Turfgrass Fertilization:

A Basic Guide for Professional Turfgrass Managers

College of Agricultural Sciences
Agricultural Research and Cooperative Extension

Contents

Introduction

Dollar for dollar, fertilization does more to improve poor-quality turfgrass or to maintain good-quality turfgrass than any other management practice. Proper fertilization practices produce a dense, medium- to dark-green turf that resists pests and environmental stresses.

Careless application techniques or excessive amounts of fertilizer applied at the wrong time of year can result in serious turf damage and contamination of water resources. Successful turf maintenance fertilization requires that you assess your turf's nutritional requirements, understand fertilizers, know how much to apply and when, and use proper application techniques.

Nutrient Requirements of Turfgrasses

Turfgrasses require at least 16 nutrients for normal growth and development. Some nutrients are needed in large amounts, other nutrients only in minute quantities. Regardless of the amount required, a deficiency of any of these nutrients will limit the growth and development of your turf. Thus, a calcium deficiency can be just as detrimental to the plant as a lack of nitrogen, even though turfgrasses use more nitrogen than calcium.

Nine of the sixteen required nutrients are needed in much larger quantities than the other seven. These nine nutrients—carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur—are called macronutrients. Carbon, hydrogen, and oxygen make up about 90 to 95 percent of the plant's dry weight. They are never deficient in turfgrasses because they are derived from carbon dioxide (CO_2) and water (H_2O).

Nitrogen, phosphorus, and potassium are referred to as primary nutrients and must be supplied periodically to turf through fertilizer applications. Calcium, magnesium, and sulfur, the secondary nutrients, are needed only occasionally in the form of fertilizer or lime.

The micronutrients iron, manganese, zinc, boron, copper, molybdenum, and chlorine are required only in minute amounts and are rarely supplied to turfgrasses through fertilization. Exceptions are if turfgrasses are planted on high-sand-content soils, such as golf course putting greens, or if iron applications are used to provide a darker green turf without stimulating excessive foliar growth.

Table 1 lists the 16 essential nutrients, the form in which grass plants are able to use them, and the approximate amounts of each found in healthy turf. The exact amounts of needed nutrients vary among species, cultivars, soil moisture contents, and time of year; hence, the amounts listed under "sufficiency range" should not be used as indicators of deficiencies or excessive concentrations.

Table 1. The essential turfgrass nutrients.

Nutrient	Symbol	Available form(s)*	Sufficiency range**
Macronutrients			
Carbon	C	CO_2	44%
Hydrogen	H	H_2O	6%
Oxygen	O	O_2, H_2O	44%
Nitrogen	N	$\mathbf{NO_3^-}$, NH_4^+	2.75–4.2%
Phosphorus	P	$\mathbf{H_2PO_4^-}$, HPO_4^{2-}	0.3–0.55%
Potassium	K	K^+	1.0–2.5%
Calcium	Ca	Ca^{2+}	0.5–1.25%
Magnesium	Mg	Mg^{2+}	0.2–0.6%
Sulfur	S	SO_4^{2-}	0.2–0.45%
Micronutrients			
Iron	Fe	$\mathbf{Fe^{2+}}$, Fe^{3+}	35–100 ppm
Manganese	Mn	Mn^{2+}	25–150 ppm
Zinc	Zn	Zn^{2+}, $ZnOH^+$	20–55 ppm
Boron	B	$B(OH)_3$	10–60 ppm
Copper	Cu	Cu^+, $\mathbf{Cu^{2+}}$	5–20 ppm
Molybdenum	Mo	MoO_4+	0.15–0.5 ppm
Chlorine	Cl	Cl^-	not known

*Bold type indicates the form more commonly available to turfgrasses.

**Sufficiency ranges are expressed as percentages or parts per million (ppm) on a dry weight basis. Values were obtained from publications by J. B. Jones, 1980, *Turf Analysis*, Golf Course Management, 48:1, 29–32; H. Marschner, 1995, *Mineral Nutrition of Higher Plants*, Academic Press, New York; and E. Epstein, 1972, *Mineral Nutrition of Plants: Principles and Perspectives*, John Wiley, New York. Ranges in some cases are based on general observations and are not necessarily applicable to all turfgrasses or every growing condition or management situation.

Each of the 16 essential nutrients has specific roles or functions in turfgrass plants. Some nutrients, such as nitrogen and phosphorus, affect many important plant functions, whereas others may only activate a few chemical reactions. Regardless of how large a role each nutrient plays, all are needed for the plant to develop normally. The primary functions of the essential mineral nutrients are presented in Table 2.

Deficiencies of nutrients in turfgrass plants can be expressed in numerous ways. The most obvious is a reddening or yellowing of leaf tissue. Deficiencies can also appear as a thinning of the stand, stunted growth, and increased susceptibility to disease. Ideally, fertilizer should be applied before deficiencies occur. The best way to assess nutritional requirements of turf is through soil testing, tissue testing, or both.

Table 2. Functions of the essential mineral nutrients.*

Nutrient	Symbol	Function
Macronutrients		
Nitrogen	N	Component of nucleic acids, amino acids, proteins, chlorophyll, and coenzymes. Affects shoot-root growth, density, color, disease resistance, and stress tolerance.
Phosphorus	P	Component of nucleic acids, membranes, adenosine triphosphate, and several coenyzmes. Affects rate of seedling development, maturation, and root growth.
Potassium	K	Activates enzymes used in protein, sugar, and starch synthesis. Important in maintaining turgor pressure in plants. Affects drought tolerance, cold hardiness, and disease resistance.
Calcium	Ca	Occurs in middle lamella of cell wall where it helps to "cement" walls together. Important in cell division and membrane function. Calcium deficiencies result in poor root and shoot growth.
Magnesium	Mg	Important component of chlorophyll, activates many enzymes. Magnesium deficiencies result in foliar chlorosis (yellowing).
Sulfur	S	Present in certain amino acids, proteins, membranes, and coenzymes. Sulfur deficiencies result in chlorosis.
Micronutrients		
Iron	Fe	Important in chlorophyll formation, photosynthesis, and nitrogen metabolism. Iron deficiencies result in chlorosis of young leaves.
Manganese	Mn	Present in chloroplast membranes and functions as enzyme activator. May be involved in resistance to some diseases.
Zinc	Zn	Involved in chlorophyll synthesis and amino acid synthesis, involved in synthesis of the growth hormone indoleacetic acid.
Boron	B	Plays a role in DNA synthesis and translocation of sugars.
Copper	Cu	Essential for photosynthesis and a component of certain enzymes.
Molybdenum	Mo	Component of enzyme that reduces nitrate in plants.
Chlorine	Cl	Plays a role in photosynthesis.

*Based on information from H. Marschner, 1995, *Mineral Nutrition of Higher Plants*, Academic Press, New York; E. Epstein, 1972, *Mineral Nutrition of Plants: Principles and Perspectives,* John Wiley, New York; and F. Salisbury and C. Ross, 1978, *Plant Physiology,* 2nd edition, Wadsworth Publishing, Belmont, CA.

Soil and Tissue Testing

SOIL TESTING

Soil testing is an important first step in developing a turfgrass fertility program. For some nutrients, it is the only way you can accurately determine how much fertilizer your turf needs. Most land grant universities and many commercial laboratories provide soil testing services, although prices and services vary among labs. For a nominal fee, Penn State offers a standard soil test for phosphorus, potassium, calcium, magnesium, and lime requirements. More comprehensive soil analyses are available upon request. Typically, nitrogen is not analyzed as part of a standard soil test because levels fluctuate too rapidly in soil to provide meaningful recommendations.

A soil test program involves sampling, laboratory analysis, interpretation, and recommendations. The results obtained from a soil test are only as good as the sample submitted. Sampling directions vary from lab to lab, so follow instructions on the test kit carefully. Instructions should tell you how many subsamples are required per test, the sampling pattern, the sampling depth, and whether thatch should be included in the sample.

Penn State soil test sampling instructions suggest collecting 12 or more subsamples per location in a regular grid pattern (Figure 1). If the site varies in soil type, previous lime or fertilizer treatment, or other past maintenance practices, take separate samples accordingly. Test kit instructions suggest sampling soil 2 to 3 inches in depth and discarding thatch. Mix all subsamples together to make one sample, then take about 1/3 pint of this mix and place it in the mailing kit (Figure 2). Be careful not to contaminate the sample with lime or fertilizer during sampling and mixing.

Typically, soil tests should be taken every three years. If you wish to monitor nutrient levels over many years, take the samples at about the same time of year every time you sample. Always test the soil before establishing or renovating a lawn.

Soil test labs vary in how they analyze soil and interpret test results. The greatest variation in analysis is usually among labs from different areas of the country. Be sure to send your samples to a laboratory that is familiar with the nutrient requirements and growing conditions of turfgrasses in your region. If you are sending samples to a national commercial laboratory, note your location.

Figure 1. Soil sampling pattern for turfgrass areas. Take soil samples 2–3 inches in depth from 12 or more locations per site.

Figure 2. Penn State soil test sampling instructions suggest mixing all subsamples together to make one sample.

Interpretation of soil test results allows your nutrient levels to be placed into categories such as low (deficient), adequate, or high based on the research and experience of turfgrass specialists. Recommendations are usually provided as pounds of fertilizer per 1000 square feet (also based on research and the experience of turfgrass specialists). Make sure you understand the recommendations before applying the fertilizer; that is, determine if the recommended amount of fertilizer is to be applied in several separate applications or if it can be provided in one application.

Recommendations offered by Penn State's soil test lab are based on research with lawn grasses in Pennsylvania and on the experience of turf specialists at the University. It is not surprising that recommendations from other states differ, since soils, research procedures, and specialists' opinions differ from those of Penn State specialists. To maintain consistent soil test results and recommendations, work with one lab that is convenient to use and whose recommendations you can understand.

TISSUE TESTING

Testing of turf leaf tissue allows you to monitor nutrient levels, which can be related to the need for fertilizer. Leaf tissue testing is also a means of diagnosing nutrient deficiencies, verifying diagnosis made from visual deficiency symptoms. Tissue nutrient levels can be determined for most or all nutrients, or for only one or two. It is becoming more popular to sample leaf tissue for nitrogen to determine fertilizer nitrogen requirements. As with soil testing, proper sampling of leaf tissue is critical. Samples must be representative of the area, collected according to lab instructions and, above all, free from soil and other contaminants.

Fertilizer Basics

Cost is a primary concern in deciding which fertilizer product to use. Selecting the least expensive fertilizer, however, does not necessarily mean you have found the best value. Fertilizer should be purchased on the basis of quality rather than on bag size or price. Quality is determined by the amounts and types of nutrients contained in the bag and by the product's physical characteristics.

NUTRIENTS IN FERTILIZERS

Turfgrass fertilizers usually contain three plant nutrients: nitrogen, phosphorus (designated on labels as available phosphate, or P_2O_5), and potassium (designated as water soluble potash, or K_2O). These three nutrients are represented on the fertilizer container as three numbers, indicating the percentages by weight of nitrogen, phosphate, and potash—always in that order (Figure 3). The three numbers are referred to as the fertilizer grade.

Figure 3. The three numbers on fertilizer containers indicate the percentages by weight of nitrogen, phosphate, and potash in the fertilizer.

When nitrogen, phosphorus, and potassium are all present in the container, the fertilizer is called a complete fertilizer. Sometimes one or two of these nutrients are not present, and the missing nutrient(s) are simply listed as “0” in the grade. Occasionally, turfgrass fertilizers contain other nutrients such as sulfur, iron, and/or calcium. These are usually listed on the label but are not part of the fertilizer grade.

A fertilizer grade is used to determine the percentage by weight of plant nutrients in the product. For example, a 100-lb bag of fertilizer with a grade of 30-0-10 contains 30 lb of nitrogen, no phosphate, and 10 lb of potash. A 50-lb bag of the same product would yield 15 lb nitrogen, no phosphate, and 5 lb of potash. Knowing the fertilizer grade is important in determining how much fertilizer to apply to your turf.

Sometimes, a fertilizer ratio is specified on soil test reports or in fertilizer recommendation sheets. The fertilizer ratio indicates the proportion of nitrogen, phosphate, and potash in the product. For example, an 18-6-6 fertilizer contains three parts nitrogen to one part phosphate to one part potash. Thus, this fertilizer has a 3-1-1 fertilizer ratio.

NITROGEN SOURCES IN FERTILIZERS

The source of nitrogen in a fertilizer is important for determining your turf’s growth rate, density, and color. Nitrogen fertilizers can be divided into two categories—quick release and slow release. Quick-release nitrogen sources are soluble in water; hence, nitrogen is available to plants immediately. They also can burn turf more easily than slow-release sources. Slow-release nitrogen sources typically release a portion of their nitrogen over relatively long periods (several weeks to several months).

The relative amounts of quick- and slow-release nitrogen in a fertilizer product are listed on the label as percentages of the total nitrogen (Figure 4). Quick-release nitrogen is designated as ammoniacal nitrogen and/or urea. Slow-release nitrogen is designated as water insoluble nitrogen (WIN) or controlled-release nitrogen. For a more detailed explanation of nitrogen sources, see “Turfgrass Nitrogen Sources” (page 10).

How to calculate a fertilizer ratio

If your soil test report recommends applying 1.5 lb of nitrogen, 0.5 lb of phosphate, and 0.5 lb of potash per 1000 sq ft, you should apply a fertilizer with a ratio of 3-1-1 since you need three times as much nitrogen as phosphate and three times as much nitrogen as potash. The simplest method of determining a ratio is to divide the weights of nitrogen, phosphate, and potash by the lowest weight of the three.

Example:
To determine a fertilizer ratio for a recommendation of 1.5 lb of nitrogen, 0.5 lb of phosphate, and 0.5 lb of potash, divide the weight of each of the three nutrients (1.5 lb, 0.5 lb, 0.5 lb) by the nutrient with the lowest weight (0.5 lb).

$1.5 \div 0.5 = 3$

$0.5 \div 0.5 = 1$

$0.5 \div 0.5 = 1$

Thus, the fertilizer ratio that best fits this recommendation is 3-1-1.

You can also determine fertilizer ratios from fertilizer grades by dividing the percentage of nitrogen, phosphate, and potash by the lowest percentage of the three nutrients.

Example:
Determine ratios for the following fertilizer grades: 21-7-7, 22-6-8, and 18-5-9.

Grade = 21-7-7	Grade = 22-6-8	Grade = 18-5-9
$21 \div 7 = 3$	$22 \div 6 = 3.7$	$18 \div 5 = 3.6$
$7 \div 7 = 1$	$6 \div 6 = 1.0$	$5 \div 5 = 1.0$
$7 \div 7 = 1$	$8 \div 6 = 1.3$	$9 \div 5 = 1.8$
Ratio = 3-1-1	Ratio = 3.7-1-1.3	Ratio = 3.6-1-1.8

How much phosphorus and potassium are really in your fertilizer?

The chemical formulas P_2O_5 and K_2O are the traditional means of expressing the amount of phosphorus (P) and potassium (K) in fertilizer. In fact, no such compounds exist in fertilizers. In the rare event that you have to determine the actual amounts of phosphorus and potassium in your fertilizer, use the following formulas:

$\% P_2O_5 \times 0.44 = \% P$

$\% K_2O \times 0.83 = \% K$

Examples:
A fertilizer containing 20% P_2O_5 has about 9% P (20% P_2O_5 x 0.44 = 8.8% P)

A fertilizer containing 10% K_2O has about 8% K (10% K_2O x 0.83 = 8.3% K)

NOTE: Typically, you do not need to perform these calculations because fertilizer recommendations are almost always provided as lbs P_2O_5/1000 sq ft and lbs K_2O/1000 sq ft.

Figure 4. A fertilizer bag may carry the following label:

Guaranteed Analysis:

Total Nitrogen		20%
10%	Ammoniacal Nitrogen	
3%	Urea	
7%	Water Insoluble Nitrogen	
Available Phosphate (P_2O_5)		10%
Water Soluble Potash (K_2O)		10%

PHYSICAL CHARACTERISTICS OF FERTILIZERS

A fertilizer's physical characteristics determines how easy it is to handle and how evenly it is applied to turf surfaces. Granular fertilizers that contain significant amounts of dust and broken particles make for poor distribution of nutrients, especially when applied through rotary spreaders. Similarly, products containing different-sized granules are not evenly distributed by rotary spreaders because the larger, heavier particles are thrown further from the spreader than smaller, lighter particles. When purchasing a fertilizer, look for a product with uniform particle sizes and minimal amounts of dust and broken granules.

The density of granular fertilizers is also an important physical characteristic. Lightweight fertilizers are thrown for only a short distance by rotary spreaders, resulting in narrow swaths and, thus, the need for more passes by the spreader operator. Also, lightweight particles are easily carried by wind, resulting in poor distribution patterns on windy days. Most professional fertilizer applicators prefer high-density fertilizers because of their improved spreading characteristics.

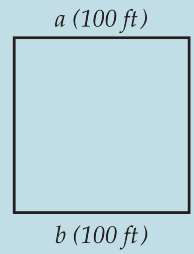
Some turfgrass fertilizers are sold as liquids or as dry formulations that can be dissolved in water for spray applications. Some liquid fertilizer formulations separate into layers when stored for extended periods in cold temperatures. Be sure to follow storage directions carefully when using liquid formulations. Dry fertilizers used for spray applications should not contain impurities that can clog or abrade spray nozzles.

CALCULATIONS USED IN TURFGRASS FERTILIZATION

Proper fertilization practices require that precise amounts of nutrients be delivered to the lawn. Small mistakes in area measurements or fertilizer rate calculations can produce poor results and, sometimes, serious turf injury. Sample problems on page 7 are designed to provide the simplest methods of solving the most frequently encountered questions regarding area measurements and fertilizer rates.

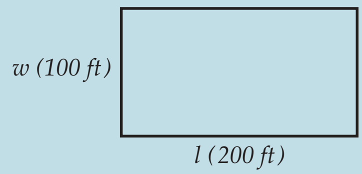
Determining the area of a site to fertilize

Square:



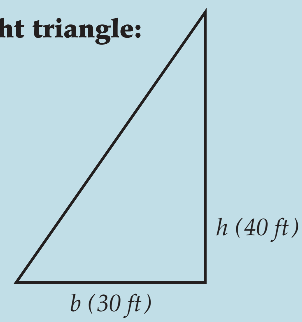
Area = a x b
Area = 100 ft x 100 ft
Area = 10,000 sq ft

Rectangle:



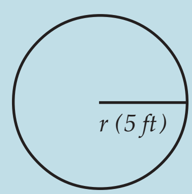
Area = l (length) x w (width)
Area = 200 ft x 100 ft
Area = 20,000 sq ft

Right triangle:



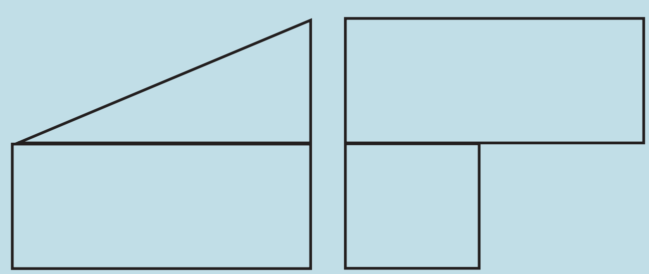
Area = 0.5 x b (base) x h (height)
Area = 0.5 x 30 ft x 40 ft
Area = 600 sq ft

Circle:



Area = (always 3.14) x r^2
Area = 3.14 x 52
Area = 3.14 x 25 ft
Area = 78.5 sq ft

To calculate the area of irregularly shaped lawns, divide the lawn into common shapes, calculate the areas of the shapes, then add the areas together.



Calculations used in turfgrass fertilization

1. A fundamental problem in turfgrass fertilization involves determining how much fertilizer is needed to supply a specified amount of nitrogen (or any other nutrient) per 1000 sq ft. Use the following examples to learn how to solve this type of problem.

Example:
You have a 50-lb bag of 26-5-10 fertilizer that you want to apply to a lawn at a rate of 1.0 lb nitrogen per 1000 sq ft. How much of the 26-5-10 fertilizer will you need to apply per 1000 sq ft?

The quickest way to solve this problem is to ignore the weight of the fertilizer bag and simply divide the amount of nitrogen desired (1.0 lb nitrogen per 1000 sq ft) by the percentage of nitrogen in the bag (26%). When using percentages in calculations, convert the number to its decimal form (for example, 26% = 0.26; 5% = 0.05).

(1.0 lb nitrogen per 1000 sq ft) ÷ 0.26 = 3.8 lb of a 26-5-10 fertilizer is needed to supply 1.0 lb nitrogen per 1000 sq ft

Example:
Find out how much phosphate and potash you are applying to the turf when you apply 3.8 lb of the 26-5-10 fertilizer per 1000 sq ft.

Multiply the amount of fertilizer you are applying (3.8 lb per 1000 sq ft) by the percentage of phosphate in the bag (5%). Do the same for potash (10%). Remember to convert the percentages of phosphate and potash to their decimal forms.

(3.8 lb fertilizer per 1000 sq ft) x 0.05 phosphate = 0.19 lb phosphate per 1000 sq ft

(3.8 lb fertilizer per 1000 sq ft) x 0.10 potash = 0.38 lb potash per 1000 sq ft

2. Another common problem involves determining the area that a bag of fertilizer can cover and how many bags are needed to cover large sites.

Example:
How much area can be covered with a 50-lb bag of 26-5-10 at the rate of 1.0 lb nitrogen per 1000 sq ft?

Now that you know 3.8 lb of 26-5-10 fertilizer will cover 1000 sq ft, determine how many times 3.8 lb goes into 50 lb.

50 lb ÷ 3.8 lb = 13.2

Now multiply 13.2 by 1000 sq ft:
13.2 x 1000 sq ft = 13,200 sq ft.

Thus, a 50-lb bag of 26-5-10 covers 13,200 sq ft at a rate of 1.0 lb nitrogen per 1000 sq ft.

Example:
How many 50-lb bags of 26-5-10 will you need to fertilize a 30,000 sq ft lawn at 1.0 lb nitrogen per 1000 sq ft?

If a 50-lb bag of 26-5-10 fertilizer covers 13,200 sq ft at 1.0 lb nitrogen per 1000 sq ft, determine how many times 13,200 goes into 30,000.

30,000 ÷ 13,200 = 2.3 bags of 26-5-10 will cover 30,000 sq ft.

3. Occasionally, fertilizer recommendations given as lb nitrogen per 1000 sq ft must be converted to lb fertilizer per acre.

Example:
You are treating a large sports turf complex and would like to determine how many lb of a 16-8-8 fertilizer should be applied per acre if the recommendation calls for 0.75 lb nitrogen per 1000 sq ft.

First: Find out how much fertilizer will be needed per 1000 sq ft (see examples in problem 1).

(0.75 lb nitrogen per 1000 sq ft) ÷ 0.16 = 4.7 lb fertilizer per 1000 sq ft

Second: Since there are 43,560 sq ft in an acre, multiply the amount of fertilizer needed per 1000 sq ft by 43,560, then divide by 1000.

(4.7 lb fertilizer x 43,560) ÷ 1000 = 205 lb of a 16-8-8 fertilizer per acre

Nitrogen in Turf

Nitrogen is an essential element for all living things and the mineral element needed in the largest amounts by turfgrasses. Although nitrogen is abundant in the atmosphere (about 80 percent of the air surrounding us is nitrogen gas), it is in limited supply in soils and available to plants only after it has been converted to nitrate (NO_3^-) or ammonium (NH_4^+) by microorganisms or industrial processes. In most cases, nitrogen fertilizer must be applied regularly to maintain high quality turf.

Although nitrogen fertilizer is required for healthy lawns, it can also contaminate ground- and surface waters through leaching and runoff. Excessive nitrate concentrations in drinking water are a health risk, especially for infants, pregnant and nursing mothers, and young children. Nitrogen movement into water can also accelerate degradation of ponds, lakes, coastal bays, and estuaries through a process called eutrophication. Eutrophication refers to the addition of nutrients to surface waters, resulting in algae blooms, dense aquatic plant growth, depletion of oxygen, and, in advanced stages, fish kills.

The goal of a nitrogen fertility program is to optimize plant uptake while minimizing leaching, runoff, and gaseous losses. To achieve this goal, you should understand how nitrogen behaves in the environment and know the conditions that influence its fate.

OPTIMIZING NITROGEN USE

Although soil testing can provide guidelines for how much phosphorus, potassium, and lime turfgrasses need, it does not give reliable information about nitrogen requirements. Just how much nitrogen should be applied depends on the species you are attempting to maintain (and, in some cases, the cultivar), the soil conditions at the site, how the turf is managed, and how the site is used. Also, the amount of nitrogen that turfgrasses take up is influenced by application timing, the source(s) of nitrogen, and the amount of nitrogen applied per application. Designing fertilizer programs for maximum uptake and use of nitrogen by turf is discussed in "Fertilizer Programs" (page 19).

LEACHING

Leaching occurs when irrigation or rainfall carries nitrogen, primarily in the nitrate form, downward through the soil profile. As nitrate moves below plant root systems, it continues to move downward, eventually ending up in groundwater. How much nitrogen is leached from a lawn depends on the soil type; the amount and rate of precipitation; and the nitrogen source, rate, and timing of application.

The greatest potential for leaching is in sandy soils during periods of wet weather or under excessive irrigation, and following applications of quick-release nitrogen at high rates. Leaching can be reduced by using slow-release nitrogen sources on high-sand-content soils or by using low rate applications of quick-release nitrogen sources. Leaching can also be curtailed by restricting nitrogen applications when plants are not actively growing (during midsummer and winter) and/or during extremely wet periods of the year. Since leaching of nitrogen can sometimes occur even in loam soils, be sure always to follow good fertility and irrigation practices.

RUNOFF

When nitrogen is applied to turf, some may be carried in runoff into surface or groundwater. Runoff is water that reaches the turf-soil surface and is not absorbed into the ground or accumulated on the surface, but runs downslope. The rate of runoff is determined by the amount and rate of precipitation, slope, infiltration capacity of soil, geological features of the site, vegetation cover, and cultural practices.

Runoff is most likely to occur following sudden, heavy rainstorms on soils with poor infiltration characteristics that support little or no vegetation. The most significant runoff threat, however, is from impervious surfaces such as sidewalks, driveways, roads, and frozen soils. Some runoff from impervious surfaces is carried into storm sewers and finds its way into surface or groundwater.

Research conducted at Penn State has shown that where a dense, well-established turf exists, the amount of nitrogen removed from the site via runoff is very low—provided the site has good infiltration characteristics. The dense cover of leaves, stems, and thatch of turf slows the rate of surface flow, allowing water and nutrients to infiltrate the soil.

ATMOSPHERIC LOSSES: VOLATILIZATION AND DENITRIFICATION

Volatilization and denitrification can cause atmospheric losses of nitrogen fertilizer. Although these losses usually are not considered a health or pollution hazard, they can reduce the efficiency of nitrogen fertilizer applications, resulting in greater costs and reduced turf quality.

Volatilization occurs when nitrogen is converted to ammonia gas (NH^3) and escapes to the atmosphere. It is more likely to occur following surface applications of urea or ammonium-containing fertilizers. Losses are favored by high soil pH (basic or alkaline conditions), high temperatures, sandy soils, and thatch. Watering-in applications of urea and ammonium-containing fertilizers will reduce volatilization in turfgrass.

Denitrification takes place in saturated soils when anaerobic bacteria (bacteria that survive in the absence of oxygen) convert nitrate to N^2, a gaseous form of nitrogen that escapes into the atmosphere. Turf that survives in poorly drained soils often turns yellow in wet weather owing to denitrification. Improved drainage at these sites will reduce N^2 losses.

Tips for getting the most out of your nitrogen fertilizer

The following are suggestions for maximizing the efficiency of your nitrogen fertilizer program while minimizing losses to leaching, runoff, and the atmosphere.

1. Soil test. Applications of phosphorus, potassium, and lime according to soil test recommendations allow more efficient use of nitrogen fertilizer by turfgrasses.

2. Apply nitrogen in amounts needed by the species you are trying to maintain—more is not necessarily better.

3. On turf, apply nitrogen fertilizer in multiple applications over the growing season so as to meet the needs of your turf at the appropriate time—usually mid to late spring, late summer, and late fall.

4. Returning clippings to lawns can cut nitrogen fertilizer use by up to one-third.

5. Don’t overwater—too much water can leach nitrogen below root systems and into groundwater.

6. Use slow-release fertilizers when making infrequent, high-rate applications in areas where soils are prone to leaching.

7. Keep nitrogen on the lawn and not on pavement. Shut off your spreader when moving across driveways or maintenance roads, or blow or sweep up granules from pavement. In small lawns enclosed by sidewalks and driveways, use a drop spreader or a liquid application for greater accuracy.

8. Do not apply nitrogen to lawns under summer dormancy or on frozen surfaces in winter.

9. Water-in urea or ammonium fertilizers, especially when applications are made in warm weather.

10. Fill and empty fertilizer spreaders in an area where spills can be easily cleaned up. Use your spilled fertilizer—don’t wash it into the street or storm sewers.

Turfgrass Nitrogen Sources

Developing a nitrogen fertility program is an important decision that can affect the quality and durability of your turf. Because of differences in site conditions, uses of turf, level of turf quality desired, and cost considerations, no single program will fit all situations. Fortunately, there are many different turfgrass nitrogen sources that you can use to develop a program to fit your needs.

Before selecting a nitrogen source(s) for your program, understand how quickly the nitrogen in the product is released and under what conditions this occurs. It is also helpful to know how the product is formulated and its potential for burning turf.

QUICK-RELEASE SOURCES

Quick-release nitrogen sources are also called "quickly available," "fast-acting," "soluble," "readily available," and other terms that indicate rapid availability of nitrogen to turf after application. This group includes compounds containing ammonium, nitrate, or urea. Quick-release sources have nitrogen contents ranging from 11 to 46 percent (Table 3) and generally are less expensive than slow-release sources. Being water soluble, they may be applied in liquid as well as in dry form. They give a rapid green-up response, and frequent applications at low rates are suggested for reducing excessive growth and fertilizer burn.

Ammonium and nitrate-containing salts (ammonium nitrate, ammonium sulfate, monammonium phosphate, etc.) are available in granular and, in some cases, sprayable formulations. In water, these nitrogen sources readily dissolve into their positively and negatively charged components. For example, ammonium nitrate (NH_4NO_3) fertilizer mixed with water forms ammonium (NH_4^+) and nitrate (NO_3^-). In soils, bacteria convert ammonium into nitrate through a process called nitrification. Plants may use nitrogen in either the ammonium or the nitrate form, but most nitrogen is taken up as nitrate.

Urea is a synthetic organic fertilizer that contains 46 percent nitrogen. It is available in granular and prilled forms for dry applications and, since it is water soluble, it can be applied as a liquid. Provided there is adequate moisture following application, it reacts quickly with water and the naturally occurring enzyme urease to form ammonium-nitrogen. This reaction usually takes place within 7 to 10 days. Under high pH (alkaline) conditions, volatilization of nitrogen as ammonia may occur from urea and ammonium. Volatilization is also favored by low soil-cation-exchange capacity (sandy soils), drying of moist soil, and high temperatures. Volatilization of ammonia is

Table 3. Some quick-release nitrogen sources used in turfgrass fertilizers.

Source	Chemical formula	Fertilizer grade	Salt index*
Urea	$CO(NH_2)_2$	46-0-0	75
Diammonium phosphate	$(NH_4)_2HPO_4$	20-54-0	34
Monammonium phosphate	$NH_4H_2PO_4$	11-48-0	30
Ammonium nitrate	NH_4NO_3	33-0-0	105
Ammonium sulfate	$(NH_4)_2SO_4$	21-0-0	69
Calcium nitrate	$Ca(NO_3)_2$	16-0-0	53
Potassium nitrate	KNO_3	13-0-44	74

* Salt index is a relative measure of the salinity of fertilizers and indicates the relative burn potential of nitrogen sources (a high salt index indicates a high potential to burn turf). Sodium nitrate is the benchmark value against which all other materials are compared, with a salt index of 100. Salt indices may vary with formulation.

greatest on grass areas, and losses as high as 30 percent of the applied nitrogen have been reported. Watering-in fertilizer keeps such losses to a minimum.

SLOW-RELEASE SOURCES

Slow-release nitrogen sources, also called "controlled-release," "slowly available," "slow acting," and "water insoluble," are an important part of turfgrass fertility programs. They provide a longer duration of nitrogen release than the quick-release sources and are safer to use on turf because of their lower burn potential. Recent studies have shown that under certain conditions, slow-release nitrogen sources are less likely to leach into groundwater than quick-release sources.

Disadvantages of slow-release nitrogen sources include their high price per unit of nitrogen and reduced efficiency (a lower percentage of the applied nitrogen is used by turf in the first year or two of use) compared to quick-release sources. The higher cost and low efficiency have prompted many manufacturers and turf managers to mix or blend both slow- and quick-release sources.

Slow-release nitrogen sources can be grouped into several categories, including the natural organics, ureaform, urea-formaldehyde products, triazones, IBDU, sulfur-coated urea, and polymer-coated nitrogen (Table 4).

Natural organics

For the most part, natural organics are by-products from the plant and animal processing industries or waste products. Examples include hoof, horn, and feather meal; fish scrap and meal; seed meals (cottonseed, linseed, castor pomace); dried and composted manures; activated and composted sewage sludges; and process tankage. Considerable variation exists in the physical and chemical properties of different natural organic fertilizers.

The natural organics can be characterized by relatively low nitrogen contents (usually below 10 percent), the presence of water insoluble nitrogen (WIN), and nitrogen release intermediate between that of quick-release nitrogen sources and extremely slow-release nitrogen sources such as ureaform. Release of nitrogen is dependent on microbial activity and is

Table 4. Some slow-release nitrogen sources used for turfgrass fertilization.

Product	Form*	Grade	%WIN**	%CRN**
Natural organics				
Milorganite	G	6-2-0	92	—
Sustane	G	5-2-4	66	—
Nature Safe	G	8-3-5	85	—
Ringer Turf Restore	G	10-2-6	90	—
Harmony 3-6-3	G	3-6-3	60	—
Ureaform				
Nitroform	G,P	38-0-0	67	—
METH-EX 38	G	38-0-0	67	—
Urea-formaldehyde reaction products				
Nutralene	G	40-0-0	36	—
METH-EX 40	G	40-0-0	36	—
HD Super Fairway	G	35-3-7	83	—
Coron	L	28-0-0	0	70
Triazones				
Formolene Plus	L	30-0-0	0	60
N-Sure	L	28-0-0	0	72
IBDU				
Par-Ex IBDU (coarse)	G	31-0-0	90	—
Par-Ex IBDU (fine)	G	31-0-0	85	—
Sulfur-coated ureas				
Lebanon Pro	G	37-0-0	—	—
Polymer-coated nitrogen				
Polyon	G	43-0-0	—	—
Sulfur Kote II	G	41-0-0	—	—
LESCO Poly Plus Std.	G	39-0-0	—	—
Poly-S	G	40-0-0	—	—
Poly-S	G	38-0-0	—	—
Poly-X Pro	G	37-0-0	—	—

*Form refers to physical state of product, G = granular, P = powder, and L = liquid.
**%WIN is the percentage water insoluble nitrogen of the *total* nitrogen; %CRN is the percentage controlled release nitrogen of the *total* nitrogen.

highly variable among products. Factors influencing nitrogen release are the chemical composition of the material and environmental conditions that influence microbial activity. Environmental conditions affecting breakdown of natural organic fertilizers include temperature, soil moisture and oxygen, and soil pH.

Ureaform

Ureaform is made by reacting urea with formaldehyde in ratios of about 1.3 to 1. Ureaform fertilizers should contain at least 35 percent nitrogen, with at least 60 percent of the total nitrogen being WIN. Urea-formaldehyde products not falling within these guidelines are referred to by other terms such as methylene urea and methylol urea.

Ureaform is divided into three, almost equal fractions based on solubility. Fraction I is soluble in cold water and contains urea, methylene diurea, and dimethylene triurea. Nitrogen availability in this fraction is similar to that of quick-release nitrogen sources, but the nitrogen is not as quickly available. Fraction II is insoluble in cold water but soluble in hot water; it is made up of the slow-release compounds trimethylene tetraurea and tetramethylene pentaurea.

Fraction III, the most slowly available, is insoluble in both hot and cold water and is made up of pentamethylene hexaurea and longer chain polymers. Studies have shown that over a 6–7 month period about 4 percent of Fraction I, 25 percent of Fraction II, and 84 percent of Fraction III remain in the soil. The slow breakdown of Fractions II and III accounts for the low efficiency of ureaform during the first years of use. With continued use and buildup of ureaform, recovery of applied nitrogen improves.

Release of nitrogen from ureaform depends on microbial activity, and the same environmental factors that affect release from natural organics also affect release from ureaform. Because of low nitrogen recovery (efficiency) in the first years of use, you will usually need to use higher rates or supplement ureaform with soluble sources in these years. This low recovery and slow response during cool periods support the concept of fertilization with combinations of ureaform and quick-release nitrogen sources.

Other urea-formaldehyde products

These are also reaction products of urea and formaldehyde but are made with wider ratios of urea to formaldehyde (more urea) than ureaform; thus, they release nitrogen faster. These products contain 30–35 percent nitrogen and are classified "slowly available." However, some contain enough water-soluble nitrogen to give a response closer to quick-release nitrogen sources, such as urea, than to slow-release nitrogen sources. Others can be expected to give a quick initial response, but they have a slightly slower release rate than the quick-release nitrogen sources. Any urea-formaldehyde product that does not claim WIN or claims CRN (controlled-release nitrogen) and not WIN as a percentage of the total nitrogen, will release nitrogen quickly (similar to urea).

Some urea-formaldehyde products are available in liquid form, whereas others are available only as granular fertilizers. They contain mostly water soluble compounds such as unreacted urea, methylol urea, and short polymer methylene ureas (methylene diurea and dimethylene triurea). The amount of each compound in a product is largely dependent on the urea/formaldehyde ratio and the conditions under which the reaction takes place during manufacture. These nitrogen sources are typically more expensive than urea and ammonium and nitrate products, but they are safer since they have reduced fertilizer burn potential.

Triazones

Triazones are water-soluble compounds containing at least 41 percent nitrogen. Triazone mixtures are produced through a reaction involving urea, formaldehyde, and ammonia. On a dry weight basis, triazone products are about 30–36 percent triazones, about 40–50 percent urea, and the remainder, methylol and methylene ureas. Triazones are classified as slow-release nitrogen sources, even though their nitrogen-releasing properties are closer to those of urea than to slow-release nitrogen sources. Although more expensive than urea, triazone products are safer because of their reduced burn potential. Products containing triazones are liquids.

IBDU

IBDU is made by reacting isobutyraldehyde and urea. It contains 31 percent nitrogen, with 90 percent of the total nitrogen being WIN in the coarse (0.7–2.5 mm) product and 85 percent WIN in the fine (0.5–1.0 mm) product. IBDU breaks down slowly in soils because of low solubility, but once in solution, it is hydrolyzed and releases nitrogen. Particle size has a large effect on the release of nitrogen, with smaller particles releasing more quickly. The release rate is faster with higher soil-water content and, to a limited extent, higher temperatures.

In tests at Penn State, we have observed a three- to four-week delay before obtaining a response from IBDU applications on Kentucky bluegrass, but not after applications to an aerated and topdressed putting green. Probably the close contact with wet soil and more liberal irrigation practices enhanced release on the putting green. If the delay in response is considered objectionable, a soluble nitrogen source can be used to supplement the IBDU. We have observed early spring greening with IBDU, and nitrogen recovery from IBDU exceeded that from ureaform during the first and second years of use. We have gotten a quicker response and greater nitrogen recovery from fine than from coarse IBDU.

Sulfur-coated urea

Sulfur-coated urea (SCU) is made by spraying preheated urea prills or granules with molten sulfur. A sealant, such as wax or a mixture of oil and polyethylene, is often applied to seal pores and imperfections in the sulfur. Nitrogen content is usually in the range of 32–38 percent and depends on coating thickness. Increasing the thickness lowers the nitrogen content.

Nitrogen is released from SCU by microbial degradation of the sealant and diffusion of soluble nitrogen through pores and cracks in the sulfur coating. The release rate quickens as coating thickness decreases and as temperature increases. Also, breakage of the coating as a result of mechanical damage or aging enhances the release of nitrogen.

Particles within a SCU product are not identical. If they were, one might expect all of them to release nitrogen at the same time. Quick release occurs with imperfectly coated particles; an intermediate rate of release takes place with particles in which the sealant has covered imperfections; and the greatest delay in release occurs with the more thickly and more perfectly coated particles. Once release begins from a given particle, it is quite rapid. Thus, the slow-release properties of SCU come from the variability in coatings among the individual particles. SCU with sealants have given good response from two applications per year on Kentucky bluegrass turf, and nitrogen efficiency has equaled that of quick-release nitrogen sources. Sealant-free SCU products typically release nitrogen at a slower rate since they have thicker sulfur coatings.

Polymer-coated nitrogen

Polymer-coated nitrogen fertilizers consist of urea, SCU, or other nitrogen sources coated with a thin layer of polymer (plastic) resin. They typically contain about 40 percent nitrogen. Several types of polymer-coated nitrogen fertilizers are available. For nitrogen release to occur from polymer-coated urea, water is absorbed through the coating and dissolves the nitrogen. Nitrogen is then gradually released through the coating by osmosis. Different coating thicknesses may be used to obtain different nitrogen release rates. The thicker the coating, the slower the release. Release increases with a higher temperature and is not significantly influenced by soil moisture levels, volume of water applied, soil pH, or microbial activity.

For the polymer-coated SCUs, water passes through the polymer coating first, then through pores and cracks in the sulfur coating. Since these products do not have wax sealants, no microbial degradation is needed. Nitrogen is released through the openings in the sulfur and diffuses through the polymer to the soil. As with polymer-coated ureas, release rates can be controlled by varying the coating thickness.

Phosphorus in Turf

Phosphorus is one of three primary nutrients needed by turfgrasses as a regular fertilizer addition. Although it is present in small amounts in turfgrass tissues (0.3–0.55 percent on a dry weight basis), phosphorus is extremely important for rooting, seedling development, cell division, and the synthesis of various compounds used by plants. Phosphorus is available to turfgrasses as $H_2PO_4^-$ and $HPO_4^=$ and is mobile in plants (meaning that it can move from one portion of the plant to another).

Phosphorus deficiencies in turf are usually expressed in the early stages of seedling development, appearing as a purple or red coloring of leaf blades and as reduced growth and tillering. Research at Penn State has shown that at least 60 lb of plant-available phosphorus per acre is required for normal growth and development of lawn grasses.

Phosphorus is present in inorganic and organic forms in mineral soils, and both are important sources for plants. Although the total amount of phosphorus in soils can be large, much is unavailable to turf because it forms insoluble complexes with other elements and/or because it is "fixed" to clay particles.

The most important factors affecting phosphorus availability to turfgrasses are soil pH and concentrations of iron, aluminum, manganese, and calcium in soils. In acid soils, the $H_2PO_4^-$ form of phosphorus predominates and combines with iron, aluminum, or manganese to form insoluble compounds that are unavailable to turfgrasses. When the soil pH drops to 5.5 and below, enough phosphorus can be rendered unavailable to cause deficiencies in turf. Also, under acid conditions, some phosphorus can be "fixed" by silicate clays, resulting in reduced availability to plants.

In high-pH soils, $HPO_4^=$ is the most common form of phosphorus. In these soils phosphorus combines with calcium to form insoluble calcium phosphates. As the soil pH approaches 8.0 or above, significant amounts of phosphorus are unavailable to turfgrasses. Maximum amounts of plant-available phosphorus (both inorganic and organic forms) are obtained by keeping the soil pH between 6.0 and 7.0.

Phosphorus can be supplied to turf as inorganic and/or natural organic fertilizers (Table 5). Inorganic phosphorus fertilizers include superphosphates and ammonium phosphates and are manufactured by treating rock phosphate with various acids. Natural organic fertilizers typically contain phosphorus derived from plant or animal by-products. These fertilizers can contain as much as 13 percent phosphorus.

Phosphorus is largely immobile in soils—meaning that it takes a long time to move from the turf surface into the root zone. Phosphorus may take weeks or months to move just a few inches in soil. Because of its poor mobility, phosphorus should be incorporated into the soil prior to seeding or sodding at the amount recommended on your soil test report. Apply the phosphorus to the surface, then incorporate it 4–6 inches deep with a rototiller so that developing roots can use the fertilizer. On estab-

Table 5. Some sources of fertilizer phosphorus.

Sources	Approximate % of available P_2O_5	% Phosphorus
Inorganic		
Ordinary superphosphate	16–21	7–9
Triple (treble) superphosphate	40–47	17–21
Monammonium phosphate	48	21
Diammonium phosphate	46–53	20–23
Natural organic		
Steamed bone meal	23–30	10–13

lished turf, some phosphorus can be incorporated into soil either just before or just after cultivating with a core aerator. Perhaps the best approach to phosphorus fertilization of established turf is to soil test every three years to monitor your phosphorus levels and to use phosphorus-containing fertilizers periodically to maintain adequate levels.

Phosphorus, along with nitrogen, is one of the major nutrient sources contributing to surface- and groundwater pollution in the United States. Although phosphorus is not readily leached from turf soils into groundwater, recent studies of phosphorus fate on cropland have shown that this nutrient can enter surface waters via erosion and runoff. Avoid applying phosphorus fertilizer where runoff is likely—such as on frozen soils and paved surfaces.

Potassium in Turf

Potassium is a primary turfgrass nutrient and is usually supplied annually as fertilizer to lawns. It makes up about 1.0–2.5 percent of the plant's dry weight, and its primary role involves regulating several important physiological processes. Potassium activates plant enzymes used in protein, sugar, and starch synthesis. It also plays a key role in maintaining turgor pressure in plants. Thus, it has a strong influence on drought tolerance, cold hardiness, and disease resistance of turfgrasses. Deficiencies of potassium in turf may be expressed as increased susceptibility to drought, winter injury, and disease.

Although large quantities of potassium are present in soils, only a small fraction is available to plants. Most soil potassium is in unavailable forms as feldspar, muscovite, and biotite minerals. Potassium is available to turfgrasses in the ionic form (K^+) and occurs in the soil solution and on negatively charged soil particles. In general, more plant-available potassium is present in fine-textured mineral soils (soils that contain high amounts of clay) than in sandy soils, especially in areas that receive high amounts of rainfall or are regularly irrigated. The best way to determine potassium needs for turfgrass is through soil testing.

Potassium is mobile in plants and sometimes can be taken up in amounts greater than needed for optimum growth. This phenomenon, called "luxury consumption," is generally considered inefficient use of the nutrient. It is difficult to determine if luxury consumption is a problem in turf culture since very little information is available on the optimum concentrations of potassium in turfgrasses.

Potassium can be supplied to turf using inorganic fertilizers, natural organic fertilizers, or both (Table 6). However, most fertilizer potassium is derived from inorganic sources, in particular, muriate of potash (potassium chloride) and sulfate of potash (potassium sulfate). Both of these fertilizers are water soluble.

Table 6. Sources of fertilizer potassium.

Sources	Approximate % of available K_2O	% Potassium
Muriate of potash (KCl)	60–63	50–52
Sulfate of potash (K_2SO_4)	50–53	44

Although it is readily leached into groundwater, potassium is not a major pollutant in surface- and groundwater in the United States. It rarely is present in concentrations toxic to people or aquatic life, and it does not deplete water of oxygen.

Secondary Nutrients in Turf: Calcium, Magnesium, and Sulfur

Calcium, magnesium, and sulfur are considered secondary nutrients because in most cases they only occasionally need to be supplied to turf in the form of fertilizer. Applications of calcium and magnesium are usually only necessary when your soil pH is below optimum for turfgrass growth. By liming soil when your soil test indicates a need, you are supplying your turf with calcium or calcium- and magnesium-containing limestone. When your soil test indicates a need for calcium but not magnesium, you can use a lime source containing only calcium carbonate. If the soil is low in magnesium, however, use dolomitic limestone since it contains both calcium carbonate and magnesium carbonate (Table 7).

In the rare event that calcium is recommended for a lawn with an adequate pH, you can use gypsum as a source of calcium. Keep in mind that gypsum is not a liming source. Also, despite claims on some gypsum labels, it will not relieve soil compaction or break up clay soils in the northeast United States. Gypsum improves soil structure in sodic and high-salinity soils found in some areas of the western United States.

Sulfur is sometimes used to lower soil pH where a high soil pH can cause turf problems. Sulfur is usually only necessary in western states where arid conditions lead to alkaline soils. In the northeastern United States, high pH values are rarely a problem and there is usually enough sulfur in soils to supply turf needs.

Table 7. Some common sources of calcium, magnesium, and sulfur.

Sources	Approximate nutrient content*
Calcium carbonate (agricultural limestone)	32% calcium
Magnesium/calcium carbonate (dolomitic limestone)	22% calcium
Gypsum	22% calcium
Calcium nitrate	19% calcium
Magnesium/calcium carbonate (dolomitic limestone)	12% magnesium
Epsom salt (magnesium sulfate)	10% magnesium
Ammonium sulfate	24% sulfur
Ferrous sulfate	19% sulfur
Gypsum	19% sulfur
Potassium sulfate	18% sulfur
Elemental sulfur	90% sulfur

*Actual percentages of nutrients may vary depending on purity and source of product.

Micronutrients in Turf

The seven micronutrients (sometimes called trace elements) required by turfgrasses include iron, manganese, zinc, copper, molybdenum, boron, and chlorine. As mentioned earlier, micronutrients are needed by turfgrasses only in minute amounts and rarely need to be supplied to turfgrasses growing in mineral soils. However, when turfgrasses are grown in high-sand-content soils (golf course putting greens and some tees) or high-pH soils, micronutrient applications can be beneficial.

IRON

Iron is an important component of plant enzymes and proteins involved in respiration, nitrogen metabolism, and chlorophyll synthesis. In individual turfgrass plants iron deficiencies appear as chlorosis (yellowing) of the youngest (upper) leaves. Turf deficiency symptoms show up as yellow mottling, rather than the uniform yellowing observed in nitrogen-deficient turf.

Most soils in the northeastern United States contain adequate levels of iron, and deficiencies are rare. In unusual cases where excessive liming has occurred or irrigation water contains high bicarbonate levels, the uptake and/or translocation of iron by turf may be reduced. This problem, sometimes referred to as lime-induced chlorosis, can be corrected by acidifying the soil and by supplying iron-containing fertilizers.

In the northeastern United States, iron fertilizer is applied by turfgrass managers to enhance turf color without stimulating excessive leaf growth. Iron applications can produce darker green turf even when levels are adequate in plant tissues before applications are made. By reducing the rate of nitrogen fertilizer and supplementing with small amounts of iron, a noticeable turf green-up can be achieved with fewer of the negative aspects associated with excessive nitrogen fertilization, such as frequent mowing and outbreaks of certain diseases.

The most common forms of iron fertilizer for turfgrasses are inorganic iron salts and organic iron chelates (chelated iron) (Table 8). An inorganic iron salt is a water-soluble form of iron that contains iron or iron and ammonium paired with sulfate (e.g., ferrous sulfate, ferric sulfate, or ferrous ammonium sulfate). Since turfgrasses can absorb iron from these products through foliage, the prod-

Chelated micronutrients

Iron, zinc, manganese, and/or copper often occur in forms that are not taken up by plants. This problem is especially marked if the soil has a high pH (8.0 or above). One way of correcting this problem is to apply the nutrient as a chelate. Chelate comes from the Greek word "clawlike" and denotes a soluble and stable product formed when an organic compound called a chelating agent bonds to the nutrient. The chelating agent keeps the nutrient in solution and releases it at the root surface where it is absorbed into the plant. Chelated nutrients can also be absorbed through turf foliage.

The most common commercial chelating agents used in the turfgrass industry are EDTA (ethylenediaminetetraacetic acid) and DTPA (diethylenetriaminepentaacetic acid). EDTA chelates iron at a pH of less than 6.3; above a pH of 6.8 it reacts with calcium, rendering it ineffective. DTPA chelates iron up to a pH of 7.5; above 7.5, calcium interferes with solubility, making it ineffective.

Chelates have been shown to be superior sources of iron, zinc, manganese, and/or copper since lower rates of chelated micronutrients can achieve the same results as higher rates of inorganic sources. Because lower rates can be used, the potential for plant injury is reduced. However, the cost of chelated micronutrients may be considerably higher than that of inorganic sources.

ucts are typically applied as foliar sprays. In soil applications, much of the iron from inorganic sources is converted to insoluble iron hydroxides, iron phosphates, or iron carbonates—compounds that are unavailable to turfgrasses.

Chelated iron sources are usually more efficient at supplying plants with iron than inorganic iron salts. Recent studies have shown that about 2 lb of iron per acre from iron chelate provides the same color enhancement of Kentucky bluegrass as 4 lb iron per acre from inorganic iron sulfate. Since lower rates of chelated iron can be used to obtain a dark green turf, there is less chance of injuring turfgrass with an iron application.

Rates of iron fertilizer for lawn grasses can vary depending on the source, time of year, and number of applications. Generally, a rate of 2 lb of iron per acre from chelated iron is adequate for a noticeable turf green-up. Turf green-up from iron applications can last between several weeks and several months, depending on weather conditions following application. Applications during cool, wet periods (when turf is growing rapidly) enhance color for only two to three weeks, whereas applications during cool, dry periods (when growth of turf is slow) may last for several months.

Excessive amounts of iron can cause noticeable discoloration (a black-green color) in turfgrasses and, in some cases, may injure them. The degree of injury depends on the type of turf, the rate of iron, and the environmental and management conditions at the time of application. Some temporary blackening of Kentucky bluegrass foliage has been observed with as little as 4 lb of iron per acre, from both inorganic and chelated sources. Some dieback of Kentucky bluegrass foliage can occur with rates higher than 15 lb iron per acre.

Table 8. Some common fertilizer sources of iron.

Source	Approximate iron content*
Ferrous sulfate	19%
Ferric sulfate	23%
Ferrous ammonium sulfate	14%
Iron chelates:	
NaFeDTPA	10%
NaFeEDTA	5–9%

*Actual percentages of iron may vary depending on purity and source of product.

Table 9. Some common fertilizer sources of micronutrients (manganese, zinc, copper, molybdenum, boron, and chlorine).

Sources	Approximate nutrient content*
Manganese:	
manganese sulfate and manganese oxide	0.05–7.27% manganese
manganese EDTA	0.05% manganese
Zinc:	
zinc sulfate and zinc oxide	0.05–1.3% zinc
zinc EDTA	0.05% zinc
Copper:	
copper oxide	0.05–0.5% copper
copper EDTA	0.05% copper
Molybdenum:	
sodium molybdate	0.0005–0.026% molybdenum
Boron:	
boric acid	0.02% boron
Chlorine:	
potassium chloride	< 10% chloride

*Actual percentages of nutrients may vary depending on purity and source of product.

OTHER MICRONUTRIENTS

Unless your soil has a high pH (greater than 8.0) and the texture is extremely sandy, micronutrient fertilizer applications are probably not needed. In fact, micronutrients other than iron are rarely beneficial and are sometimes harmful when applied to turfgrasses. Boron, for example, is toxic to turfgrasses even when applied in small amounts. Indiscriminate use of copper can lead to deficiencies of iron in turfgrasses. If you are managing turf in high-sand-content soils, work with a reputable soil and tissue testing lab to determine if micronutrient supplements are needed. If they are, use high-quality turfgrass fertilizers containing only the micronutrients that you need to correct the deficiency (Table 9).

Fertilizer Programs

No single turfgrass fertilizer program is ideal for all lawns, athletic fields, and golf courses. The type and amount of fertilizer you use and the timing of your applications will depend on many factors, including grass species and cultivars, soil type, management practices, how the turf is used, and the users' expectations.

Turfgrass species differ in the amount of fertilizer, especially nitrogen fertilizer, that they require for best performance (Table 10). Kentucky bluegrass and perennial ryegrass typically need 3–4 lb nitrogen per 1000 sq ft per year, whereas the fine fescues respond best to about 2–3 lb nitrogen per 1000 sq ft per year. If Kentucky bluegrass turf is fertilized only with 1 or 2 lb of nitrogen per 1000 sq ft during the growing season, it will usually become light green or yellow, thin, and more susceptible to pest damage.

Table 10. Annual nitrogen requirements for turfgrass species used in the northeastern United States.

Turfgrass species	Amount of nitrogen required each growing season* (lb/1000 sq ft)
Kentucky bluegrass	3–4
Rough bluegrass	3–4
Perennial ryegrass	3–4
Annual ryegrass	2–3
Tall fescue	2–3
Fine fescues (creeping red, Chewings, hard, and sheep)	2–3
Creeping bentgrass	3–6

* Use rates in the high range for turf grown in infertile soils, when clippings are removed from the site, and in high traffic areas. Rates in the low range can be used for turf grown in inherently fertile soils and when clippings are returned to the turf.

In contrast, if a fine fescue turf receives nitrogen in amounts required by Kentucky bluegrass (3–4 lb nitrogen per 1000 sq ft per year), it can become more susceptible to drought, heat stress, and some diseases. Therefore, be sure to identify the species you are managing and to adjust your fertility program accordingly. With lawns containing mixtures of species, fertility programs are usually designed to favor the most desirable species.

Turfgrass cultivars can also vary in their nitrogen requirements. However, specific recommendations for individual cultivars are seldom made because nitrogen requirements have not been determined for most new cultivars. In addition, many managers have no way of knowing which cultivars are present in the turf.

Turfgrass fertilizer programs will vary with soil quality and type. Turfgrasses growing on sites where much of the topsoil has been removed or in sandy soils usually require more fertilizer than turf growing in good-quality topsoils. This is because of the lower amounts of nutrients found in poor-quality soils and the fact that nitrogen is more easily leached from sandy soils. Improving poor-quality soils with additions of organic amendments, such as good-quality compost, can improve soil structure, add nutrients, and enhance nutrient retention, thus reducing fertilizer needs.

Management practices such as mowing and irrigation can significantly influence the amount of fertilizer that turfgrasses will need. By returning grass clippings to your lawn you can reduce nitrogen, phosphorus, and potassium fertilizer needs by up to one-third. Lawns irrigated often during the summer months will use more fertilizer than those not irrigated.

How the turf is used also dictates how much fertilizer is needed. For instance, turfgrasses growing in high traffic areas, such as athletic fields, usually require more fertilizer for better recovery from wear than low traffic areas. Roadside turf, used to create a buffer between lanes on highways and to control erosion on banks, generally receives little or no fertilizer since aesthetics is not a primary goal and mowing must be kept to a minimum.

Ultimately, users will have differing expectations concerning the function and aesthetics of turfgrass areas. Thus, fertilizer programs will vary according to these expectations.

APPLICATION FREQUENCY

The number of fertilizer applications you make during the growing season is just as important as the amount and type of fertilizer you use. To maintain high-quality turf, two or more fertilizer applications per year are generally required. If only two applications are made, higher rates of nitrogen (1.25 to 1.5 lb nitrogen per 1000 sq ft per application) are usually necessary. In this case, fertilizers containing slow-release nitrogen sources are desirable since the nitrogen is released gradually over extended periods and turf burning is less likely.

In most cases, fertilizer programs involve more than two and as many as five applications per year. These programs allow more flexibility in application rate and nitrogen source than two-application programs since there is less time between applications. A four application per year program, for example, can involve rates less than 1 lb nitrogen per 1000 sq ft per application. These lower rates allow the use of quick-release nitrogen sources.

SCHEDULING FERTILIZER APPLICATIONS

The best times of year to fertilize cool-season turfgrasses are in late summer, late fall, and mid to late spring. Sometimes, two spring applications may be desirable—one in early spring and another in late spring. Fertilizers applied to turf during periods of heat and drought in midsummer can stress plants and lead to injury.

The most important time of year to fertilize turfgrasses is late summer (early to mid September). Fertilizer is very necessary at this time because it promotes recovery from drought and heat-related injury sustained during midsummer. Late summer to early fall is also the time of year that cool-season grasses begin to manufacture and store carbohydrates. Carbohydrates are used by turfgrasses for root and rhizome growth, disease and stress tolerance, and protection from winter injury. Nitrogen applied during late summer stimulates foliar growth, but not to the extent that occurs in spring. Thus, slightly higher rates of nitrogen (1.0–1.5 lb nitrogen per 1000 sq ft) can be used for late summer application.

An application of fertilizer in late fall can serve as a replacement for an early spring application. Late fall, in this case, is the time that foliar growth slows or stops, but soils are not frozen. In most areas of Pennsylvania, late fall fertilization should take place in mid to late November.

The advantages of late fall fertilization over early spring fertilization are: (1) nitrogen taken up by turf in late fall is used primarily for and by roots (before the soil freezes); (2) little, if any, foliar growth occurs; and (3) carbohydrates are not exhausted as quickly when late fall fertilizer applications are made in place of early spring applications. If done correctly, late fall fertilization provides early and noticeable turf green-up in spring with less foliar growth. Excess growth is often associated with high rates of nitrogen applied in early spring.

The main disadvantage of late fall fertilization is that, in some situations, nitrogen leaching may occur. Consequently, this practice should not be performed on sandy soils with quick-release nitrogen fertilizers. Slow-release nitrogen sources, such as natural organics and IBDU, are ideal for late fall applications mostly because they are not as likely to leach as quick-release sources.

If late fall fertilizer applications are not made, a small amount of fertilizer may be desirable in early spring. Applying high rates of nitrogen to turf in early spring produces excessive foliar growth and forces plants to use up valuable food reserves needed for root growth and disease resistance. Thus, lower rates should be used. Typically, rates of 0.5 to 0.75 lb nitrogen per 1000 sq ft allow early spring green-up of lawns without excessive foliar growth. Since 0.5 lb nitrogen per 1000 sq ft does not supply enough nitrogen to carry the turf through the summer months, a late spring application is probably needed. A late spring application can be made in late May or early June; rates can vary from 0.75 lb to 1.5 lb nitrogen per 1000 sq ft. A fertilizer containing some slow-release nitrogen is desirable at this time of year because it can supply limited amounts of nitrogen to turf in early to midsummer.

POTASSIUM AND PHOSPHORUS

Recommendations from a soil test lab should specify the amounts of phosphorus and potassium (usually in lb phosphate and potash per 1000 sq ft) your turf needs. The rate of phosphate applied in a single application should be similar to rates of nitrogen (0.5–1.5 lb per 1000 sq ft) or slightly higher (2 lb phosphate per 1000 sq ft), but it should not exceed 5 lb phosphate per 1000 sq ft. Potassium is usually applied at rates of 0.5 to 2.0 lb potash per 1000 sq ft.

EXAMPLES OF LAWN FERTILIZER PROGRAMS

The three sample fertilizer programs at right are designed for medium- to high-maintenance lawns growing under environmental conditions and soils found in central Pennsylvania.

Example of a fertilizer program for a perennial ryegrass and/or kentucky bluegrass lawn (clippings returned)*

Dates of application	Nutrients/1000 sq ft
May 1–June 10	1.25 lb nitrogen (20% or more as WIN, CRN, or a coated nitrogen source**)
	0.5 lb phosphate
	0.5 lb potash
Sept. 1–Sept. 20	1.5 lb nitrogen (20% or more as WIN, CRN, or a coated nitrogen source**)
	0.5 lb phosphate
	0.5 lb potash
Nov. 10–Nov. 30	1.25 lb nitrogen (50% or more as WIN, CRN, or a coated nitrogen source**)
	0.75 lb potash

* If soil test indicates high levels of phosphate and potash, omit from program and use nitrogen sources only. If soil test indicates phosphate and potash are needed, use fertilizer with high proportions of each nutrient.
** WIN = water insoluble nitrogen, CRN = controlled release nitrogen; coated nitrogen sources can include sulfur-coated urea or polymer-coated nitrogen.

Example of a fertilizer program for a fine fescue lawn (clippings returned)*

Dates of application	Nutrients/1000 sq ft
May 1–June 10	1.0 lb nitrogen (20% or more as WIN, CRN, or a coated nitrogen source**)
	0.5 lb phosphate
	0.5 lb potash
Sept. 1–Sept. 20	1.0–1.5 lb nitrogen (20% or more as WIN, CRN, or a coated nitrogen source**)
	0.5 lb phosphate
	0.5 lb potash

* If soil test indicates high levels of phosphate and potash, omit from program and use nitrogen sources only. If soil test indicates phosphate and potash are needed, use fertilizer with high proportions of each nutrient.
** WIN = water insoluble nitrogen, CRN = controlled release nitrogen; coated nitrogen sources can include sulfur-coated urea or polymer-coated nitrogen.

Example of a fertilizer program for a tall fescue lawn (clippings returned).*

Dates of application	Nutrients/1000 sq ft
May 1–June 10	1.0 lb nitrogen (20% or more as WIN, CRN, or a coated nitrogen source**)
	0.5 lb phosphate
	0.5 lb potash
Sept. 1–Sept. 20	1.0 lb nitrogen (20% or more as WIN, CRN, or a coated nitrogen source**)
	0.5 lb phosphate
	0.5 lb potash
Nov. 10–Nov. 30	1.0 lb nitrogen (50% or more as WIN, CRN, or a coated nitrogen source**)
	0.75 lb potash

* If soil test indicates high levels of phosphate and potash, omit from program and use nitrogen sources only. If soil test indicates phosphate and potash are needed, use fertilizer with high proportions of each nutrient.
** WIN = water insoluble nitrogen, CRN = controlled release nitrogen; coated nitrogen sources can include sulfur-coated urea or polymer-coated nitrogen.

Prepared by Peter Landschoot, professor of turfgrass science

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