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in an increase in clipping yield (topgrowth) and nitrogen content of clippings. In contrast, sod strength (a reflection of root and rhizome growth) and rhizome weight decreased at the higher nitrogen levels. Thus, when most of the plant's carbohydrate was directed toward producing shoot growth, root growth and other plant growth processes suffered accordingly. Agronomists well recognize that a plant is no better than the root system that supports it.

Research has shown that a considerable amount of root initiation and root growth of cool-season grasses occurs in the spring (2). Liberal nitrogen fertilization in the spring will have a tendency to restrict root growth. The turfgrass plant will go into the summer with a shorter root system than where moderate rates of nitrogen fertilizer are used. Furthermore, high amounts of nitrogen will increase topgrowth and increase the need for more frequent mowing in the spring. The rapid topgrowth may result in the removal of large amounts of clippings at each mowing. The removal of excess foliage (i.e. more than a third of the foliage at any one mowing) is known to retard both tiller and root development. Thus, mismanagement of nitrogen during the spring can have a dramatic effect on the root system under the turfgrass going into the summer.

Liberal nitrogen fertilization also causes a lush, succulent plant growth that is characterized by decreased cell wall and cuticle thickness, increased cell size, and an increased level of plant tissue hydration. The thinner plant cell walls are most like the result of more rapid plant growth and the production of condition increases the severity of plant disease and lowers the hardiness of the plant to heat, cold, and drought. Lush, succulent tissue also contains high concentrations of nitrogen-rich storage compounds. The nitrogen-rich compounds accumulate in guttation fluid (leaf exudates). The guttation fluid serves as an ideal medium for the enhancement of many turfgrass diseases. Thus, mismanagement of nitrogen in the spring can take the plant into the summer in a soft growth condition in which it is more vulnerable to disease, heat, and drought.

Liberal nitrogen fertilization is known to increase the severity of Pythium, brown patch, Fusarium blight, stripe smut, snow mold, and Helminthosporium (leafspot) diseases (5). Leafspot, a serious disease of both Kentucky bluegrass and bentgrass in the midwest, is much more serious at high nitrogen levels, especially in the spring. Kentucky bluegrass varieties like Park, Kenblue, and Delta are very susceptible to leafspot. Many lawns and older turfgrass areas have been established to these common-type Kentucky bluegrass varieties. Research at the University of Illinois (4) has shown the incidence of Fusarium blight in the summer to be greater with increasing nitrogen application rates in the spring. Nugget, Merion, Fylking, and Pennstar were highly susceptible to the disease when more than a total of two pounds of soluble nitrogen per 1,000 ft. was applied in the spring. Kenblue was affected by the disease at all the fertility levels. This information lends support to moderate levels of nitrogen fertilizer in the spring. It more specifically suggests a critical limit of no more than two pounds of total soluble nitrogen in the spring.

Liberal nitrogen fertilization is also critical during the summer (1). As seasonal temperatures increase, photosynthesis of cool-season grasses decreases and respiration increases. As mentioned earlier, carbohydrates are consumed during respiration. Respiration is known to increase with increasing nitrogen fertility levels. Thus, during periods of high temperature, liberal nitrogen fertilization may reduce carbohydrate reserves due to rapid growth and high respiration. Additional stress may result from lower photosynthetic rates. Because carbohydrates are produced at a slow rate and respiration is high during the summer, nitrogen should be applied at low rates for cool-season grasses.

Nitrogen is a necessary component of turfgrass fertilization programs. High quality turf exhibiting acceptable green color and density requires periodic application of nitrogen. Nitrogen however, is frequently referred to as the "TNT" of turfgrass fertilization programs. It can be just as detrimental as beneficial, if mismanaged. Proper timing and rate of application are important in successful long-term programs. Always remember! Greener is not always better. A happy medium must be met between agronomics and aesthetics.

WTT

Table 1. Nitrogen treatment effects on a Merion Kentucky bluegrass sod (3).

Nitrogen Rate	Annual Clipping Yield (dry wt.)	Nitrogen Content in Clippings	Sod Strength	Rhizomes
lb/A/month	lb/A	%	lb to tear	grams
0	463	3.0	146	99
15	1807	3.3	188	89
30	2555	3.6	130	120
60	5676	4.5	97	43
120	8447	5.4	67	14

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NITROGEN SOURCES FOR TURF FERTILIZATION

CHARACTERISTICS OF WATER SOLUBLE NITROGEN FERTILIZERS

By Roger Funk, Vice President of Research and Development, Davey Tree, Kent, Ohio

Nitrogen is the keystone of a lawn fertilization program, and both soluble and slowly soluble sources are available to the turfgrass industry. Soluble nitrogen fertilizers are less expensive than the slowly soluble sources but, in general, have a higher burn potential and are more likely to be lost through leaching and volatilization. These risks can be minimized, however, if the contributing factors are understood.

Fertilizer burn

Fertilizers contain salts that are similar to table salt (sodium chloride) except that fertilizer salts contain the elements essential for plant growth. When salts dissolve in water, they dissociate into positively and negatively charged ions, **and it is in this form that nutrients are absorbed by plant roots.** Soluble fertilizers are in the salt form when applied to turfgrass, which accounts for their immediate availability for absorption. Slowly soluble fertilizers may contain some soluble salts, but most of the nutrient salts are released over a period of time as the slowly soluble fertilizer is hydrolyzed or decomposed in the soil. Thus, a major difference between soluble and slowly soluble fertilizer is the release rate of the nutrient salts.

Salts dissolved in soil solution increase the osmotic pressure that governs the flow of water across a root cell membrane. Water always moves through a cell membrane from the side that has the lowest osmotic pressure to the side that has the highest pressure. Since root cells actively absorb nutrient salts, the osmotic pressure of the cell sap is normally higher than that of the surrounding soil solution — and water is absorbed into the root tissue. This process, in fact, is how plants absorb water. However, if excess fertilizer salts in the soil solution increase the osmotic pressure above that of the cell sap, water is drawn out of the roots, and the resultant injury is termed "fertilizer burn." Symptoms of fertilizer burn resemble those of drought injury since, in both cases, the immediate problem is lack of water in the plant.

The relative tendency of a fertilizer to release salts and increase the osmotic pressure of the soil solution is measured by the salt index. The higher the salt index value, the greater the tendency of a fertilizer to increase the osmotic pressure and the greater the burn potential. The salt indexes of common soluble nitrogen fertilizers are listed in Table 1, which also compares the adjusted salt indexes, based upon the total nutrient content.

Environmental factors such as temperature, humidity, and soil moisture also affect the burn potential of a fertilizer. As the air temperature increases and as the humidity decreases, the water requirement of plants increases. Because of the increased water requirements for plants, the level of soluble salts in soil solution that is "safe" during

Table 1. Solubility and Salt Indexes of Soluble Nitrogen Fertilizers

Fertilizer	Formula	Primary analysis (percent) N	P_2O_5	K_2O	Total plant food[a]	Salt index[b]	Adjusted salt index[c]	Solubility[d]
ammonia	NH_3	82.0	—	—	82.0	47.1	57.4	90
urea	H_2NCONH_2	46.0	—	—	46.0	75.4	163.9	67
ammonium nitrate	NH_4NO_3	33.5	—	—	33.5	104.7	312.5	118
ammonium sulfate	$(NH_4)_2SO_4$	21.0	—	—	21.0	69.0	328.6	71
sodium nitrate	$NaNO_3$	16.0	—	—	16.0	100.0	625.0	73
calcium nitrate	$Ca(NO_3)_2$	15.0	—	—	15.0	65.0	433.3	134
potassium nitrate	KNO_3	13.0	—	46.0	59.0	73.6	124.7	13
monoammonium phosphate	$NH_4H_2PO_4$	11.0	48.0	—	59.0	29.9	50.7	43
diammonium phosphate	$(NH_4)_2HPO_4$	18.0	46.0	—	64.0	34.2	53.4	25
ammonium polyphosphate (liquid form)	NH_4PO_3	10.0	34.0	—	44.0	29.9[e]	67.9	—

[a]Percent N + percent P_2O_5 + percent K_2O (primary analysis).
[b]Rader, L. F., Jr., et al. 1943. *Soil Science* 55(3):201-18.
[c]Salt index per unit of plant food = (2) x 100/(1).
[d]Parts in 100 parts pure water at 32° F.
[e]TVA.

cool, humid weather may cause burn injury during periods of warm weather or low humidity or both.

Soil moisture is a major factor in determining the fertilizer's potential to burn. If the soil is relatively dry, a fertilizer will have a greater effect on increasing the osmotic pressure of the soil solution. Conversely, if the soil is saturated, the fertilizer salts will disperse and the osmotic pressure will not increase greatly. In addition, the evapotranspiration of water will help cool the plant and raise the humidity near the soil surface, effectively reducing the plant's water requirement.

Leaching

Nutrient leaching is the removal of soluble fertilizers from the root zone by the downward percolation of water. Most of the soluble fertilizer nitrogen will be present in one or more of three forms: ammonium (NH_4+), nitrates ($NO_3—$), and urea ($CO(NH_2)_2$).

Ammonium is water soluble, but the strong attraction between the positively charged ammonium ion and the negative sites on clay minerals and soil organic matter prevents leaching. Ammonium, however, is rapidly oxidized to nitrates when the soil temperature is above 50°F.

Nitrate is a negatively charged ion and, as such, is readily leached because it does not bind to soil particles. Leaching of nitrate from the rooting zone is a much greater problem in coarse-textured soils. Research has shown that nitrate may be leached about 1 inch of rainfall for each inch of rainfall in clay loam soils to 2.5 inches for each inch of rainfall in sandy loam soils.

Urea fertilizer is readily soluble when it is first applied to the soil, but when it changes to ammonium it is held by clay and humus is a form that is readily available to plants. Under favorable temperature and moisture conditions, urea hydrolyzes to ammonium carbonate and then to nitrate within less than a week.

Volatilization

Volatilization involves the conversion of nitrogen to ammonia gas, which is lost to the atmosphere. This process is favored by alkaline soils, dry soils, soils with a low exchange capacity, and warm temperatures. When conditions favor volatilization, 25 percent or more of the applied nitrogen may be lost to the atmosphere.

When ammonic fertilizers and urea are placed in the soil, the ammonia gas that they release is held by the soil particles. However, when urea or ammonic fertilizers are placed on top of the soil, the released ammonia does not have the clay or moisture to hold it from being partly volatilized.

All of the characteristics of nitrogen fertilizers should be considered when a turf fertilization program is planned. If the materials are applied properly for the existing soil and environmental conditions, soluble nitrogen fertilizer can be just as effective as slowly soluble sources in providing the turfgrass plant with the nitrogen it requires. **WTT**

NITROGEN SOURCES FOR TURF FERTILIZATION

LONG TERM FIELD PERFORMANCE OF NITROGEN FERTILIZERS

By Don Waddington, Department of Agronomy, Pennsylvania State University, University Park, PA

More complete information can be obtained to characterize nitrogen (N) sources or N fertilization programs if long-term studies are used. The residual effects of slow-release N sources are of particular importance in such studies. "Long-term" is not defined in this presentation because assigning an exact time or minimum time would be difficult. Certainly, making observations or collecting results from a single application or during a single season could be considered short-term. Depending on the type of information desired, various lengths of time would be needed to obtain meaningful data from long-term studies.

Field Observations

Continued use of an N source or N fertilizer program has produced satisfactory turf for many turf managers. Although individuals may not agree on a "best" N source or N program, many have stuck with practices that work for them. It should be common knowledge that long-term use of activated sewage sludge (in particular, Milorganite) has proven successful. Also, continued use of ureaform or IBDU has given good results. Sulfur-coated urea, a relative newcomer to the family of slow-release N sources, has not been available long enough to have had years of use on turfgrass like these other sources, but I am confident that long-term use of this product will also be favorable. Use of soluble N sources and various combinations of soluble and slow-release sources in mixed fertilizers have also given good long-term results. This is not to say that all materials will work in all situations, but instead that many people have selected a program that works under their conditions. We also have turf managers who are continually changing their fertilizer program for one reason or another. Their reasons are varied: N sources may not do what they expected, salesmen may sell them on the merits of another fertilizer, cost may be a deciding factor, or they may be searching for that panacea that will cure all their turf's ills.

Now, back to those who have stuck with one program, perhaps making minor adjustments as needed. How do they know that a different program or N-source would not have worked better? Usually they do not know for sure. However, if a person has a program that works, he is best advised to stick with it. Most turf managers are not in a position to evaluate several N sources or programs at one time. Comparisons among N treatments are usually left to the turf researcher.

Long-Term Research

In research studies several N sources or fertilizer programs can be observed at one time. The longer a study is conducted, the more can be learned concerning the effects of a treatment. Long-term studies are also valuable for providing mine the residual effects of slow-release N sources, which are often inefficient in the first years of use. Even if residual effects are not of major importance, it is a good idea to obtain data from several growing seasons, which can provide different weather patterns or disease pressure. Longterm studies are also valuable for providing information on responses such as turfgrass species competition, weed encroachment, disease incidence, and thatch development when these responses are desired. However, in studies designed with N-source evaluation as the prime objective, it is best to minimize the effects of things such as species changes, weeds, and diseases. The researcher likes to know for sure that responses such as slow growth, poor color, and thin turf are related directly to the availability of N from an N

Nitrogen Source Test on Merion After Seven Years

Material	Treatment (lb. N/1,000 ft²)	Appl.*	1966	1967	1968	1969	1970	1971	1972
			Average clipping yields (grams)						
IBDU	5	2	72	121	116	108	122	94	98
Ureaform	5	2	46	68	82	90	120	75	103
Urex	5	2	102	109	103	106	124	85	100
ADM	5	2	103	129	116	125	135	105	118
Milorganite	5	3	69	87	89	88	106	67	96
Urea	3	9	76	96	80	74	91	67	82

*Number of equal applications to obtain annual rate of N shown.

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source rather than being due to a turf disease or a shift in species composition.

Turf stands developed in long-term N research studies provide sites with known histories. These areas can then be used for other research subjects such as physiological responses to various stresses, soil test calibration, diseases, and weeds.

Perhaps the greatest deterrents to and disadvantage of long-term studies are time and cost. One may wonder about the value of studies involving experimental materials that never reach the market. However, it is better that these materials are dropped after research rather than being dropped after they have been passed onto the public without adequate testing.

Representatives of a few companies want to make decisions after one season's results. At the university level we feel that long-term research gives us a much better basis for our opinions and extension recommendations. Representatives of other companies agree with this philosophy, and they often provide grants to help support these studies.

Results from Long-Term Research

Perhaps the best argument for long-term research can be provided by comparing initial results with those obtained later in an experiment. The results given here were obtained in studies at Penn State.

Lawn Fertilizer Test. Milorganite and ureaform were included in a test with various lawn fertilizers having lower amounts of water-insoluble nitrogen. In treatments in which 2 pounds of N per 1,000 square feet were applied in spring and fall for two years, Milorganite and ureaform gave relatively low yields and color response in the first year. The greatest response was obtained in the first year by fertilizers having lower amounts of water-insoluble N. By August of the second year, prior to fall fertilization, the best color was found on plots fertilized with these two N sources. Fertilizer was not applied in the third year, but clipping weights were taken for 13 weeks beginning in late April and ending in mid-July. The good residual effects of Milorganite and ureaform, and also of Scott's 23-7-7, were quite apparent in the third year.

N Source Test on Merion Kentucky Bluegrass. Eight N sources were used to fertilize Merion bluegrass for 7 years. Nitrogen recovery in the clippings was calculated for the first 2 years. The inefficiency of Milorganite and Uramite (ureaform) was striking. Urex (a urea-paraffin matrix), ADM (plastic coated urea), and urea had higher recoveries.

The study was continued for 5 more years. To cut expenses, nitrogen analyses of clippings were discontinued. However, clipping yields, which give almost as good an indication of N use by the grass, were continued. Average fresh-weight yields showed that 3 pounds of N from urea produced greater yields than 5 pounds of N from IBDU in the first year and more than 5 pounds of N from ureaform and Milorganite in the first two years. The residual effects of IBDU were noted in the second year, but with ureaform and Milorganite it took longer for the response to reach that obtained from other sources.

In the summer of 1973, tests for soil N, turf color, and clipping yield showed that the greatest residual effect was obtained from ureaform. Milorganite and IBDU ranked second and third.

At least two findings in this research tie in with the actions of turf managers. First, the slow start from ureaform has been the reason for their dropping it from consideration after short-term use. Second, long-term users of ureaform and Milorganite have been able to reduce application rates as residual N has built up. Occasionally we hear of superintendents drastically reducing N rates and still maintaining adequate turf. If a man who has been using 6 or 8 pounds of N per 1,000 square feet can successfully drop to 3 pounds of N, it may be because of the N reserves that have accumulated in the soil.

Evaluation of Sulfur-Coated Urea Formulations. Not all sulfur-coated ureas are the same. Different coating methods and thicknesses are used during their manufacture. A study was started in 1974 to evaluate five TVA formulations and Gold N, a product of ICI in England. Spring applications of 4 pounds of N per 1,000 square feet were made. Initial response decreased as the coating weight of the material increased. Response was also slower when a sulfur-only coating rather than a sulfur-plus-wax coating was used. We thought that the slower releasing materials would come on during the fall. They did not. Then we thought that perhaps the residual effects would show the next spring. They did not. We applied 4 pounds of N again in 1975, expecting that we would observe some residual response if we continued for another year. It did not happen. In May of 1976, we sampled the plots for residual sulfur-coated urea and found as much as 37 percent of the applied material still there. We applied another 4 pounds of N that spring. Still no striking residual effect occurrred. We sampled for residual pellets that fall, again in 1977, and twice in 1978. No more fertilizer was applied after 1976.

The difference in residual N release over a two-year period (11/76 to 11/78) was as high as 2.5 pounds of N per 1,000 square feet. However, no visual effects from residual N were noted during this time. The first visual effect noted was in August of 1979, when SCU-17 treated plots had significantly less dollar spot and better color than Gold N plots. The slight differences observed at this time were not significant. Additional studies are now being conducted to characterize the release of N from different N sources. **WTT**