Turfgrass Fertilization

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Plants are unique in that they derive their energy for growth from the basic elements of soil minerals, light, water and air. They do not require any organic constituents for growth. Since the early work of Liebig in the mid-1800's that established the role of minerals in plant growth, we have tended to emphasize fertilization as the solution to plant nutrition problems. Yet the fertilizer nutrients (NO_3^-, NH_4^+,K^+, $H_2PO_4^-$) do not provide the energy plants need for growth. These nutrients are only the raw materials which together with sunlight, water and carbon dioxide enables the plant to produce the organic compounds necessary for growth-sugars, starch, amino acids, etc. Consequently, when we evaluate the nutrient needs of a turf we must consider factors such as nutrient levels, nutrient availability and interactions between nutrients; and, we must also consider environmental conditions that determine the availability of the nutrients to the grass.

Nutrient Availability. Grass obtains the nutrients it needs from soil minerals, organic matter, fertilizer and to a lesser extent from the atmosphere. Deficiencies of one or more nutrients may occur because of several reasons:

1. the nutrient may be lacking in the soil or in the environment.
2. the nutrient may be tied-up or too slowly available, or
3. there may be an in balance between nutrients.

For nutrients to be taken up by the grass they must be present in a form that the plant can use. Nitrogen is not taken up as elemental nitrogen (N_2) from the air, but as nitrate (NO_3^-) or ammonium (NH_4^+) from the soil. Likewise, phosphorus and potassium may be present in the mineral form in large concentrations, but they must be in available forms ($H_2PO_4^-$, and K^+) to be taken up by the grass. Nutrients in the available form are readily soluble in water and are taken up with water by grass roots. However, depending on management and environmental conditions, these nutrients may be lost by leaching or volatilization or they may be utilized by soil microorganisms before taken up by the grass. A brief discussion of nutrient availability in relation to each fertilizer nutrient may help explain some of the responses obtained from fertilizer applications.

Nitrogen. Grasses may obtain nitrogen from organic matter, but fertilizers provide the major source of nitrogen to turfgrasses. Organic matter, organic fertilizers and some slow release fertilizers contain organic nitrogen that must be broken down by soil microorganisms before the nitrogen can be used by the grass. This transformation is called mineralization and may be described as follows:

R-NH2 + H2O + microbes ® NH4+
(organic N) (water) (ammonium)

The ammonium (NH4+) form of nitrogen may be taken up by the grass or may be transformed to nitrate (NO3-). The latter transformation is called nitrification and may be described as follows:

NH4+ + 2 O2 + microbes ® NO3- + H2O + 2H+
(ammonium N) (nitrate N)

Note the acidifying effect of nitrification (2 hydrogen ions). These transformations are dependent upon soil microbes and are sensitive to a number of environmental conditions. They do not occur below freezing temperatures and are slow to take place in poorly aerated soils, very dry soils or very wet soils and in highly acid soils. Thus, the application of an organic source of nitrogen or ureaformaldehyde does not necessarily provide the grass with its nitrogen requirement. Environmental conditions (temperature, moisture, compaction, pH, etc.) may prevent or restrict the transformations necessary for conversion to available forms of nitrogen. Since aeration is not adequate due to compaction or overwatering in many soils on which turfgrasses are maintained, nitrification is often inhibited and ammonium (NH4+) tends to accumulate. When NH4+ accumulates, nitrogen losses due to volatilization may be excessive.

On the other hand, nitrification may be very rapid in soils moistened by rain or irrigation after being dry for a prolonged period. In this case, the grass may be over stimulated or nitrogen losses due to leaching may be excessive.

Since the nitrate (NO3-) form of nitrogen is highly soluble in water, it is readily moved below the rootzone of grasses following heavy rainfall or irrigation. This leaching is most likely to occur during dormant periods or when the grass is not growing vigorously. Thus, leaching may account for a significant loss of nitrogen during the winter.

Nitrification

- Does Not occur Below Freezing
- Insignificant Above 105°F.
- Slow in Acid Soils

- Very Slow in Compacted or Poorly Aerated Soils
- Limited in Dry or Wet Soils

Mineralization and nitrification serve to convert nitrogen from an organic source to a form that is available to the grass. However, environmental conditions may favor plant uptake or nitrogen loss through leaching or volatilization.

Denitrification is the conversion of nitrate nitrogen to gaseous elemental nitrogen which is lost to the atmosphere. This process is favored by low oxygen levels in the soil, high soil moisture, alkaline soils and high temperatures. Denitrification can account for 10 to 30% losses of applied nitrogen under compacted soil conditions or waterlogged soils particularly where soils are alkaline (pH 7.5-8.5).

NO3- ® NO2 ® N2O ® N2
(nitrate N) (elemental nitrogen)

Other soil conditions may favor the loss of nitrogen through volatilization. Volatilization involves the conversion of ammonium nitrogen to ammonia gas which is lost to the atmosphere. This process is favored by alkaline soils, warm temperatures, dry soils and soils with a low exchange capacity. Where conditions favor volatilization 30% or more of the applied nitrogen may be lost to the atmosphere. The classic example of this method of losing nitrogen is the application of ammonium fertilizer to alkaline soils:

2NH4+ + CaCO3 D 2NH3 + H2CO3 + Ca++
(lime) (ammonia)

Nitrate (NO3) is Lost from Soil By:

- Leaching
- Soil Microorganisms
- Taken Up By Grass
- Denitrified
- Volatilized

Nitrogen fixation is the conversion of elemental nitrogen (N2) from the air to a form that can be used by plants. Nitrogen is fixed in nodules formed on the roots of grasses and legumes by bacteria that grow in close association with the roots. The nitrogen fixed by the bacteria is recycled through the turf following the decay of plant parts. Thus, the need for nitrogen fertilizer may be reduced. Grasses and legumes can be inoculated with the bacteria to promote the biological fixation of nitrogen. Inoculated legume plants grown on cropland in the U.S. are estimated to fix 12 million tons of atmospheric nitrogen per year.

To date, there are no known bacteria and host grasses that produce sufficient nitrogen for turf maintenance. Although some grasses may be able to survive on the nitrogen levels produced, they would not be suitable for turf.

Nitrogen Sources for Turfgrasses

Turf can be grown without N fertilizers, but not to today's standards. Mineralization of organic matter, nitrogen fixing microorganisms, and nitrogen oxidized by lightning and dispersed by rainfall all contribute to the natural supply of nitrogen. Where demands on grass are low, these natural sources may be adequate. But, hybrid turfgrasses, the promotion of dark green color as being standard, widespread use of automatic lawn sprinklers, and the advent of commercial lawn care have all prompted greater use of nitrogen fertilizers.

When evaluating a nitrogen source for turfgrass use, availability from suppliers, nitrogen release rate, mechanism of nitrogen release, cost, burning potential, nitrogen residual, salinity hazard and turf response must be considered. Perhaps the most important, yet most difficult to measure, characteristic of nitrogen sources is turf response. Traditionally, turf response has been evaluated by color and growth rate (yield). These responses are relatively easy to measure, but they are not the most important criteria for determining turf quality. Root growth, carbohydrate reserves, shoot density and stress tolerance are the most important turf responses to nitrogen; however, they are more difficult to measure than color and growth rate. Thus, we frequently rely on color and growth rate to evaluate the response of turfgrasses to nitrogen sources.

When using growth rate to evaluate the response of nitrogen sources, we must consider the seasonal growth patterns of turfgrasses. Even with no supplemental nitrogen, grasses have periods of high and very low growth rates. Warm season turfgrasses should not be fertilized with high rates (above 1 lb/1,000 sq. ft.) of nitrogen sources immediately prior to or during periods of rapid growth (late spring and summer). Likewise, cool season turfgrasses should not receive high rates of nitrogen in the early spring or summer. By carefully timing nitrogen applications the growth periods can be extended and the peaks and valleys moderated to some extent. Also, using slow-release and organic nitrogen sources along with soluble sources to build up levels of "residual" nitrogen can help to maintain uniform growth rates.

Soluble Nitrogen Sources. Urea, ammonium sulfate, potassium nitrate and ammonium nitrate are commonly used soluble nitrogen sources. A soluble nitrogen source provides a readily available supply of nitrogen to the turf. Following the application of a soluble nitrogen source to turf, the growth rate increases sharply about 2 days after application, reaches a peak growth rate in 7 to 10 days after application and tapers off to the original growth rate in 4 to 6 weeks depending on the rate of application. If we carry this response to the extreme and apply very small amounts of soluble nitrogen on a daily schedule, a uniform growth rate could be produced. The only practical method of applying nitrogen on a daily schedule would require applying nitrogen through the irrigation system-fertigation.

The "peaks" and "valleys" in growth rate observed between applications of soluble nitrogen fertilizers may not be obvious on frequently mowed turf areas, but they can have a detrimental effect on the grass. Short bursts of growth after fertilizer application followed by a period of slow growth can deplete carbohydrate reserves in the grass, reduce root development and eventually thin a turf. These effects are not readily apparent by observing growth rate and color responses to fertilization. Long term observations and responses to stress would more accurately establish the effect of soluble nitrogen sources on turf.

At rates of application above 0.5 pound of N per 1,000 sq. ft., soluble sources may desiccate or burn the foliage if not watered into the turf shortly after application. A commercial lawn service organization cannot depend on the homeowner to water the lawn as needed. Also, at rates above 0.5 pound of N per 1,000 sq. ft. soluble N fertilizers produce a burst of growth for a short period after application. This is not desirable from the standpoint of mowing, watering and other maintenance requirements. Also, excessive leaf growth depletes the grass of energy reserves, retards root growth and increases the susceptibility of the grass to insects and diseases. Finally, soluble N sources have only a 4 to 6 week residual after which N supply is exhausted.

In their favor, soluble N sources are the lowest cost per pound of N, produce a rapid greening response, are effective at all temperature extremes, and are suited to either liquid or dry programs. Where N can be applied at 0.5 pound per 1,000 at monthly intervals, the soluble products are the choice of most applicators. However, the need for frequent applications limits their use in most lawn service operations.

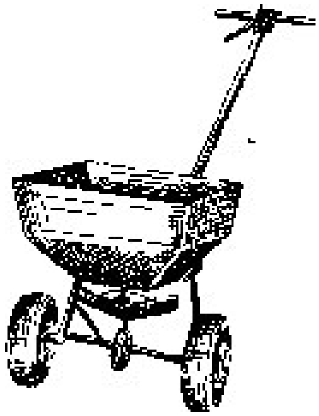
A relatively new product-Formolene (methylol urea)-overcomes several of the shortcomings of the soluble N sources, but does not have a long residual. The methylol urea has a greatly reduced burn potential and 1.0 to 1.5 pounds of N per 1,000 sq. ft. can be applied in a single application without burning the foliage. Also, the product does not produce the rapid burst of growth produced by other soluble N fertilizers. However, the residual is only slightly greater than soluble N fertilizers. A further disadvantage is that the product is tightly bound to the foliage and clipping removal after application can remove significant amounts of nitrogen. Formolene is a liquid concentration with 25 to 30% nitrogen. It mixes readily with other fertilizer nutrients and pesticides and is well suited to liquid applications. The user should be advised not to remove the grass clippings for at least two mowings after application.

Slow Release Nitrogen Sources. A low, uniform supply of available nitrogen during the growing season is the objective of most turfgrass fertilizer programs. Such a program is difficult to accomplish without the use of slow release sources of nitrogen. "Residual" soil nitrogen-that which becomes available to the grass over a relatively long period of time-cannot be built up with soluble materials. Slow-release nitrogen sources build up "residual" soil nitrogen that is made available to the grass at varying rates. The rate at which "residual" nitrogen is made available (released) may vary with nitrogen source, temperature, moisture, pH, particle size and time of application. Knowledge of a particular nitrogen source and of conditions favorable for nitrogen release is necessary for a turf manager to determine the timing and rates of application of slow-release fertilizers.

Urea-formaldehyde (UF). Urea-formaldehydes (UF) are products of reacting urea with formaldehyde under carefully controlled temperatures, pH and reaction times. The nitrogen release characteristics of the UF produced are determined by the ratio of urea to formaldehyde in the product. Methylene urea has a ratio of 1.9 to 1 and is 2/3 water soluble and 1/3 water insoluble. Other UF products such as Nitroform and Fluf have a ratio of urea to formaldehyde of 1.3 to 1 and are 1/3 water soluble and 2/3 water insoluble. The rate of nitrogen release of these products is closely related to the solubility of the UF. Methylene urea has a faster nitrogen release and greening response than Nitroform; but the "residual" nitrogen is much greater for Nitroform.

All of the nitrogen in UF is dependent on soil microorganisms to breakdown the methylene urea chains to urea before nitrogen can be released. But, the short chain (water soluble) methylene urea polymers are broken down much faster than the long chain (water insoluble) polymers. The water insoluble fraction of UF may not be completely broken down in the first year. And, with relatively short growing seasons, significant carryover (residual) can be expected into the second and third seasons. Where normal rates of UF are applied, 2 or 3 years may be required to build up "residual" nitrogen to a level that annual applications of UF release an adequate amount of nitrogen. To overcome this lag in nitrogen availability, higher initial rates of UF can be applied or supplemental soluble nitrogen can be used.

Since microorganisms are required to breakdown UF, environmental conditions (high temperatures, neutral soils, and an adequate supply of moisture and oxygen) that favor microbial activity also promote nitrogen release from UF. Conversely, low temperatures, nutrient deficiencies and acid soils inhibit the release of nitrogen from UF.



Losses of nitrogen due to leaching and volatilization are less from UF than from soluble nitrogen sources. Thus, if we evaluate the efficiency over a period of several years, UF sources are at least equal to soluble sources in terms of nitrogen use efficiency. And, under conditions that favor leaching and volatilization UF sources are more efficient. Nitrogen losses due to removal of fertilizer granules with grass clippings can be significant on closely mowed turf. Losses may be as high as 20% on golf greens. For the first several days after application, the grass should be allowed to dry before mowing.

Urea-formaldehyde has little effect on soil pH or salinity. Thus, even at high rates of application, UF does not burn the grass.

Isobutylidene diurea-IBDU. IBDU, a condensation product of urea and isobutyraldehyde with slow-release characteristics, is a nitrogen fertilizer. Contrary to UF, IBDU does not depend on soil microorganisms for release of nitrogen. In the presence of water, IBDU is hydrolyzed to urea. The rate of hydrolysis varies with soil pH, temperature, particle size and moisture. IBDU is effective as a controlled release nitrogen source for turfgrasses between pH 5 and 8. Below pH 5, the rate of hydrolysis is very rapid and above pH 8 the rate of hydrolysis is quite slow.

Temperature does not influence the release of nitrogen from IBDU to the degree that it does for UF and organic nitrogen sources. But, high temperatures favor the hydrolysis of IBDU and significantly increase nitrogen release. The rate of nitrogen release from IBDU is 2 to 3 times as fast at 75°F than at 50°F; whereas, for UF and organic sources the same temperature difference may result in a 10-fold increase in nitrogen release rates.
Particle size of IBDU granules has a significant influence on hydrolysis rates and nitrogen release. The finer the particle, the greater the surface area and the faster is the rate of hydrolysis. Thus, by varying the size of the IBDU granules, nitrogen release can be distributed over a longer period of time. A material with a range of particle sizes between 8 and 24 mesh is recommended for turfgrasses. Particle size does not influence the rate of nitrogen release from UF.

Since water hydrolysis is the rate controlling process, soil moisture levels also influence the release of nitrogen from IBDU. Wet soil conditions favor the release of nitrogen from IBDU. Soil moisture levels of 40 to 70% of field capacity are favorable for a controlled release rate of nitrogen from IBDU. Above these levels nitrogen release is very rapid, and below these levels, nitrogen release is very slow. IBDU would not provide a uniform level of available nitrogen where turf is exposed to prolonged wet and dry cycles.

Nitrogen losses due to leaching and volatilization are quite low from IBDU. And, efficiency, in terms of nitrogen recovery, is similar to other slow-release nitrogen sources. Nitrogen losses due to mower pick-up of the IBDU granules are similar to those that occur with UF sources,

Unlike UF sources, IBDU does not require a build up of "residual" nitrogen to provide adequate levels of available nitrogen. Unless particle sizes of IBDU granules are quite large, greater than 2 mm in diameter, most of the nitrogen is hydrolyzed within 60 days after application. However, where particles are much over 2 mm in diameter, mowers will pick-up significant quantities of IBDU granules on closely mowed turf.

IBDU has little effect on soil pH, although a temporary increase in pH may occur following a high rate of application. Also, IBDU does not affect turfgrasses at normal rates of application. However, temporary chlorosis has developed 3 to 4 weeks after the application of very high rates of IBDU (above 6 lbs N/1,000 sq. ft.). This chlorosis has been attributed to excessive absorption of ammonia by the grass.

Sulfur-coated Urea. Sulfur-coated urea is produced by spraying pre-heated urea with molten sulfur in a rotating drum. A wax coating may be applied on top of the sulfur coating to seal the pinholes and cracks in the sulfur coating. Finally, the product is cooled and a clay conditioner applied to reduce cracking. The product is screened to remove any oversize granules.

Sulfur-coated urea (SCU) granules have been shown to provide a slow-release nitrogen source. The rate of release of nitrogen from SCU depends on the time required for microorganisms to break down the sulfur coating. Thus, the nitrogen release rate can be decreased by heavier sulfur coating and by inclusion of a microbial inhibitor in the coating. However, a problem occurs with heavy sulfur coatings for turfgrass fertilizers because the mower crushes or picks-up the larger fertilizer granules.

Factors that influence the release of nitrogen from UF (temperature, pH and moisture) also affect nitrogen release from SCU. High temperatures, neutral pH and moist soils favor the release of nitrogen from SCU.

Sulfur-coated urea is the least uniform of the slow-release nitrogen sources discussed. Imperfections exist in the coatings of SCU because of irregularities on the surface of urea. Also, the sulfur coating may not be uniformly applied to the urea granule. These defects together with incompletely covered granules and cracks in the coatings provide the sites for urea to be released when SCU is exposed to water. Thus, each SCU granule will have a slightly different rate of nitrogen release depending on the extent of the "imperfections". Whereas, UF and IBDU granules are homogenous and are not affected by "imperfections" in the coating. Sulfur-coated urea granules are also subject to being crushed by the fertilizer distributor during application or by the mower reel, roller or wheel during mowing.

Dissolution (solubility) rates for SCU are expressed as the percent urea released when the product is placed in water at 100°F for seven days. Commercial products usually have a dissolution rate between 20 and 30%. Below 20% the product is considered too slowly available; while much above 30% the product would not be considered a slow-release nitrogen source.

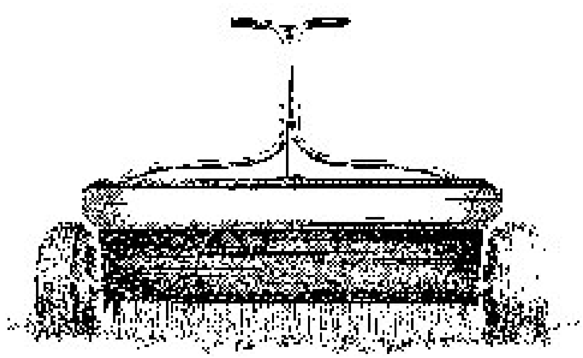
Nitrogen losses from SCU due to leaching and volatilization are intermediate between urea and UF or IBDU. Perhaps the greatest losses of nitrogen from SCU occur when the sulfur coating is broken and urea is readily released or when the SCU granules are picked-up with the grass clippings by the mower. SCU has little affect on salinity, but may reduce soil pH. The sulfur released by SCU after the coating is broken down tends to reduce soil pH. Where sulfur is deficient in soils, SCU provides an additional benefit with the release of sulfur that eventually becomes available to the grass.

Nitrogen recovery for SCU is greater than for urea and other soluble nitrogen sources. However, recovery would need to be measured over a longer period of time for SCU than for soluble sources.

Polymer Coated Nitrogen Sources. Polymer coated nitrogen sources such as Grace Sierra's Once and Pursell Industries Polygon provide controlled release of nitrogen by diffusion through a polymer membrane (coating). Release rates are dependent on moisture and temperature and by the composition and thickness of the coating. Such products are very uniform and provide predictable release rates of nitrogen.

Organic Nitrogen Sources. The oldest sources of nitrogen used for turfgrass fertilization are the natural organic materials-manure, composted crop residues, sludges and humus. These materials are quite low in nitrogen content, difficult to store and apply, expensive and, in some cases, contain undesirable substances such as salts, heavy metals and weed seeds.

Nevertheless, organic nitrogen sources can be effectively used in most turf maintenance programs. Nitrogen release from organic sources is dependent on microorganisms; thus, factors that favor microbial activity increase the rate of nitrogen release from these materials. Organic materials are not considered good nitrogen sources for winter months because of the low activity of microbes. During other seasons organic sources are very effective.



Organic sources should not be considered slow-release sources. When conditions favor nitrogen release from organic sources, the nitrogen usually becomes available to the grass within 4 to 6 weeks. A significant amount of the nitrogen from organic sources may remain tied-up in the organic form for years.

Organic sources have the advantage that they will not "burn" the grass, have little effect on pH, contain "nutrients" other than nitrogen and may raise soil temperatures during cool periods. Also, some of these materials such as manures, sludges and composts may improve the physical condition of soils.

Milorganite. The most widely used organic nitrogen source on fine turf is Milorganite-a product of the Milwaukee Sewage Commission. Milorganite is an activated sewage sludge that contains 6% nitrogen. The product is granulated, screened and packaged for application to fine turf. It is, perhaps, the most widely recognized nitrogen source for golf green turf.

Advantages of Milorganite for putting green turf include a uniform nitrogen release rate over a period of 3 to 4 weeks, a very low burning potential, the addition of phosphorus and iron, soil warming during cool periods and a minimum effect on soil pH and salinity. Leaching and volatilization losses of nitrogen from Milorganite are also very small.

Disadvantages of Milorganite include a low nitrogen content, a short nitrogen residual, a relatively high cost per pound of nitrogen and a poor winter response. The limited availability of the product might also be considered a disadvantage.

Turf response to Milorganite in terms of growth rate and color are excellent during the spring, summer and fall. Additionally, turf researchers have reported less thatch accumulation where Milorganite was used in place of soluble nitrogen sources.

Combinations of Nitrogen Sources for Turfgrass. In low maintenance areas a single source of nitrogen may meet the needs of the turf. But where demands are greater as for lawns, golf courses and athletic fields, combinations of nitrogen sources provide the most uniform level of nitrogen to the turf.

The objectives of the fertilization program have a significant influence on the source of nitrogen needed. If the objective of fertilization is to simply maintain a grass cover, a single application of a slow-release fertilizer, or perhaps, two applications of a soluble fertilizer will meet the requirement of the grass. But, where a continuous supply of nitrogen is needed to maintain growth, to recover from wear or to maintain good color, a combination of nitrogen sources will best meet the needs.

For lawns, fairways, athletic fields and other intensively maintained turf areas mowed at a °-inch height or greater, coated products, UF, or IBDU can provide the "residual" nitrogen while soluble sources can be used to produce rapid green-up. For closely mowed turf areas such as golf greens, tennis courts and bowling greens, UF and IBDU should be used for "residual" nitrogen and Milorganite or similar organic sources should be used for rapid green-up. In cold temperatures, IBDU or soluble sources must be used to produce a fast greening response.

Other factors that must be considered include the acidifying potential of SCU or ammonium sulfate, the salinity hazard of ammonium nitrate and ammonium sulfate and the cost of the slow-release and organic nitrogen sources.

On a cost per pound of nitrogen basis relative to urea, SCU is about 2 times greater, UF and IBDU are 3 to 4 times greater and organic sources are 5 to 6 times greater than urea. Thus, for larger turf areas where soluble sources can be safely used, they may be the logical choice for nitrogen fertilization. The most important factors when using soluble sources include the rate and timing of applications. Single applications should not exceed 1.0 pound of nitrogen per 1,000 sq. ft. and should not be made prior to or during a period of rapid growth.

Response of Turf to Nitrogen

Turfgrass response to nitrogen fertilizers is generally measured in terms of yield (dry matter production), color or turf density. These are the responses that are most readily measured or observed. Other more difficult to measure responses to nitrogen such as water use, disease resistance, thatch accumulation, root growth, and cold tolerance may be more important to the turf manager. The rate and timing of nitrogen applications, nitrogen source, environmental conditions and turf management practices determine the response of turf grasses to nitrogen.

Growth Rate, Color and Density. Bermudagrass readily responds to nitrogen in terms of growth, color and density. Yellow leaves, thin turf and little growth characterizes nitrogen deficient bermudagrass. When termperature and moisture are not limiting and grass clippings are removed, bermudagrass produces a yield response to nitrogen at rates as high as 20 pounds per 1,000 sq. ft. and a color and density response up to 12 pounds per 1,000 sq. ft.

In contrast, a St. Augustine grass lawn where clippings are not removed is much less responsive to nitrogen. St. Augustine shows a yield response up to about 8 pounds of nitrogen per 1,000 sq. ft. and a color and density response up to only 4 pounds of nitrogen.

How does that kind of information help? To begin with, it provides a range of nitrogen rates to consider. For example, if you are maintaining a St. Augustine grass turf, you can expect a desirable response to 4 pounds of nitrogen per 1,000 sq. ft. per year. You would not expect significant improvement in color or density in St. Augustine grass to rates above 4 pounds if clippings are not removed. The only apparent response to higher rates of nitrogen would be increased growth (dry matter production). There are other undesirable responses to excessive rates of nitrogen such as greater water use, increased disease susceptibility and thatch accumulation. Excessive rates of nitrogen (rates above those that produce a noticeable color response) significantly increase water use by turfgrass. A St. Augustine grass turf fertilized with 8 pounds of nitrogen per 1,000 sq. ft. per year would require about 40 percent more water than one fertilized with only 4 pounds of nitrogen. Also, heavily fertilized turfgrasses are always the first to wilt during periods of drought stress.

Leaf spot, dollar spot and other warm season diseases of turfgrasses are also increased by improper nitrogen fertilization. Gray leaf spot on St. Augustine grass, for example, can be a serious problem following excessive applications of nitrogen fertilizers. In contrast, Helminthosporium leaf spot and dollar spot can be severe on warm season turfgrasses maintained at very low nitrogen levels. In some cases, the application of soluble nitrogen fertilizer will correct the problem. In general, turfgrasses fertilized with adequate, but not excessive, rates of nitrogen are more resistant to diseases.

Bermudagrass and St. Augustine grass continue to produce a growth response to nitrogen ar rates above those that produce maximum color response. Tifgreen bermudagrass, for example, produces a growth response up to about 3 pounds of nitrogen per month. Of course, thatch accumulation is a concern where growth rate becomes excessive. To demonstrate this concern, we measured thatch accumulation in a Tifgreen bermudagrass putting green six months after beginning monthly applications of soluble nitrogen at 1 and 3 pounds per 1,000 sq. ft.

As expected, the color to the grass was significantly darker at the higher rate of nitrogen. Thatch accumulation, as measured by depth, was also 30 percent greater at the higher rate of nitrogen. The greater level of thatch was evidenced by the degree of scalping on the higher nitrogen plots. Certainly, 3 pounds nitrogen per 1,000 sq. ft. per month is excessive on a bermudagrass green, and 1 pound is probably minimal. Thus, 1/2 pound of nitrogen at 7 day intervals should produce satisfactory color and growth without contributing to thatch accumulation.

In addition to annual rates of application of nitrogen, rate per application and source of nitrogen influence the response produced. As a general rule, do not apply more than 1 pound of soluble nitrogen per application. Again, the only apparent response for higher rates would be more growth. Since St. Augustine grass requires 0.5 pound of nitrogen per month during the gorwing season to maintain optimum color and density, 1 pound of nitrogen should last for two months. Therefore, at least 50 percent of the nitrogen should be from a slow release source or only ° pound of soluble nitrogen should be applied every month on St. Augustine grass lawns.

Bermudagrass, particularly hybrid bermudagrasses such as Tifgreen and Tifway, requires about 1 pound of nitrogen every two weeks to maintain optimum color and density. Again, no more than 1 pound of soluble nitrogen should be applied per application.

To support these recommendations, I applied soluble nitrogen at 1 and 2 pounds per month to a St. Augustine lawns and a Tifgreen bermudagrass putting green from May through September. Color ratings made in June, July, August and September show that St. Augustine grass does not respond to more than 1 pound of soluble nitrogen per month. In contrast, Tifgreen bermudagrass continued to show a color response up to 2 pounds of soluble nitrogen per month. Thus, ° pound of soluble nitrogen every week should produce maximum color and density on Tifgreen bermudagrass. Certainly, only the most intensive culture of bermudagrass such as that used on golf greens would require that level of nitrogen.

Nitrogen Suppresses Roots. Deterioration of roots is another undesirable response to excessive rates of nitrogen. At high rates of nitrogen, root diameter generally increases, but root number and root elongation decrease. The net result is a decrease in root weight. Thus, the shoot (leaves and stems) to root ratio increases signficiantly with nitrogen fertilization. Tifgreen bermudagrass demonstrates this response quite well. In greenhouse investigations significant reductions in roots were observed in Tifgreen bermudagrass grown in sand and in hydroponic culture at high rates of nitrogen. Tifgreen bermudagrass growing in a low nitrogen medium produced twice as much root growth as that growing in a high nitrogen medium. Similar responses to nitrogen by other grasses are reported in the literature.

Considering the increased leaf production and shoot growth at high rates of nitrogen, the shoot/root ratio gets way out of balance at high rates of nitrogen. Ideally, we would like to see a shoot/root ratio of about 1.5 to 2 on regularly mowed turf. At high rates of nitrogen the ratio would likely be above three; while at very low levels of nitrogen the ratio would be about one.

Turf responses to high rates of nitrogen such as rapid wilting under drought stress and increased winterkill support the evidence that high nitrogen suppresses root growth. In cool season grasses, the deleterious effects of high nitrogen rates on root systems are much better documented.

Cold Tolerance. Lush, rapid growth that generally follows the application of soluble nitrogen fertilizers usually causes a decrease in cold tolerance in grasses. Again, much of the work on cold tolerance has been conducted on cool season grasses. Kentucky bluegrass and bentgrass withstand cold temperatures better at low levels of nitrogen fertilizers.

Work conducted at North Carolina showed that Tifgreen and Tifdwarf bermudagrasses fertilized in the fall with nitrogen only were less resistant to low temperatures than that fertilized with a complete fertilizer. In their study the fertilizer that produced the greatest cold tolerance was a 4-1-6 ratio fertilizer. Researchers in Texas have demonstrated similar responses to nitrogen. Tifgreen bermudagrass receiving high nitrogen and potassium demonstrated the greatest resistance to cold temperatures. In their study high nitrogen levels in the grass did not show much effect on cold tolerance, but high nitrogen levels were associated with high potassium levels did increase cold tolerance. It was apparent from their work that nitrogen was required to increase potassium uptake by the grass.

In the Texas study, high levels of phosphorus in the plant had a detrimental affect on cold tolerance. However, when potassium was applied, it appeared to counteract the detrimental effect of phosphorus.

St. Augustine grass does not show the same cold tolerance response to nitrogen fertilization as bermudagrass. Work in Texas has shown no significant difference in cold tolerance between fertilizer treatments. St. Augustine grass is much less cold tolerant than bermudagrass and it seems to suffer significant winterkill when temperatures drop below 10°F regardless of nitrogen fertilization. The only apparent nitrogen response with respect to cold tolerance was that St. Augustine which was fertilized with nitrogen recovered faster in the spring from winter injury.

Grass Establishment. During establishment from seed, sprigs or plugs, both bermudagrass and St. Augustine show a tremendous response to nitrogen fertilization. On a sandy soil, the rate of cover of bermudagrass is greatest with weekly applications of soluble nitrogen at ° pound per 1,000 sq. ft. On clay or clay loam soils, applications of soluble nitrogen at 1 pound per 1,000 sq. ft. every two weeks will produce the fastest rate of cover. Unfertilized bermudagrass seed or sprigs are very slow to spread on most soils.

St. Augustine grass plugs planted on two-foot spacings will cover in about 10 weeks if fertilized monthly with 1 pound of soluble nitrogen per 1,000 sq. ft. Higher rates of nitrogen do not produce significantly faster cover with St. Augustine. Unfertilized St. Augustine planted the same way would only produce 30 to 40 percent coverage after 10 weeks.

In addition to nitrogen, phosphorus is also important in promoting grass establishment . In the Texas study, St. Augustine grass plugs fertilized monthly with a two-to-one phosphorus to nitorgen ratio fertilizer at 1 pound nitrogen per 1,000 sq. ft. produced the fastest rate of cover of all fertilizer treatments; while a one-to-one ratio of phosphorus to nitrogen fertilizer produced about the same response as a straight nitrogen fertilizer.

Phosphorus

Grasses take up phosphorus primarily in the orthophosphate ($H_2PO_4^-$) form. Although soils may contain relatively large amounts of phosphorus, much of it is in forms not available to grasses. Some phosphorus is provided by soil minerals and soil organic matter, but it is very slowly available from these sources:

$Ca_3(PO_4) + 4H^+$ ® $Ca(H_2PO_4)_2 + 2Ca^{++}$
(Rock Phosphate) + (acid) (superphosphate)

Other phosphorus sources include superphosphate and polyphosphate fertilizers:

$Ca(H_2PO_4)$ + water ® $2(H_2PO_4^-)^- + CA^{++}$
(superphosphate) (orthophosphate)

$(H_2PO_4^-)_n$ + water ® $H_2PO_4^-$
(polyphosphate) (orthophosphate)

Fertilizer applications provide the major source of phosphorus for turfgrasses. Since phosphorus moves very little through the soil, it usually accumulates in the surface layer of soil. Thus, cultivation with a coring type aerator prior to applications of phosphorus helps to move the phosphorus into the rootzone.

Compacted and waterlogged soils also limit the availability of phosphorus. On clay or clay loam soils traffic control and water management are critical to maintaining phosphorus availability. Newly planted sites, which are frequently overwatered, are also subject to phosphorus deficiencies.

Phosphorus provided by:

- Soil Minerals
- Organic Matter
- Fertilizers
- Small Amounts Present in Soils

Phosphorus is:

- Readily Fixed by Ca, Fe, Al, and Microorganisms
- Very Slowly Available

Phosphorus availability is also influenced by soil pH. At a pH below 5.5 iron and aluminum become soluble and form a complex with phosphorus that is not available to the grass. At a pH above 7.5 calcium complexes with phosphorus so that it is not available. Phosphorus is most available between pH 6.0 and 7.0.

Ca(H2PO4)2 + free CaCO3 ® CaHPO4 or Ca3(PO4)2
(superphosphate) + (alkaline soil) (insoluble)

Maintaining a sufficient supply of phosphorus in the soil requires more than the application of fertilizer. Adequate cultivation, water management and the addition of lime or sulfur to adjust pH may be just as important.

Phosphorus availability influenced by:

- pH
- Soluble Fe, Al (low soil pH)
- Soluble Ca (high soil pH)
- Amount of Organic Matter
- Activity of Microorganisms

Potassium

Potassium is often present in large quantities in soils, but very small amounts may be in the available form (K+). Potassium is a constituent of many soil minerals and is held very strongly by clay particles. For potassium to be taken up by the grass it must be in the solution in the potassium ion (K+) form. An equilibrium exists between the K+ in solution and that held by clay particles (see illustration). As the grass root takes up the K+ from the soil solution, additional K+ is released from the soil solution to the clay particles. Clay particles, thus, serve as a reservoir for K+ and help to reduce the amount of K+ lost by leaching.

Soil microorganisms also require considerable amounts of potassium and they compete with grass for the available potassium. Removal of grass clippings also severely depletes the soil of potassium since the grass contains higher amounts of potassium than any other fertilizer nutrient except nitrogen. Where high levels of potassium are available the grass will absorb much more than it requires for growth. High potassium levels in plant tissue are associated with improved cold tolerance, drought tolerance, wear tolerance and disease resistance.

Potassium. Often present in large amounts:

- Soil Minerals
- Organic Matter

Potassium loss from soils occurs by:

- Removal by Plants
- Readily Leached from Sandy Soils
- Microorganisms Utilize K+

To maintain adequate levels of K+ in the soil apply light, frequent applications of potassium fertilizer, return grass clippings where possible and avoid overwatering to reduce leaching losses.

Nutrient Interactions

Nutrient uptake is a function of nutrient levels and interactions between nutrients. The level of one nutrient can affect the uptake of another nutrient. For example a high concentration of NH+ can reduce the uptake of K+ by the grass. Also where NO3- levels are deficient, K+ uptake will be restircted even though high levels of K+ may be present. These interactions between nitrogen and potassium can have a significant influence on the growth of turfgrasses.

In turfgrasses, interactions between phosphorus and iron are quite common. Where phosphorus levels are excessive, iron which would be available to the grass becomes insoluble and unavailable. This problem can be prevented by monitoring soil levels of available phosphorus and avoiding excessive phosphorus fertilization.

Trace Nutrient or Micronutrients.
Fe, Mn, Zn, Cu, Bo, Mo, Cl, Na

- Soils Minerals
- Organic Matter
- Fertilizers

Iron deficency may also occur because of excessive levels of zinc, manganese or copper. In sandy soils these interactions between nutrients can present a problem. In highly buffered clay soils these interactions are less likely to present a problem.

Conditions Conducive to Micronutrient Deficiencies.

- Sandy Soils
- High Soil pH
- Clipping Removal

Environmental Conditions. Environmental conditions including aeration, temperature, light, moisture and soil pH have a significant affect on turf response to fertilization. Where soils are poorly aerated due to compaction or overwatering, biological activity required to convert nitrogen to an available form is inhibited. Thus, nitrogen efficiency is greatly reduced and the expected response may not occur. Where soils are compacted or waterlogged aeration should be a routine cultural practice in conjunction with fertilization. Soil amendments such as organic matter, calcined clay aggregates, sand and gypsum should be considered for topdressing mixtures.

Temperature and light also influence fertilizer response, but there is little that turf managers can do to alter these factors. Fertilizer applications should be timed to coincide with favorable temperatures for growth of turfgrasses. Also, nitrogen sources should be selected based on their availability to grasses under expected temperature conditions. For example, organic nitrogen sources and ureaformaldehyde do not release nitrogen at sufficient rates for turf growth when soil temperatures are below 50ºF.

Soil moisture is required for the grass to effectively use fertilizer nutrients. All biological activity requires adequate soil moisture for the conversion of nutrients to an available form. Also, the utilization of fertilizer nutrients requires adequate soil moisture for root growth and nutrient uptake. Where grass is grown under dry conditions, fertilizer application rates should be much less than where water is not limiting.

Some nitrogen fertilizers such as IBDU require moisture for the release of nitrogen. Since most turfgrasses are irrigated, this characteristic of IBDU could be considered ideal. However, soil pH also affects the release of nitrogen from IBDU. At a pH of 7.5 of greater the effectiveness of IBDU is significantly reduced. Soil pH also influences the availability of phosphorus, iron and most other micronutrients.
Soil pH can be increased by liming acid soils, or decreased by adding elemental sulfur to alkaline soils:

CaCO3 + acid soils ® H2O + CO2 + Ca++
(lime) (neutralizing)

Elemental S + H2O + alkaline soil ® SO4 + 2H+
(acidifying)

Adjusting soil pH to near neutral conditions (pH 6.5-7.2) increases the availability of phosphorus, iron and other nutrients. In some soils such as adjustment is practical; but, in many calcareous soils there is too much limestone present to significantly lower soil pH.

All of these factors (aeration, temperature, moisture, pH, etc.) must be considered when planning a turf fertilization program. Applying a fertilizer without consideration of its affect on the level of nutrients present, the availability of nutrients, or the interactions with environmental factors can only increase turf nutrition problems. To meet the nutritional requirements of a turf, all factors affecting the availability of nutrients must be considered.

Factors Affecting Nutrient Availability.

- Oxidation - Reduction State of the Nutrient
- Concentration of the Nutrient
- Water Content of Soil
- Oxygen
- Temperature
- pH