Turfgrass Fertilization, Part I

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.

By Peter J. Landschoot

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.

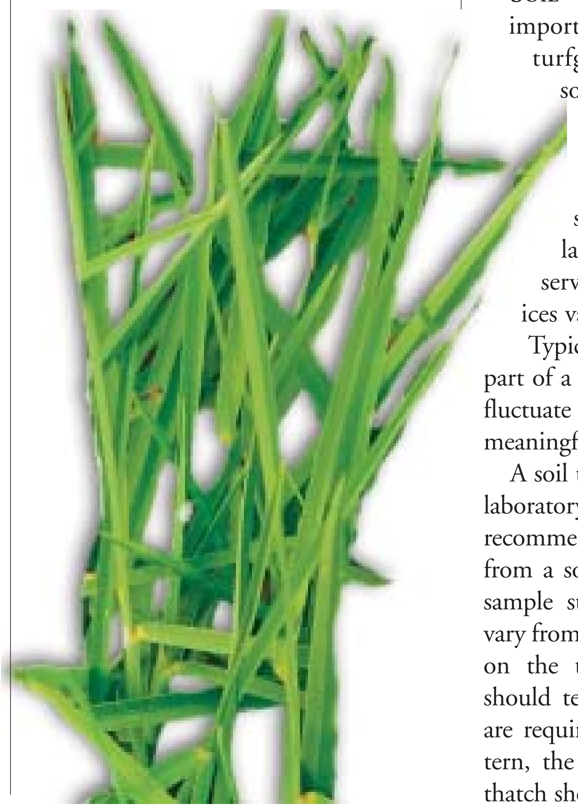
Turfgrasses require at least 16 nutrients for normal growth and development. Some nutrients are needed in large amounts, other nutrients only in minute quantities. Regardless of the amount required, a deficiency of any of these nutrients will limit the growth and development of your turf. Thus, calcium 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 16 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 micronutrients. 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 and water.

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.

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.



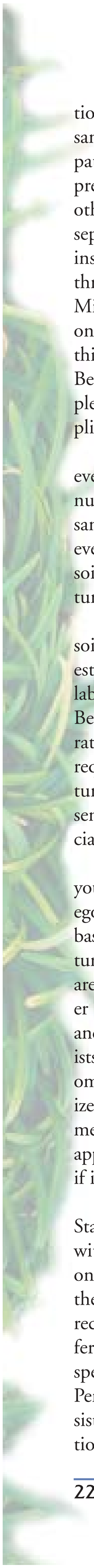
Deficiencies of nutrients in turfgrass plants can be expressed in numerous ways. The most obvious is a reddening or yellowing of leaf tissues. Deficiencies can also appear as a thinning of the stand, stunted growth, and increased susceptibility to disease. Ideally, fertilizer should be applied before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

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.

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 instruction on the test kit carefully. Instructions should tell you how many sub-samples 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 sub-samples per location in a regular grid pattern. 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 two to three in. in depth and discarding thatch. Mix all sub-samples together to make one sample, then take about 1/3 pint of this mix and place it in the mailing kit. 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 turfgrasses.

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.

Interpretation of soil test results allows your nutrient levels to be placed into categories such as low, adequate, or high based on the research and experience of turfgrass specialists. Recommendations are usually provided as pounds of fertilizer per 1,000 sq ft (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 way to diagnose 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 the 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. The three numbers are referred to as the fertilizer grade.

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 of nitrogen, no phosphate, and five 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, the 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.

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.

Physical Characteristics of Fertilizers. A fertilizer's physical characteristics determine 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.

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 turf. Small mistakes in area measurement or fertilizer rate calculations can produce poor results and, sometimes, serious turf injury.

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 groundwater 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 eutrophication.

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.

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 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 mid-summer and winter) and/or during extremely wet periods of the year. Since leaching of nitrogen can sometimes occur even in loam soils, be sure to follow good fertility and irrigation practices.

RUNOFF. When nitrogen is applied to turf, some may be carried in runoff into surface or groundwater. 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. 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 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, 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 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.

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

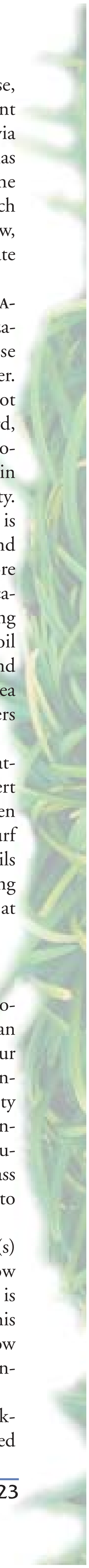


Table 1. Quick-Release Nitrogen Sources Used in Turfgrass Fertilizers

Source	Chemical Formula	Fertilizer Grade	Salt Index[1]
Urea	$CO(NH_2)_2$	46-0-0	75
Diammonium phosphate	$(NH_4)_2$	20-54-0	34
Monammonium phosphate	$NH_4H_2PO_4$	11-48-0	34
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

[1] 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.

"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 1) 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 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 positive 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 seven to ten days. Under high pH (alkaline) conditions, volatilization of nitrogen as ammonia may occur from urea and ammonium. Volatilization is favored by low soil-cation-exchange capacity (sandy soils), drying of moist soil, and high temperatures. Volatilization of ammonia is 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 2—see next page).

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 ten 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 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 1:3:1. Ureaform fertilizers should contain at least 35 percent nitrogen, with at least 60 percent of the total nitrogen being WIN. Ureaformaldehyde products not falling within these guidelines are referred to by other terms such as methylene urea and methyol 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

Table 2. Some Slow-Release Nitrogen Sources Used for Turfgrass Fertilization

Product	Form[1]	Grade	WIN (%)[2]	CRN (%)[2]
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	—	—

[1] Form refers to physical state of product: G =Granular, P = Powder, L = Liquid.

[2] WIN (%) is the percentage water insoluble nitrogen of the *total* nitrogen; CRN (%) is the percentage controlled release nitrogen of the *total* nitrogen.

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 six- to seven-month period about four 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 controlled-release nitrogen (CRN) 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 ration 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 50 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

Phosphorous 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 turfgrasses.

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, man-

Table 3. Some Sources of Fertilizer Phosphorus

Sources	Approximate 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

Table 4. Sources of Fertilizer Potassium

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

ganese, 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 3). 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 before seeding or sodding at the amount recommended on your soil test report. Apply the phosphorus to the surface, then incorporate it 4-6 in. deep with a rototiller so that developing roots can use the fertilizer. On established 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 among 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 on cropland have shown that this nutrient can enter surface waters via erosion and runoff.

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 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 4). 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.

In the July/August 2005 issue of *Government Engineering*, "Turfgrass Fertilization, Part 2" will discuss secondary nutrients like calcium, magnesium, and sulfur in turf; micronutrients in turf; and fertilizer programs.

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