
<th>CONTROLLER DESIGNATION:</th>
<th>CONTROLLER LOCATION:</th>
<th>IRRIGATION TYPE</th>
<th>BROKEN HEADS</th>
<th>CLOGGED HEADS</th>
<th>MISSING HEADS</th>
<th>SUCKEN HEADS</th>
<th>HIGH VEGETATION</th>
<th>HEADS NOT VERTICAL</th>
<th>MIXED HEADS</th>
<th>MIXED NOZZLES</th>
<th>HIGH PRESSURE</th>
<th>LOW PRESSURE</th>
<th>OVERSPLAY</th>
<th>VARIABLE SPACING</th>
<th>BROKEN PIPE OR FITTINGS</th>
<th>OTHER</th>
<th>NOTES</th>
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</table>

Source: Irrigation System Maintenance and Repair, U of A Cooperative Extension 194026, September 1995
## SPINKLER IRRIGATION EQUIPMENT PERFORMANCE CHECKLIST

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>WHAT TO LOOK FOR</th>
<th>SOLUTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clogged/broken/ missing</td>
<td>Brown spots. Standing water. Incorrect spray pattern. Water-stained asphalt or</td>
<td>Replace missing or broken heads and nozzles. Replace with the same type and performance head. Clean clogged nozzles. Select matched</td>
</tr>
<tr>
<td>nozzles or heads</td>
<td>sidewalk.</td>
<td>precipitation rate heads and nozzles. Institute a weekly after-mowing inspection routine.</td>
</tr>
<tr>
<td>Malfunctioning wiper seals</td>
<td>Water spraying from base of head.</td>
<td>Replace wiper seal or replace entire head with same type and brand.</td>
</tr>
<tr>
<td>Sunken heads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head rotation out of adjustment</td>
<td>Brown spots. Excessively wet areas.</td>
<td>Adjust head so that each head is rotating correctly and at the same rate.</td>
</tr>
<tr>
<td>Heads not vertical or flush with grade</td>
<td>Standing water. Brown spots.</td>
<td>Adjust sprinklers to a vertical position that is flush with the soil grade. Compact soil tightly around the head. Swing joint installation may be required.</td>
</tr>
<tr>
<td>Low head drainage</td>
<td>Draining water after system is turned off. Excessively wet spot.</td>
<td>Install check valves at low heads.</td>
</tr>
<tr>
<td>Low pressure</td>
<td>Water sprays in large droplets. Rotor sprays rotate slowly. Pop-up sprays slow  to</td>
<td>Install lower flow nozzles. Make sure two stations are not operating at the same time. Increase the setting at the pressure reducing valve. Check for broken pipes or fittings. Reduce number of heads on the line and install another valve. Increase the size of line components. Install booster pump.</td>
</tr>
<tr>
<td>High pressure</td>
<td>Green &quot;doughnuts&quot; around head.</td>
<td></td>
</tr>
<tr>
<td>Overspray</td>
<td>Water mists, drifts, and evaporates. Overspray on paved areas.</td>
<td>Install pressure regulating valve. Turn the flow control stem down. Use spray nozzles with pressure compensating devices. Install pressure compensating inserts in spray head.</td>
</tr>
<tr>
<td>Variable spacing</td>
<td>Brown spots. &quot;Scallops.&quot; Excessively wet areas.</td>
<td>Adjust nozzles and pressure. Determine manufacturer’s recommended spacing. Relocate and add heads. Or change to heads or nozzles that perform at the measured spacing and pressure.</td>
</tr>
<tr>
<td>Broken pipe or fittings</td>
<td>Standing water. A washed-out hole.</td>
<td>Fix pipe. Replace fittings with a flexible swing joint. Flush soil from system.</td>
</tr>
</tbody>
</table>

Source: Irrigation System Maintenance and Repair, U of A Cooperative Extension 194026, September 1995
References


xl "Chapter 12: Nutrient Management, 281."


"Chapter 12: Nutrient Management, 281."