Nutrient BMPs for Golf Courses in Louisiana and Mississippi

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Importance of developing and implementing fertility plans and best management practices for golf courses

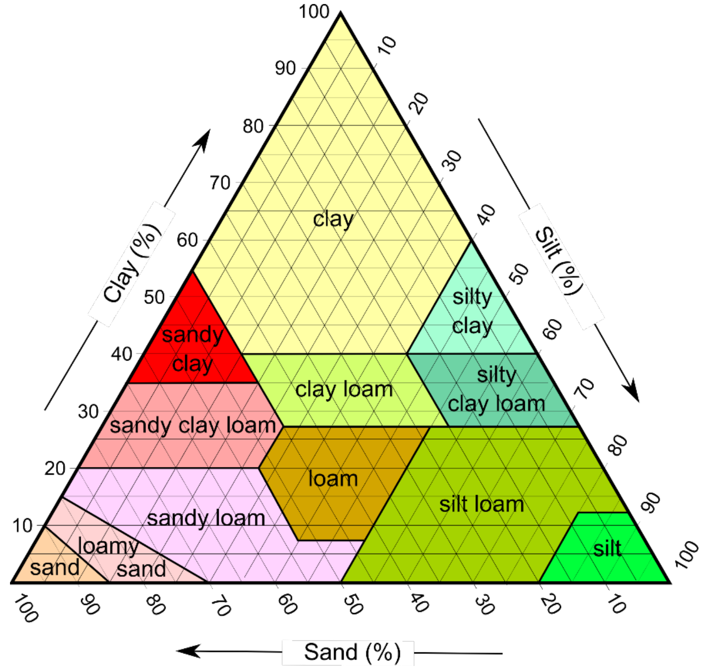
Golf courses in Louisiana and Mississippi provide recreational areas for many communities. These turfgrass areas are intensely managed to provide both suitable aesthetics and playability. As a part of any turfgrass management program, fertilizers are often needed to grow a healthy, dense turf. However, improper application of fertilizers can have negative impacts on turfgrass growth and surface and ground waters. Essential plant nutrients, such as nitrogen and phosphorus, can become pollutants. Excessive nutrient concentrations in water can accelerate algae and plant growth in streams, lakes and ponds, resulting in oxygen depletion or critically low dissolved oxygen levels. This condition is referred to as nutrient enrichment or hypoxia and is a major concern in many water bodies along the Gulf of Mexico. By developing and implementing knowledge-based fertility plans and best management practices, golf course superintendents can provide a healthy, aesthetically pleasing turf, protect the environment and, in some cases, save money.

Soil basics

Soil texture can greatly affect nutrient availability, retention and movement within turfgrass systems. Therefore understanding some basic soil terminology and physical and chemical characteristics is beneficial when developing fertility plans. The following section was written to give a brief overview of soil properties and characteristics. More in-depth information concerning soils can be found at sources listed in the reference section of this document.

Soil composition

Soils are composed of biotic (living) and abiotic materials. For this section the mineral and organic matter will be briefly discussed. Mineral components of the soil can be categorized into sand, silt and clay. Particles larger than sand, such as gravel and stones, are not considered soil. Sand is the largest particle, followed by silt and then clay. The percentages of sand, silt and clay in a soil determine its texture. Using the United States Department of Agriculture (USDA) textural triangle, the soil texture can be determined:



Soils with different textures will differ in pore space, and this will affect water-holding capacity, hydraulic conductivity (water movement through the soil), gas exchange and tendency to compact (6, 7). These characteristics will affect cultural and fertility management of turfgrasses. Sands have more macropores compared to clays, which have more micropores. Macropores are pores with diameters larger than 0.6 mm and allow for greater water drainage and gas exchange (2). Micropores are pores with diameters smaller than 0.6 mm (2). Micropores are also known as capillary pores because these types of pores retain water within the soil. In general, soils with coarser textures have greater drainage, higher gas exchange and reduced tendency to compact but have lower water-holding capacities and CEC. However, soils with a finer texture generally have greater water-holding capacity and higher CEC but slow drainage, less gas exchange and increased tendency to compact.

Soil texture is important when discussing soil fertility and potential routes of nutrient loss. For example, a clay soil is more prone to surface runoff than sand, while sand is more prone to leaching than clay. Understanding how pore structure affects soil characteristics helps us to understand the benefits and management that are required to grow turfgrass.

Organic matter

All organic matter is composed of carbon. However, not all soil organic matter is the same. Soil organic matter can differ greatly depending on its composition and state of decomposition. Well-decomposed organic matter is known as humus. In perennial turfgrass systems, an organic thatch layer of living and dead plant material can form above and into the soil surface. Organic matter can affect soil characteristics, such as water hydraulic conductivity, cation exchange capacity, compaction, pH, buffering capacity and nutrient retention. In sand-based golf greens, organic matter is often added to increase water-holding capacity and CEC.

Role of cation exchange capacity

Cation exchange capacity (CEC) is the number of negatively charged sites in a soil (6). This is important because CEC sites allow the soil to hold and release cations into the soil solution and root rhizosphere for plant uptake.

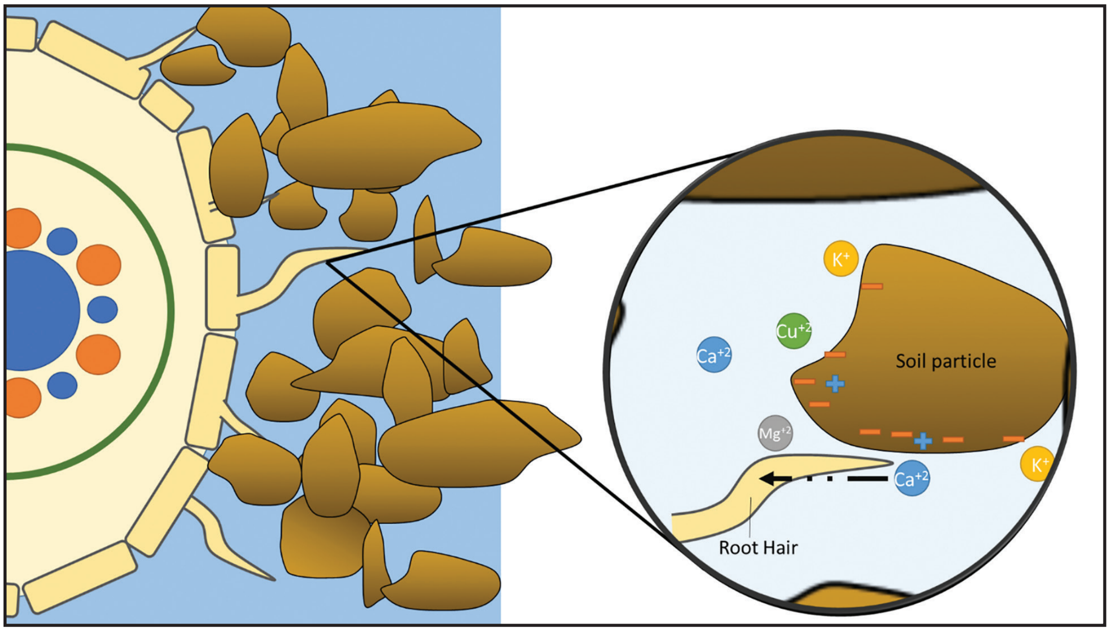
Examples of cations that are essential nutrients include Ca^{2+}, Mg^{2+}, K^{+}. Cation exchange capacity is affected by the type and amount of soil and organic matter present. In general, higher CEC is associated with finer textured soils and organic matter. However, differences in CEC do exist between fine textured soils, such as clays (e.g., 1:1 versus 2:1 clays), and the state of decomposition of the organic matter (2). Another factor that can greatly affect some soils and organic matter CEC is soil pH. This is known as pH-dependent CEC. The CEC of a soil can be measured by soil analysis laboratories if requested.

Higher soil CEC can reduce leaching losses of cations and help buffer the soil. Buffering capacity of a soil helps the soil to resist chemical changes, such as pH, that affect nutrient availability and microbial activity (2). Remember, microorganisms are involved in nutrient transformations in soil as well as decomposition of organic matter, such leaf clippings and thatch. Therefore, maintaining suitable environmental soil conditions is important to microbial activity.

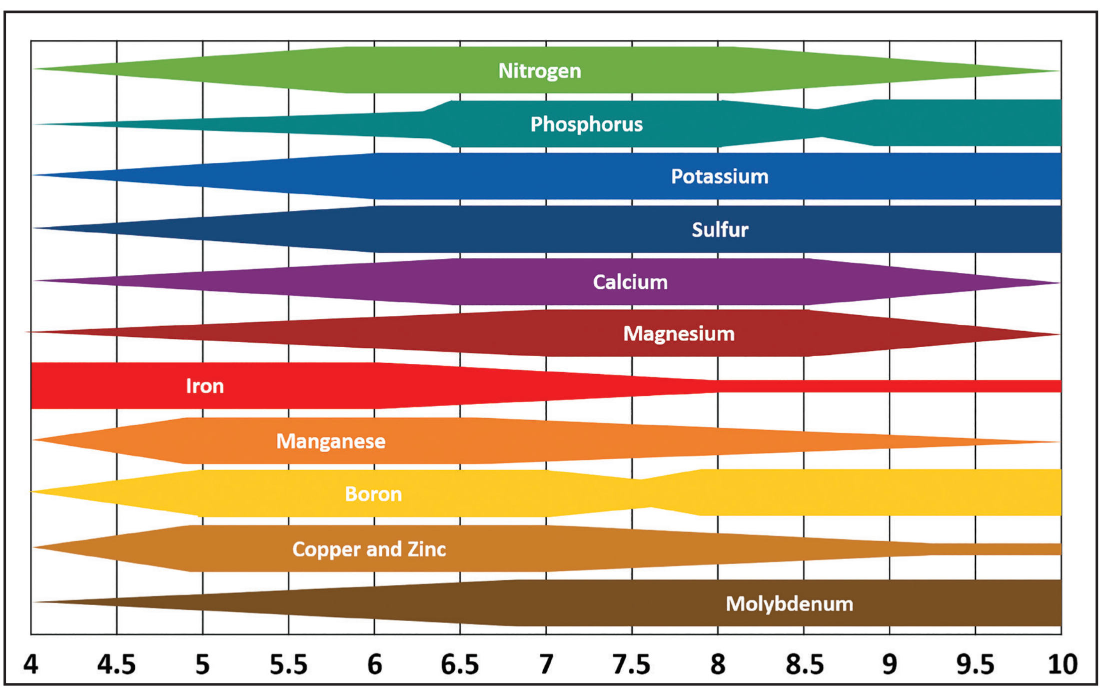
Role of soil pH

Soil pH is the measurement of the acidity or alkalinity of soil (6). Soil pH is the negative log of the concentration of H^+ and is measured on a 1 to 14 scale with pH 7 neutral, pH less than 7 acidic, and pH greater than 7 alkaline. The pH of soil can affect nutrient availability, elemental toxicities, microbial activity, and, consequently, turfgrass growth (7). Soil pH can be altered through the addition of lime or amendments that result in the addition of hydrogen to the soil (ex. Elemental sulfur, Urea, Ammonium Sulfate) . Lime (typically Calcium Carbonate) is used to raise soil pH and elemental sulfur or other acidifying amendments are used to lower soil pH. Additions of either compound should be based on the recommendations of a soil test, followed by proper application rates and frequencies to reduce potential plant damage.

Some fertilizers, such as ammonium sulfate, have acidifying effects on soil pH. Leaching of basic cations can also lead to changes in soil pH. The ability of a fertilizer to alter soil pH should be taken into account when developing a fertilizer plan.



Cation exchange capacity (CEC) is the total capacity of soils to retain and exchange cations (or positively charged plant nutrients). Relatively low CEC soils lead to limited available retention of nutrients and thus poorer soils for growing plants. CEC also influences soil buffering against soil acidification.

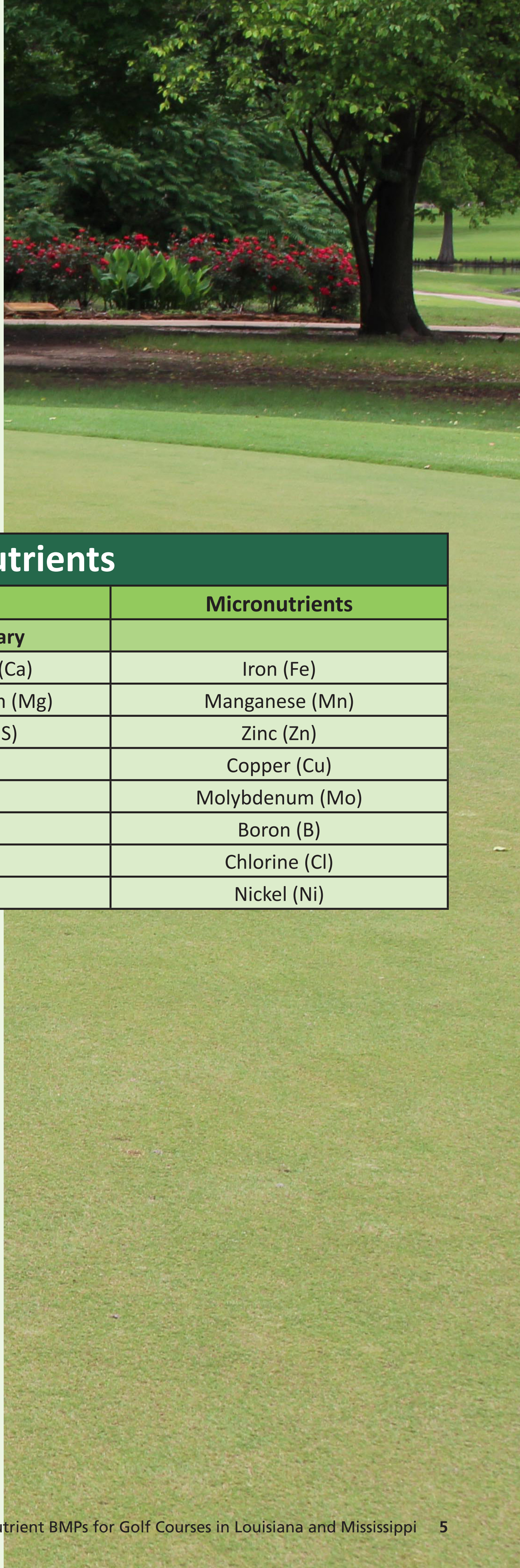


The soil pH range, or the acidity and alkalinity of a soil, affects plant available nutrients. A pH range of approximately 6 to 7 optimizes turfgrass health due to readily available nutrients.

Essential plant nutrients

Proper soil fertility is essential in maintaining healthy, dense turfgrass for recreation and aesthetics, as well as protecting the environment. However, management of turfgrass fertility requires knowledge in several areas, such as plant growth and nutrition, soils, fertilizers, and environmental conditions. Developing a fertility program for any turfgrass takes time with adjustments to the plan occurring over months or years. The following section was written to provide a basic overview of the essential nutrients for plant growth. More in-depth information can be found at sources listed in the reference section of this document.

Turfgrasses require 17 essential nutrients. Essential nutrients are defined as: nutrients that are needed for the plant to complete its lifecycle; an element that performs a function within the plant that cannot be substituted by another element; or an element that is directly involved in plant metabolism or required for an essential metabolic reaction (1).



Essential Plant Nutrients

Macronutrients			Micronutrients
Basic	**Primary**	**Secondary**	
Carbon (C)	Nitrogen (N)	Calcium (Ca)	Iron (Fe)
Hydrogen (H)	Phosphorus (P)	Magnesium (Mg)	Manganese (Mn)
Oxygen (O)	Potassium (K)	Sulfur (S)	Zinc (Zn)
			Copper (Cu)
			Molybdenum (Mo)
			Boron (B)
			Chlorine (Cl)
			Nickel (Ni)

Based on information from references 1 and 2

Macronutrients are essential nutrients needed in higher quantities for proper plant growth and development (1). The categorization of macronutrients also indicates that these nutrients often need to be applied as fertilizers at some frequency to maintain adequate available soil concentrations for a healthy turf. Micronutrients are also essential nutrients but are required in lower quantities relative to macronutrients (1). The quantity of a nutrient does not indicate its importance within the plant. Remember, all the nutrients listed are essential. Learning about essential nutrients, especially nitrogen and phosphorus, not only helps maintain a healthy turfgrass but can also potentially reduce fertility costs and movement of nutrients into surface and ground waters.

Basic nutrients

Carbon, hydrogen, and oxygen are essential basic macronutrients for plant growth because of their importance in plant structures and functions such as photosynthesis and respiration. Carbon, hydrogen, and oxygen can make up to 45 percent, 6 percent, and 45 percent, respectively, of turfgrass dry matter (2). These elements are obtained by the plant through CO_2 exchange (photosynthesis) and water uptake (5).

Primary nutrients

Nitrogen

Importance of nitrogen

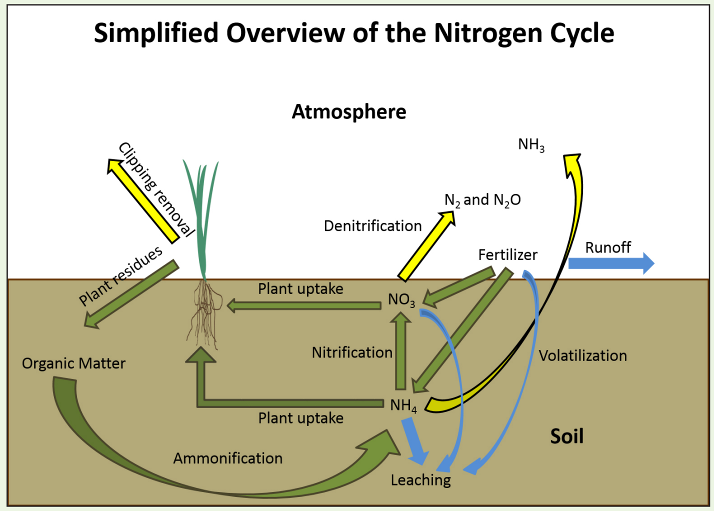
Nitrogen is often the most discussed and the most difficult-to-manage nutrient when developing turfgrass fertility plans. Nitrogen is required in the highest amounts by the plant, excluding carbon, oxygen and hydrogen. Nitrogen typically constitutes 2 to 5 percent of the turfgrass dry matter and is important in the synthesis of compounds, such as amino acids, proteins, chlorophyll, phytohormones and nucleic acids (2). These compounds are involved in the growth and metabolism of the turfgrass. However, compared to other essential nutrients, soil testing for nitrogen does not provide season-long predictions of available nitrogen (2). Therefore, nitrogen applications should be based on factors such as species, function or use of the turfgrass temperature, length of the growing season, soil type, soil organic matter content and other environmental factors (11).

Proper Nitrogen Fertility of Turf

1. **Increases shoot growth**
2. **Increases density**
3. **Increases rooting**
4. **Enhances color**
5. **Increases tolerances to drought, as well as cold and warm temperatures**
6. **Increases recuperation**

Response of turfgrass to nitrogen fertilization

Application of nitrogen to a turfgrass affects: shoot growth in terms of density, leaf extension, rhizome and stolon growth; root growth; color; tolerances to temperature, drought, compaction and wear; thatch accumulation; and recuperative potential (2, 5, 7). Providing the turfgrass with adequate nutrition allows the plant to properly grow and develop so that the turf provides a functional and aesthetic surface. Insufficient or surplus nitrogen can limit plant growth and affect the function and aesthetics of the turfgrass. Turfgrasses that are deficient in nitrogen often appear chlorotic with older leaves turning yellow and exhibiting slowed growth, reduced density and less stress tolerance (2). However, over application of nitrogen can lead to excessive growth, fertilizer burn from increased soluble salt concentrations and higher nitrogen losses (6).



The design of the nitrogen cycle is based on figures and information from references 1, 2 and 6.

Overview of the nitrogen cycle

Nitrogen can be found in air, soil and the plant. It is important to understand where nitrogen is found, the different forms of nitrogen and how nitrogen moves and transforms. Through this understanding of the nitrogen cycle, one is better able to apply cultural practices, management techniques and fertilizers for better turfgrass growth and function while also limiting nitrogen movement.

Nitrogen uptake

Nitrogen can be taken up by turfgrass roots or absorbed through leaves (foliar fertilization). Plant available forms of nitrogen include nitrate (NO_3^-), ammonium (NH_4^+) and urea (6). The predominant form for plant uptake from the soil is nitrate. Ammonium can be taken up by turfgrass roots, but ammonium generally is in very low quantities in the soil. Urea movement into the plant is often associated with foliar applications to highly managed turfgrasses (2, 7). Once available in the turfgrass, nitrogen is mobile within the plant.

Plant N taken up as NO_3^- and NH_4^+

Nitrogen in the air

Nitrogen in the air is primarily found in the form of N_2 with other gaseous forms, such as nitric oxide (NO) and nitrous oxide (N_2O), in much lower percentages (2). In general, these forms of nitrogen are not available to turfgrass.

Movement of nitrogen from soil, thatch or leaf surfaces into the air occurs through two processes: denitrification and volatilization. Although each process is the transformation of nitrogen into a gaseous form, there are differences concerning when and how these transformations occur. Learning the differences between the two processes can reduce nitrogen losses from turfgrass systems and increase nitrogen availability for turfgrass growth (see Nutrient losses for further details describing the conditions under which this occurs).

Nitrogen in the soil

Nitrogen mineralization is a process in which microorganisms release nitrogen from organic forms that can be used for plant growth.

The majority of soil nitrogen is contained in organic matter, meaning soils with higher organic matter tend to have higher nitrogen concentrations (6). However, not all nitrogen in organic matter is readily available to turfgrass. The complexity of organic nitrogen and microbial activity determine nitrogen availability. For example, lignified forms of organic matter are more slowly degraded for nitrogen release. Nitrogen added through supplemental fertilizers is not only available for plant uptake, but it is also used by microorganisms.

The process by which organic forms of nitrogen are transformed into available forms of nitrogen is known as mineralization. The mineralization process involves aminization, ammonification and nitrification (6). These processes are made possible through specific microorganisms at each step in the transformation of organic nitrogen to readily available nitrogen forms. Factors such as temperature, moisture, soil pH and oxygen affect microorganism growth and activity, and thus mineralization. Warmer temperatures along with maintaining adequate soil moisture, oxygen and proper pH can accelerate mineralization (2). Mineralization contributes to turfgrass nitrogen fertility throughout the growing season and is an important process for thatch and organic matter management.

Nitrogen fertilizers

(see fertilizer section)

Phosphorus

Phosphorus is an essential nutrient for turfgrass growth and development. However, management of phosphorus has become increasingly important given its association with impairment of waterways. Understanding phosphorus fertility is not only important for maintaining a healthy turfgrass but in retaining phosphorus on site to reduce movement into water bodies.

Importance of phosphorus

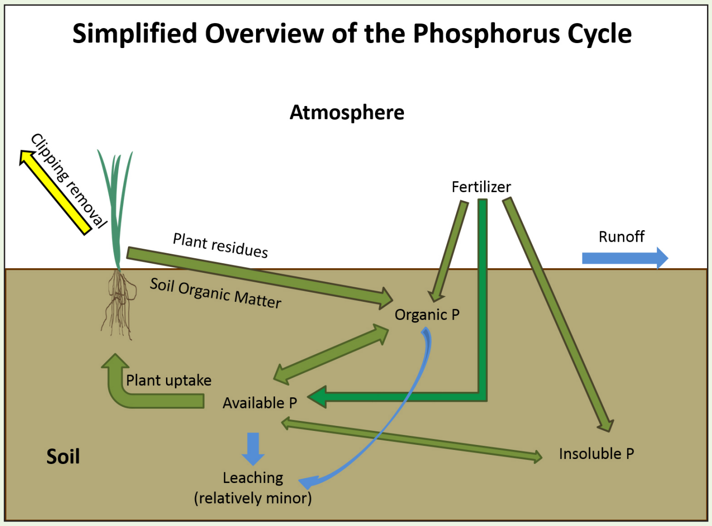
Phosphorus constitutes 0.1 percent to 1 percent of the turfgrass dry matter (2). Although phosphorus is found in lower concentrations compared to nitrogen, phosphorus is important within turfgrass both metabolically and structurally. Phosphorus is involved in energy transfer through compounds such as adenosine diphosphate (ADP) and adenosine triphosphate (ATP) (1, 2, 10). Phosphorus is also important in the structures of DNA and RNA as well as in the synthesis of phospholipids, which allow membranes to regulate the passage of compounds in and out of cells and cellular structures. Phosphorus is also involved in synthesis of phosphoproteins, nucleic acids, sugar phosphates, nucleotides and coenzymes (1, 2, 10).

Response of turfgrass to phosphorus fertilization

Application of phosphorus to turfgrass has been shown to affect: root growth, tolerance of warm-season turfgrass to lower temperatures and water use efficiency (2). Providing turfgrass with proper nutrition allows the plant to properly grow and develop so that the turf provides a functional and aesthetic surface. Insufficient phosphorus can limit plant growth and, as a result, the function and aesthetics of the turfgrass. Turfgrass that is deficient in phosphorus first appears stunted, with older leaves turning darker green (2). Over time leaves of the plant become red to purple in color with root growth declining. Proper phosphorus fertility is particularly important during establishment (7). Phosphorus toxicities are not common but have been reported for bermudagrass in Florida (2). Phosphorus fertility can be managed through routine soil and tissue testing.

Simplified overview of the phosphorus cycle

Phosphorus is generally available from the soil to the plant in low quantities. It is important to understand where phosphorus is found, the different forms of phosphorus and how phosphorus transforms. Through this understanding of the phosphorus cycle, one is better able to manage phosphorus fertilization for a healthy turfgrass as well as limit off-site phosphorus movement.



The design of the phosphorus cycle is based on figures and information from references 1, 2, and 6.

Phosphorus uptake

Phosphorus is taken up by turfgrass roots in the forms of $H_2PO_4^-$ and HPO_4^{-2}.

Phosphorus in the soil

Inorganic phosphorus

Routine soil tests are important in the development and management of phosphorus fertility.

The readily available forms of phosphorus include $H_2PO_4^-$ and HPO_4^{-2}. However, phosphorus can precipitate (form complexes) with Fe (iron), Al (aluminum), Mn (manganese) and Ca (calcium) or adsorb to mineral surfaces (6). Phosphorus will absorb to Al and Fe oxides and hydroxides and kaolinite clays at acidic soil pH. At a basic soil pH, phosphorus will absorb to $CaCO_3$. Both of the processes of precipitation and absorption can form insoluble phosphorus complexes that make phosphorus unavailable for plant uptake (6). However, over time dissolution of some less insoluble phosphorus complexes can occur for increased phosphorus availability. Soils with increased concentrations of Fe, Al and Mn; Al and Fe oxides and hydroxides; $CaCO_3$ and Ca, and clay content such as kaolinite can increase inorganic phosphorus fixation (2). Therefore, knowing the type and composition of the soil is critical in determining the potential availability of phosphorus. Maintaining soil pH between 6 and 7 can increase phosphorus availability.

Organic phosphorus

High concentrations of phosphorus can be found in soil organic matter. Of the known organic phosphorus sources, inositol phosphates are the most prevalent followed by phospholipids and nucleic acids (2). Phosphorus becomes available for turfgrass uptake through mineralization of organic matter. The mineralization process involves the degradation of the organic matter by microorganisms. Factors such as temperature, moisture and soil pH will affect microbial growth and activity and thus mineralization. Mineralization also occurs more readily in soils that have higher organic matter, and in organic matter with higher phosphorus concentrations (2, 6).

The depletion of available phosphorus can occur through immobilization. This process can be thought of as the opposite of mineralization. Microorganisms utilize available phosphorus and immobilize the phosphorus in organic forms. Plant residues can be a source of immobilized phosphorus.

Phosphorus fertilizers *(see fertilizer section)*

Potassium (potash)

Potassium, commonly referred to as potash, affects turfgrass water use and tolerances to drought, cold and warm temperatures and wear. Management of potassium fertility is of particular concern for sandy soils.

Importance of potassium

Potassium composes 1 percent to 3 percent of turfgrass dry matter and is second to N in concentration within turfgrass (2). Potassium is important in the regulation of water and enzyme activation within the plant. Potassium is involved in osmoregulation of vacuoles, stomates for CO_2 exchange during photosynthesis, and turgor pressure of cells (1, 10). Maintaining plant turgor pressure is not only important to increasing wear tolerance but allows for photosynthesis and other processes to continue during periods of stress. In addition, potassium maintains enzyme shape and is thought to help in protein synthesis.

Response of turfgrass to potassium fertilization

Potassium is often referred to as potash

Unlike nitrogen, which can have a very visual effect on turfgrass growth and color, initial deficiencies in potassium often present declines in stress tolerances to cold or warm temperatures, wear or drought (2). Problems associated with potassium deficiencies often occur with water relations within the turfgrass (10).

Application of potassium to a turfgrass has been shown to affect root growth, tolerance of warm-season turfgrass to lower temperatures and water efficiency (2, 7). Providing the turfgrass with the correct nutrition allows the plant to properly grow and develop so that the turf provides a functional surface. Insufficient potassium can limit plant growth and functions of turfgrass, such as wear tolerance. Plants that are deficient in potassium typically have yellowing between the veins of older leaves followed by scorching of leaf tips and margins (1, 2). Plants also have slowed growth and other issues, such as lack of stress tolerance. Excessive potassium in the soil can affect other nutrients and contribute to higher salt concentrations. Proper potassium fertility can be managed through routine soil and tissue testing.

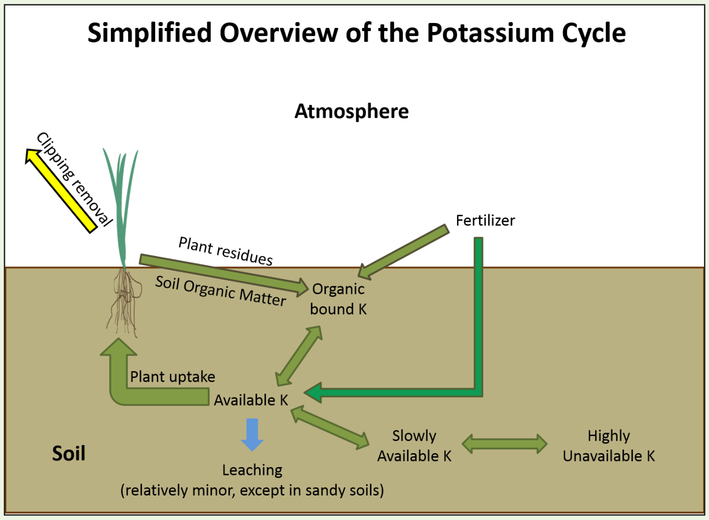
Potassium uptake by turfgrass

Potassium can be root- or leaf-absorbed as K^+ (1, 2). Concentrations of calcium and magnesium can affect potassium availability and losses. Also, high rates of nitrogen have been shown to have an effect on plant levels of potassium (2).

Soil potassium

K^+ is the form of potassium taken up by plants

Potassium can be found in four major forms within the soil: primary minerals, fixed potassium, readily available potassium and soil organic matter (2). Potassium in primary minerals, such as feldspars and micas, constitute the largest amount of potassium in the soil; however, potassium from these sources are released very slowly over time and are not major sources of potassium for turfgrass growth (6). Fixed potassium occurs in 2:1 clays where potassium becomes trapped within the clay interlayers (6). Potassium is not readily available but can be released from the edges of the clay layers slowly over time. The majority of readily available potassium is held by cation exchange capacity (CEC) (6) sites or in soil solution. Soils with higher CEC are able to retain potassium for exchange with the soil solution. Once in soil solution, potassium can be readily absorbed through turfgrass roots. Potassium is also found within organic matter. Very little potassium is a constituent of organic matter, but potassium does interact with organic matter CEC (2). Potassium bound by organic matter CEC is considered to be exchangeable potassium.



The design of the potassium cycle is based on figures and information from references 1, 2, and 6.

Secondary nutrients

Calcium, magnesium and sulfur are considered secondary nutrients relative to the primary nutrients of nitrogen, phosphorus and potassium. These may need to be applied less frequently compared to primary nutrients. However, secondary nutrients are essential, and in certain soils and environments, nutrient deficiencies occur. Proper calcium, magnesium and sulfur fertility can be managed through routine soil and tissue testing and following recommended application rates and timings.

Calcium (Ca)

Calcium composes 0.5 to 1.25 percent of turfgrass dry matter and is important as a constituent of cell structures. Calcium aids in membrane function, is involved in cell division, helps regulate osmotic potential and is particularly important in rooting and root function (2).

Calcium deficiencies in turfgrass are less common in finer-textured soils but do occur in highly acidic or well-drained sandy soils (2). Soils with higher CEC are able to retain calcium for release into soil solutions for plant uptake. Other conditions that require the addition of calcium include soils with high concentrations of sodium, because sodium will displace calcium on CEC sites. Visual symptoms of calcium deficiency include: deformed leaf formation, red to brown leaf coloring, leaf tip discoloration, and stunted or discolored rooting (1, 2).

Calcium is absorbed as Ca^{2+} through root uptake and foliar absorption (2). Sources of calcium for application can be categorized as quickly or slowly available.

Magnesium (Mg)

Magnesium constitutes 0.15 to 0.5 percent of the turfgrass dry matter and is important as a constituent of chlorophyll molecules, in the activation of enzymes for photosynthesis and movement of sucrose into the phloem, as a component of cell walls and for its involvement in osmotic regulation (2, 10).

In the case of magnesium, deficiencies tend to occur in acidic soils, soils with excess calcium, potassium, or sodium (Na) concentrations and sandy soils (2). Calcium and other cations can lead to magnesium deficiency by displacing magnesium ions on soil CEC sites followed by leaching of magnesium in the soil solution. Plants that have magnesium deficiency exhibit chlorosis on older leaves with leaf margins becoming darker colored or red. Over time, photosynthesis declines, resulting in stunted shoot and root growth (1,2).

Magnesium is absorbed as Mg^{2+} through root uptake and foliar absorption and is a mobile element in the plant (1).

Sulfur(S)

Sulfur is taken up by plant roots as sulfate (SO_4^{2-}) and composes 0.15 percent to 0.5 percent of turfgrass dry matter (2). Sulfur is an important component of amino acids, protein structures and electron transport. It is involved in the formation of glutathione, which is part of the pathways that bind heavy metal cations and protect plants from oxidative stresses (1, 3).

Sulfur deficiencies tend to occur in soils with low organic matter or in well-drained soils, such as sand (2, 6). Younger turfgrass leaves will show the first signs of deficiency with yellowing leaf tips and browning margins. Sometimes visual symptoms are not easily distinguished during initial sulfur deficiency compared to other essential nutrients. Over time growth is stunted with wear and environmental stress tolerances declining (2).

Micronutrients

Micronutrients are needed in lower quantities by the plant compared to primary and secondary essential nutrients. Micronutrients include iron, manganese, zinc, copper, boron, molybdenum, chlorine and nickel. Management of many of these nutrients can be accomplished through routine soil and tissue testing. The following section was written to provide a basic overview of the essential micronutrients for plant growth. More in-depth information can be found at sources listed in the reference section of this document.

Iron (Fe)

Iron constitutes 100 to 500 ppm of turfgrass dry matter (2). Iron is important in the formation of chlorophyll, affects photosynthesis in the thylakoids, is involved in electron transport and is a component of several proteins and enzymes (1, 10). Deficiencies in iron occur as yellowing between the veins of younger leaves followed by increased yellowing over time. Iron deficiency can cause turfgrass to appear mottled with reduced growth (1, 2). Toxicities of iron can occur with excessive Fe applications.

Although iron is a relatively abundant element, the majority of iron is not in soluble forms. The plant can take up Fe^{+2}, Fe^{+3} and chelated forms (2). Soil pH affects iron availability in the soil with Fe^{+2} and Fe^{+3} being more available at lower soil pH. Other soil factors that affect iron availability are soil aeration, temperature, organic matter and elemental nutrient interactions. Proper iron fertility can be managed through routine soil and tissue testing.

Manganese (Mn)

Manganese can constitute 20 to 500 ppm of turfgrass dry matter and is primarily absorbed as Mn^{2+} by plant roots (1, 2). Manganese is important in photosynthesis, specifically related to O_2 release and thylakoid membrane synthesis. Additionally, it is important for activation of several enzymes (1). Visual symptoms of manganese deficiency include reduced growth with gray spotted chlorosis on newer leaves. Leaves may also show yellowing between veins with tips turning white (1, 2). Deficiency of manganese results in disruption of photosynthesis with prolonged deficiency resulting in reduced growth and rooting. Manganese deficiency can occur on acidic sandy soils or calcareous sands in areas with high rainfall (2, 6). Frequent applications of foliar iron (Fe) can also affect manganese uptake (2). Factors such as soil pH, aeration, and soil temperatures can affect manganese availability. As soil pH becomes more acidic, manganese becomes more available for plant uptake. Manganese toxicity can occur at very low soil oxygen concentrations.

Zinc (Zn)

Zinc composes 20 to 70 ppm of turfgrass dry matter and is taken up by the plant primarily as Zn^{2+} (1, 2). Zinc is important as a structural component of enzymes, including superoxide dismutase (an antioxidant), and is involved in DNA and RNA replication and carbohydrate metabolism with zinc-containing proteins (1, 2).

Copper (Cu)

Copper constitutes 10 to 50 ppm of turfgrass dry matter and is taken up by the plant primarily as Cu^{2+}, $Cu(OH)^{+}$ and chelated Cu (1, 2). Copper is important for electron transport in photosynthesis, in superoxide dismutase (an antioxidant) and some proteins and enzymes (1, 2, 10).

Boron (B)

Boron is taken up by the plant primarily as H_3BO_3 at soil pH less than 9 (2). Boron is important in cell wall structures, such as hemicellulose, in lignin formation and is involved in cell elongation (1, 2).

Molybdenum (Mo)

Molybdenum composes 1 to 4 ppm of turfgrass dry matter and is taken up by the plant as MoO_4^{2-} and $HMoO_4^{-}$ (2). Molybdenum is important in some enzymes involved in redox reactions and is a cofactor in other enzyme reactions, such as nitrate reductase (1, 2).

Chlorine (Cl)

Chlorine composes 0.1 to 0.6 percent of turfgrass dry matter and is taken up by the plant as Cl^{-}(2). Chlorine is important in reactions to split water molecules during photosynthesis and is involved in osmotic regulation (1,2).

Nickel (Ni)

There is limited information regarding nickel in turfgrass.

Soil and tissue testing

Soil testing

Soil testing is the most basic element of a sound turf management fertility program. A soil test is a chemical analysis that estimates concentrations of essential plant nutrients to determine if nutrients are sufficient to support proper turfgrass growth. Soil tests are important to ensure desired turfgrass health and minimize loss of non-utilized nutrients when they are in excess and not used for turfgrass growth. Nutrients can be removed from soil through runoff, leaching, plant uptake, or gaseous losses. Potassium is especially prone to movement, whereas phosphorus reacts with soil minerals to form compounds that are not readily available for plants. Soil tests can be used to determine if nutrient applications are necessary. Tests are also critical to determine which nutrients and how much of a given nutrient should be added to establish or maintain a healthy turf.

How to collect a soil sample for laboratory analysis

Depending on conditions, soil tests need to be collected routinely (e.g., yearly). Soil tests should be conducted prior to new turf installations or landscape modifications. Keep the following steps in mind when collecting soil samples:

1. Know your area. Golf greens, fairways, tee boxes and roughs are all areas on a golf course that serve different functions and often have different fertility needs. Multiple soil samples may be required because of differences in soils, turfgrass species, use of the turfgrass and fertilization history.
2. Do not collect soil samples from areas that have recently received fertilizer or soil amendment applications.
3. For each sample, collect several random subsamples of soil. The larger the area, the more subsamples will be required to better represent the area. Remove debris. Make sure to place subsamples in a plastic container for mixing.
4. Mix all random subsamples from one sampling area thoroughly, and then fill a sampling carton or container with the soil mixture to be delivered to the soil analysis laboratory. Contact the soil analysis laboratory to determine the amount of soil required to run the analyses. Most require one-half to 1 pint of soil mixture for each area sampled.
5. Sampling depth depends on if the turf area is mature or if a sample is being collected prior to establishment. For most mature turfgrass sites, taking samples from the top 3 to 4 inches of soil is suitable. Sample depth prior to turfgrass establishment should be to a depth of 6 inches. For landscape plants, collect the upper 6 to 12 inches of soil depending on rooting depth of the species.
6. If possible, collect and submit samples several months before your projected planting date to ensure enough time to plan a liming and fertilization program if necessary. If tracking changes in soils is desired, sample at the same time each year.

Tissue testing

Tissue testing is a tool that can be used with soil testing to determine fertility of a turfgrass site. Tissue testing is a chemical analysis of the turfgrass leaf tissue to measure elemental concentrations so that it can be determined if nutrient concentrations are sufficient for proper plant growth. In the past, tissue testing was conducted on high maintenance areas, such as golf greens, but has gained wider acceptance for other turfgrass areas.

How to collect a tissue sample for laboratory analysis

1. Know your area. Golf greens, fairways, tee boxes and roughs are all areas on a golf course that serve different functions and often have different fertility needs and schedules. Multiple tissue samples need to be collected if there are difference species, differing soil types or delineation in use. For example, bermudagrass growing on a sand-based green would be sampled separately from bermudagrass growing on a clay tee box.
2. Do not collect tissue samples from areas that have recently received fertilizer, amendments or pesticide applications.
3. For each sample, collect several random tissue subsamples so that the area is well represented. The larger the area, the more subsamples will be required to better represent the area. Make sure to use a plastic container and remove soil and other debris (e.g., seedheads) from the tissue samples.
4. Mix all random subsamples from one sampling area thoroughly, and then fill a sampling carton or container with the tissue to be delivered to the plant analysis laboratory. Check with the plant analysis laboratory regarding the amount of tissue required and the time requirement in sending samples. A lag in time between sample collection and submission to the laboratory can affect analysis results due to tissue decomposition.

Fertilizers

Fertilizer source, method of application and timing are important components to consider when developing a fertility plan. This section is a brief overview of fertilizer terminology and focuses on types of nitrogen and phosphorus fertilizers used in the turfgrass industry.

Fertilizer terminology

Fertilizer is a compound that contains at least one essential nutrient for plant growth (2). A fertilizer has a label that contains the manufacturer's information, nutrient sources and nutrient amounts. The fertilizer grade is composed of three numbers that represent nitrogen (N), phosphorus (P) and potassium (K). A ratio of nitrogen, phosphorus and potassium is known as a fertilizer ratio (e.g., 10-5-20 is a 2:1:4). The label can also contain other essential nutrients in addition to nitrogen, phosphorus, and potassium. All nutrients are listed as a percentage (e.g., by weight) of the fertilizer on the label. In addition, the label will list the formulations of the nutrients (source of nutrients) as well as the amount of a nutrient that is water soluble or readily available to the plant.

Fertilizers can be composed of one or more essential nutrients. Fertilizers that contain all three (nitrogen, phosphorus and potassium) are considered complete fertilizers. It is important to read the fertilizer label to know how much of each nutrient is the fertilizer contains.

Fertilizer forms

Fertilizers come in two forms, solid and liquid. Solid forms of fertilizer include granular, non-granular and soluble fertilizers. The most common types of solid fertilizers applied include granular and soluble fertilizers. Granular fertilizers are composed of particles that range in size from 0.85 to 4.75 mm (2). Soluble fertilizers readily dissolve in water and are applied in a liquid.

Liquid fertilizers are fertilizers that are in solution, suspension or slurry form. The three differ with regard to solubility of the fertilizer. In a solution the nutrients are completely dissolved, whereas in suspensions and slurries, not all of the nutrients are dissolved. Liquid applications have become a popular method for applying fertilizers at low rates (spoon-feeding) on highly managed areas, such as golf greens.

Inorganic water-soluble nitrogen

Water-soluble inorganic nitrogen fertilizers are useful as readily available sources of nutrients and are generally high-grade. They are quickly dissolved by water and available for rapid turfgrass growth. Precisely because they are so dissolvable, they also are more prone to movement, such as leaching, especially in soils with high sand content. Sandy soils have higher leaching potential. Therefore, use of inorganic water-soluble formulations should be applied with care. Nitrate (NO_3^-) and ammonium (NH_4^+) are the principle sources of inorganic nitrogen that plants absorb. Common water-soluble fertilizers applied to turfgrass include:

Readily available nitrogen sources	Analysis
Ammonium nitrate	34-0-0
Ammonium sulfate	21-0-0
Calcium nitrate	15-0-0
Diammonium phosphate	18-46-0
Monoammonium phosphate	10-50-0
Potassium nitrate	13-0-44
Urea	46-0-0

Some readily available nitrogen sources can be coated to produce slow-release formulas with less volatilization and leaching. Examples include urea and urea-ammonium nitrate. Others are available with urease enzyme or nitrification inhibitors. Inhibitors reduce losses to the atmosphere and slow the rate of nitrogen release. These coated and stabilized nitrogen fertilizers can reduce the risks of contaminating groundwater and increase the utilization of nitrogen applied. Slow-release nitrogen sources are more variable in N content and release characteristics. Many nitrogen sources can be applied in granular or liquid form.

Inorganic water-soluble phosphorus

There are two types of superphosphates, ordinary superphosphate (OSP) that contains 16–22 percent P_2O_5, and triple (concentrated) superphosphate (TSP or CSP) with 44–52 percent P_2O_5. Single superphosphate is made by treating rock phosphate with sulfuric acid, so it is less pure. Triple superphosphate is a purer form of P that is produced by acidulating rock phosphate with phosphoric acid. Phosphorus in both of these fertilizers is readily available to plants.

Ammonium phosphates: Two common forms of ammonium phosphate are monoammonium phosphate and diammonium phosphate; both are granular fertilizers that are completely water soluble.

Water insolubility and slow-release fertilizers

Slow-release fertilizers that contain nitrogen and phosphorus have been developed for a variety of reasons, such as more even turfgrass growth and reduced application frequency. These products are known as slow-release fertilizers and can be useful to promote turfgrass growth and development. Facilities in environmentally sensitive areas may consider their use when possible. These nutrients are slowly soluble or coated. Slowly soluble fertilizers and coated fertilizers (typically in pellet form) depend on soil moisture and temperature to release nutrients. Controlled release of nutrients provide turf nutrition over a period of time, some lasting up to 12 months, so fewer applications are needed and losses can be minimized.

Slow-release nitrogen sources	Analysis (%)
IBDU	31-0-0
Methylene urea	40-0-0
Natural organics	Varies
Polymer coated	Varies
Sulfur coated urea	Varies
Ureaform	38-0-0

Differences between organic/natural and inorganic/synthetic fertilizer

All fertilizers, regardless of the source, are designed to provide chemical elements necessary for plant development and growth. Organic fertilizers, like manures, composts and bone meal, are derived directly from plant or animal sources. Inorganic or synthetic fertilizers like ammonium sulfate or ammonium phosphate are called synthetic fertilizers because they are produced through a manufacturing process. However, most originate from naturally occurring mineral deposits. Typically, inorganic fertilizers contain only a few nutrients, such as nitrogen, phosphorus and potassium in various combinations. These nutrients are in concentrated form readily available to plants and thus have an increased potential to be lost from the turfgrass system.

Organic fertilizers often contain plant nutrients in much lower concentrations. Most of these nitrogen, phosphorus and potassium forms must be chemically or biologically converted in the soils into inorganic forms before plants can use them, so they are slowly released over time. However, depending on the source, nutrients can be readily available to the plant and, consequently, movement off-site.

Basic fertilizer calculations

Proper calculation of fertilizers can be advantageous in regards to costs, turfgrass health, and environmental sustainability. Below are some basic dry and liquid calculations for fertilizers. For further information regarding calculation for fertilizers, please see the reference section.

Dry fertilizer application

Example 1. Bermudagrass fairways at a golf course total 50 acres. The superintendent wants to apply 20 pounds of nitrogen per acre using a granular fertilizer with an analysis of 34-0-0. The fertilizer will be applied as a dry product.

(a) How much fertilizer is required for 50 acres of fairways?

20 lbs N/acre x 50 acres of fairways = 1,000 lbs N

The first equation calculates the amount of nitrogen that will be applied to 50 acres of fairways at a rate of 20 pounds of nitrogen per acre.

1,000 lbs N ÷ 0.34 = 2,941 lbs fertilizer

The second equation calculates how much fertilizer will be needed to supply the amount of nitrogen required to fertilize the 50 acres of fairways. The term 0.34 (34 percent) is the percentage of nitrogen in the fertilizer. This percentage of nitrogen in the fertilizer can be found on the fertilizer label.

Liquid fertilizer application

Example 2. Bermudagrass greens at a golf course total 90,000 square feet. The superintendent wants to apply 0.2 lb of nitrogen per 1,000 square feet as a liquid. The liquid fertilizer has stated on the label that it contains 2 lbs of nitrogen per gallon of product. Fertilizer will be mixed with water and applied using a boom sprayer at 10 gallons per acre (GPA).

(b) How much fertilizer is required for 90,000 square feet of golf greens?

0.2 lbs N/1000 sq ft x 90 = 18 lbs N

The first equation calculates the amount of nitrogen that will be applied to 90,000 square feet of golf greens at a rate of 0.2 lbs of nitrogen per 1,000 square feet. The 90 is from 90,000 square feet ÷ 1,000 square feet.

18 lbs N ÷ 2 lbs N/gallon of product = 9 gallons of product

The second equation calculates how much product will be needed to supply the amount of nitrogen required to fertilize the 90,000 square feet of golf greens. The 2 pounds of nitrogen per gallon of product comes from the product label. The amount of product will be mixed with water in a solution to be applied at 10 GPA using a boom sprayer. See the section on equipment calibration to learn how to properly calibrate liquid application equipment.

Equipment calibration

Much like soil testing, equipment calibration is an important component in developing a fertility plan. Understanding the benefits and limitations of each piece of application equipment can help to more efficiently and effectively apply fertilizers. Remember that calibration should be completed for every fertilizer applied and, in the case of man-powered application equipment, that equipment should be calibrated for each person. Also make sure that the fertilizer label does not restrict or advise against the use of certain application equipment.

Drop Spreader

Rotary Spreader

Solid application

Drop spreader

Drop spreaders provide a simple and accurate mechanical method for applying solid fertilizers to an area. True to their name, drop spreaders allow a solid fertilizer to fall through orifices to the ground below. Advantages of the drop spreader include its mechanical simplicity and controlled application to a specific area. Below is a basic method for calibrating a drop spreader.

1. Check the equipment to make sure all parts are in working condition.
2. Make sure the hopper is clean and dry.
3. Measure the width the fertilizer will be applied from the drop spreader.
4. Determine the calibration area. For example, if the drop spreader has a drop width of 3 feet, mark with flags a length of 100 feet. This would give a calibration area of 300 square feet (3 feet x 100 feet).
5. Based on the fertilizer analysis and desired rate of application, determine the amount of fertilizer that will be needed to apply to the calibration area.
6. Place fertilizer in the hopper. Make sure the hopper is closed. Be sure the fertilizer is evenly distributed across the hopper and that it is at sufficient depth to complete the calibration.
7. Attach a pan or trough under the drop spreader to catch the fertilizer during calibration.
8. Most drop spreaders have dials or slides that control the orifice size that the fertilizer drops through at the base of the fertilizer hopper. It may be demarked with numbers or letters. Choose a setting and write down the setting.
9. Begin walking well behind the first marker of the calibration area in order to reach a comfortable walking or travel speed. It is important to maintain a constant speed during calibration. Turn on lever to release the fertilizer into the catch pan as you cross the first flag. Make sure to turn off the lever to stop fertilizer release when you reach the second flag or end of the calibration area.
10. Remove the fertilizer from the catch pan and weigh the fertilizer. Determine if the weight of the fertilizer from the catch pan equals the amount calculated in step 5.
11. If the fertilizer does not equal the amount calculated in step 5, then change the orifice size with the control dial and repeat calibration steps until the amount of fertilizer in the catch pan equals the amount calculated in step 5.

Rotary spreader

Rotary spreaders allow for distribution of dry fertilizers to a larger area faster than a drop spreader. Rotary spreaders can be walk-behind or attached to equipment, such as a tractor. Below is a basic method for calibrating a rotary spreader.

1. Check the equipment to make sure all parts are in working condition.
2. Make sure the hopper is clean and dry.
3. Make sure the distribution of the fertilizer follows a bell-shaped curve.
4. Measure the width the fertilizer will be applied from the rotary spreader. This step requires some assistance. People walking on both sides can mark the distance a material is applied while someone is applying the fertilizer using the rotary spreader. Measure and record the distance between the two flags. This is the application width.
5. Determine a calibration area. For example, if the rotary spreader has an application width of 10 feet, mark with flags a length of 100 feet. This would give a calibration area of 1000 square feet (10 feet x 100 feet).
6. Based on the fertilizer analysis and desired rate of application, determine the amount of fertilizer that will be applied within the calibration area.
7. Place a known weight of fertilizer in the hopper (this is not limited to the amount measured in step 6). Be sure the fertilizer is evenly distributed across the hopper and that it is at sufficient depth to complete the calibration.
8. Rotary spreaders have controls that affect the orifice size that the fertilizer drops through before hitting the rotating paddle. It may be marked with numbers or letters. Choose a setting and write the setting down.
9. Begin well behind the first marker of the calibration area in order to reach a comfortable walking or travel speed. It is important to maintain a constant speed during calibration. Turn on the lever to release the fertilizer at the first flag and continue the length of the calibration area. Make sure to turn off the lever at the second flag or end of the calibration area.
10. Turn around and repeat step 9. Remember the application of a rotary spreader is not spread evenly across like a drop spreader. Therefore it requires two passes within the calibration area to properly calibrate.
11. Remove the fertilizer from the fertilizer hopper and weigh it. The difference between the original weight of fertilizer placed in the hopper and the remaining weight of the fertilizer after traveling the calibration area is the amount of fertilizer applied in the calibration area. Determine if the weight of the fertilizer applied to the calibration area equals the amount calculated in step 6.
12. If the fertilizer does not equal the amount calculated in step 6, then change the orifice size with the controls and repeat until the amount of fertilizer applied in the calibration area equals the amount calculated in step 6.

Liquid application

Liquid application of fertilizers on golf courses primarily occurs on highly managed areas, such as golf greens. Applying fertilizers as a liquid allows for a more even, frequent application of nutrients at low rates (e.g., spoon feeding) and can increase the opportunity for foliar absorption. When applying fertilizers as a liquid, it is important to calibrate for an accurate carrier volume, typically referred to as gallons per acre (GPA) or gallons per 1,000 square feet. Below are two methods for calibrating the carrier volume output (GPA) of a boom sprayer.

Broadcast sprayer

Shortcut method

1. Check the equipment to make sure all parts are in working condition.
2. Make sure the tank is clean.
3. Make sure the nozzles are clean and applying according to manufacturer's specifications. Spray tips should emit a uniform fan of small droplets.
4. Measure and record the distance in inches between two nozzles. This is the nozzle spacing measurement.
5. Using the chart or equations below, determine the distance needed to complete the calibration for the nozzle spacing. Mark the distance with two flags.

Nozzle spacing (inches)	Calibration distance (feet)
10	409
12	341
14	292
16	255
18	227
20	204
22	185
24	170
26	157
28	146
30	136

The calibration distance can also be determined using the following equations:

(a) Nozzle spacing in inches ÷ 12 = _____nozzle spacing in feet

The first equation converts nozzle spacing from inches into feet.

(b) 340.3 sq ft ÷ ______nozzle spacing in feet = ______feet

The second equation calculates the calibration distance.

6. Fill the tank with enough clean water to complete the calibration procedure.
7. Record the time it takes to travel from one side of the calibration area to the next. Maintain a constant speed when traveling across the calibration area. It is a good idea to repeat this step and average the times.
8. Using a container that measures in fluid ounces, collect water from one nozzle for the amount of time it takes to travel the calibration area.
9. The volume of water collected in fluid ounces equals the gallons per acre (GPA).
10. Repeat step 7 several times with different nozzles to ensure equal GPA rates across nozzles on the boom.
11. To adjust the GPA, adjust travel speed.

The 5940 method

This formula tells you how many gallons you would have to catch in 1 minute (GPM) from a single nozzle assuming speed, nozzle spacing and desired output volume (GPA) are known.

Practitioners may use this equation to refine application speed and nozzle selection when a desired output volume is known.

$$\underset{\textit{(flow rate of nozzle)}}{\text{GALLONS PER MINUTE}} = \frac{\text{GPA} \times \text{MPH} \times \text{NSI}}{5940}$$

1. Check the equipment to make sure all parts are in working condition.
2. Make sure the tank is clean.
3. Make sure the nozzles are clean and applying according to manufacturer's specifications. Spray tips should emit a uniform fan of small droplets.
4. Fill the tank approximately half full with water to complete the calibration procedure.
5. MPH — Measure speed in miles per hour.

   For example, if it takes 45 seconds to cover 200 feet.
   - Convert seconds to hours: 45 /3600 = 0.0125 hours
   - Convert feet to miles: 200/5280 = 0.038 miles
   - 0.038 miles/0.0125 hours = 3.04 MPH
   It is important to calibrate speed on similar terrain and under similar conditions as the intended application. Do this on the same surface and with the pump in operation to ensure that the speed accurately reflects real conditions.
6. NSI — Measure and record the distance in inches between two nozzles. This is the nozzle spacing measurement (NSI). If your sprayer is "boomless" and has only one spray nozzle, then the expected spray width of the nozzle is equal to the NSI. For instance, if your single nozzle covers 15 feet, then convert to inches: 15 × 12 = 180 NSI.

   Alternatively, practitioners may wish to calculate output volume based upon a known flow rate (GPM).

$$\underset{\textit{(Output Volume)}}{\text{GALLONS PER ACRE}} = \frac{\text{GPM x 5940}}{\text{NSI x MPH}}$$

Paths for nutrient losses from a turfgrass system

Off-site nutrient losses can lead to poor turfgrass growth and quality, require greater fertilizer inputs, increase costs and result in movement of nutrients into environmentally sensitive areas. Learning the paths that nutrients can be lost off-site not only conserves nutrients for plant growth, but can potentially reduce costs and movement of nutrients into ground and surface waters.

Gaseous nitrogen losses

As mentioned earlier in the nitrogen section, nitrogen can be converted to a gas through two processes, denitrification and volatilization. The denitrification process is associated with low oxygen (anaerobic) environments suitable for anaerobic microbial activity. Environmental factors, such as temperature, pH, and moisture, affect these microorganism populations and their activity levels, thereby reducing or increasing the rate of denitrification. Denitrification occurs mostly in areas with high organic matter, high moisture, low oxygen concentrations and slightly acidic to basic soil pHs. Increasing temperatures also leads to increased rates of denitrification.

Volatilization is the second process by which nitrogen is transformed into a gas as ammonia. Some ammonium losses through volatilization may occur when ammonium based fertilizers are applied to calcareous soils but more commonly the transformation of nitrogen to ammonia is accomplished by microorganisms. Factors that affect microbial growth and metabolism of these microorganisms will affect the rate of volatilization. Factors such as the amount of urea or ammonium, temperature, pH and moisture affect the rate at which volatilization occur. Increasing temperatures can lead to volatilization (2). Urea is susceptible to nitrogen losses through volatilization.

Nutrients in surface runoff

Surface runoff occurs when the intensity of rainfall exceeds the infiltration and percolation rate of a soil. Finer soils (e.g., clay) are more susceptible to surface runoff than coarser soils (e.g. sand). Other factors, such as rainfall intensity, slope, and turfgrass coverage, can affect surface runoff occurrence and severity.

Soluble forms of nitrogen, such as nitrate and ammonium, as well as phosphorus and other nutrients, can be dissolved and transported in flowing waters to off-site locations (11). Nutrients that are held by the soil, such as phosphorus, can be transported through erosion of sediment and organic matter. The result is that nutrients can be transported off-site into lakes, rivers and other surface water bodies (13). This not only reduces the fertility of the site and wastes money but can lead to impaired waterways that disrupt the natural waterway ecosystem.

Many golf courses in Louisiana and Mississippi have finer textured soils that use surface drainage to remove excess moisture from areas such as fairways and roughs that compose the majority of acreage of a golf course. Remember, surface drainage is a naturally occurring process. The goal is to reduce potential movement of nutrients and sediments transported by surface flow. In many cases, a dense, healthy turfgrass will limit the movement of solids, such as sediment. However, movement of dissolved nutrients can still occur.

Nutrient leaching

Nutrient leaching is the process by which water moves nutrients within the soil below the roots. This in effect limits the potential uptake of nutrients by plants. Nutrients that are negatively charged (anions) are more susceptible to leaching compared to cations or positively charged ions (2). However, in well-drained soils, cations such as Ca^{+2}, K^{+} and NH_4^{+} become more susceptible to leaching (2). Nitrate is the most common form of nitrogen leached from soils. Sandy soils with large particle sizes typically allow for rapid water diffusion, and nitrogen forms such as nitrate are highly water soluble. Clay soils with low organic matter and CEC also have the potential for leaching, albeit at a slower rate than sands because nutrients are not as readily retained.

Leaching of nutrients through the soil can ultimately lead to increased nutrient concentrations in groundwater (14). Factors that affect nutrient leaching include: soil texture, turfgrass species, rooting depth, soil CEC, water volume (e.g., rainfall and irrigation) and cultural and fertility management practices.

Many golf courses in Louisiana and Mississippi have finer-texture native soils for fairways and roughs. These areas are prone to surface runoff during intense rainfall. However, it is important to remember that an area on a golf course that is extremely susceptible to leaching is sand-based golf greens. Sand-based golf greens allow for quick drainage during or immediately preceding rainfall for resumption of play, but these areas require increased management to maintain nutrient concentrations due to nutrient losses from clippings removal. Recognizing the difference in use, soil type and characteristics can help when developing a fertility plan.

Although this section is focused on leaching as a pathway for nutrient losses, leaching can be an important tool when discussing salt-affected sites. That discussion is beyond the scope of this document, but it is important to note drainage is a natural process and one that can be quite useful. Therefore, understanding the factors that lead to leaching with regards to nutrient fertility is a primary step in reducing potential nutrient losses.

Strategies to reduce nutrient losses

1. Understand how the drainage of the golf course occurs and the course's proximity to water bodies. This would include basic knowledge of soils, topography and environmental conditions (e.g., rainfall). When developing a fertility plan, categorize areas from low to high importance based on potential impact of nutrient movement. For example, if a golf course fairway has a pond, the fairway could potentially contribute to nutrient movement into that pond.
2. For drainage areas, maintain swales or grassed areas if possible to slow water movement for greater infiltration and sediment and nutrient retention.
3. If possible, develop non-play or native areas. These areas serve several purposes, such as reducing areas that require routine fertilization, increasing areas for water and nutrient retention and providing wildlife habitats.
4. Consider developing or maintaining proper riparian areas around surface water bodies.
5. Apply proper cultural practices to maintain a healthy, dense turfgrass. Practices such as aerification reduce soil compaction and increase infiltration while allowing for better turf growth.
6. Develop a fertility plan for the entire golf course according to soil test results, and take into account turfgrass species, topography, use of the area, time of year and other environmental factors. Not all areas will require the same fertility. For example, golf greens will generally require higher fertility than rough areas due to increased use from players.
7. Properly calibrate fertilizer application equipment as necessary.
8. Use the proper fertilizer application equipment for the site of application and the fertilizer being applied.
9. Apply nutrients when turfgrass is actively growing.
10. Be aware that highly soluble nutrients are prone to movement immediately after application (leaching, runoff and volatilization). Consider the use of less soluble or slowly available nutrient sources where appropriate.
11. Apply nutrients at the recommended rates and timings.
12. Do not apply fertilizers if intense rainfall is forecast.
13. Incorporate soluble nutrients with irrigation.
14. Do not apply excessive irrigation that results in surface runoff or leaching after fertilizers have been applied.
15. Return clippings to areas such as tee boxes, fairways, and roughs. Clippings contain nutrients that can support turfgrass growth.
16. For areas such as golf greens that typically have clippings removed, consider composting these clippings in a suitable location for later use. Control nutrient run-off from these compost sites and ensure that nutrients are not a source of surface water contamination.
17. Do not apply nutrients to non-permeable areas or directly into surface waters or drains during fertilization of turfgrass areas.
18. Maintain clean, dry storage facilities in areas that are not prone to flooding.
19. Clean wash pads and other areas regularly to prevent nutrients from fertilizers, soil or plant residues moving directly into a drainage system.

References

1. Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press. New York.
2. Carrow, R. N., D. V. Waddington, and P. E. Rieke. Turfgrass Soil Fertility and Chemical Problems: Assessment and Management. Ann Arbor Press. Chelsea, Michigan.
3. Taiz, L. and E. Zeigler. 2002. Plant Physiology. 3rd ed. Sinauer and Associates. Sunderland, MA.
4. Balogh, J. C. and W. J. Walker. Editors. 1992. Golf Course Management and Construction. Lewis Publishers. Chelsea, MI.
5. J. Fry and B. Huang. 2004. Applied Turfgrass Science and Physiology. John Wiley and Sons. Hoboken, NJ.
6. Brady, N. C. and R. R. Weil. 1996. The Nature and Property of Soils. 11th ed. Prentice-Hall, Inc. Upper Saddle River, NJ.
7. Turgeon, A. J. 1995. Turfgrass Management. 4th ed. Prentice-Hall, Inc. Upper Saddle River, NJ.
8. Patton, A., F. Whitford, D. Weisenberger, G. Hardebeck, J. Trappe, K. L. Smith. 2013. Calibrating Ride-on Pesticide Sprayers and Fertilizer Spreaders: Keys to Application Accuracy. Extension Publication PPP-104. Purdue University.
9. Mills, H. A. and J. B. Jones, Jr. 1996. Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis, and Interpretation Guide. Micromacro Publishing Inc. Jefferson City, Mo.
10. Florida Department of Environmental Protection. Best Management Practices for the Enhancement of Environmental Quality on Florida Golf Courses. 2007. http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/glfbmp07.pdf. Last accessed 2017 March 2.
11. Petrovic, A. M. 1990. The Fate of Nitrogenous Fertilizers Applied to Turfgrass. J. Environ. Qual. 19:1-14.
12. Brede, D. 2000. Turfgrass Maintenance Reduction Handbook: Sports, Lawns, and Golf. Sleeping Bear Press. Chelsea, MI.
13. Silva, A. and R. Uchida, Editors. 2000. Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.
14. Follett, Ronald D. 1995. Fate and Transport of Nutrients: Nitrogen. Working Paper No. 7. USDA, Agricultural Research Service.



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