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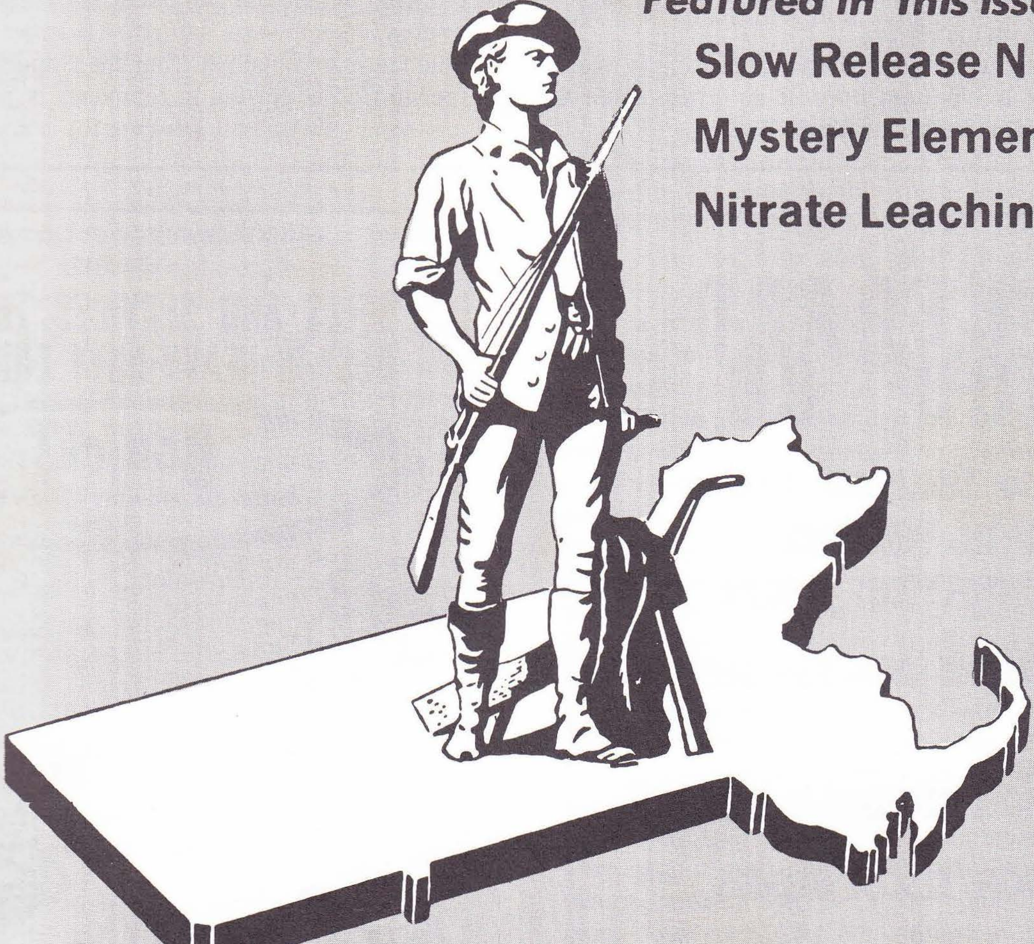

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Slow Release N

Mystery Element

Nitrate Leaching

WINTER 1977

BETTER TURF THROUGH RESEARCH AND EDUCATION

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Influence of Management and Season on Fate of N Applied to Golf Greens[1]

By K. W. Brown, R. L. Dubie, and J. C. Thomas[2]

ABSTRACT

Because golf greens are constructed of very sandy soil mixtures over a gravel and tile drainage system and subjected to heavy irrigation schedules, there is a high potential for loss of applied N through leaching. This study was undertaken to determine the influence of management practices during different seasons on the fate of N applied to golf greens. Small isolated golf greens (3 m on a side) were constructed according to USGA specifications and equipped with drainage and runoff collection systems. Mixtures of sand and Houston black clay soil (Udic Pellusterts) were used in some plots while others were made of a Tabor sandy loam soil (Udertic Paleustales). All plots were planted with Tifdwarf Bermudagrass (*Cynodon dactylon* L.) N sources were applied at various rates during different seasons. The golf greens were irrigated at three different rates. Leachate and runoff samples were analyzed for NO_3 to evaluate the influence of management practices on N losses from the golf greens. The results show that N losses and concentrations of NO_3 in the leachate immediately after application of soluble sources were a function of the rate of N and water applied. When the irrigation rate was kept at or near the evapotranspiration rate, the loss of NO_3 from inorganic soluble sources was minimized. The irrigation rate did not affect the NO_3 losses from organic sources. Seasonal studies indicated that losses and concentrations of NO_3 were highest in winter. This appeared to be associated with the large volume of water which leached from the plots during the season. It was concluded that N losses and NO_3 concentrations could be lowered by: using organic sources of N; reducing irrigation rates to equal the evapotranspiration rate; and decreasing fertilizer rates during periods of slow growth.

Additional index words: Turf, Pollution, N source.

Golf greens are built and designed for their aesthetic value and are subject to intensive management. A significant part of this management is the frequent application of N-containing fertilizers. Some of the applied N may be lost either by leaching from greens with high infiltration rates or by runoff from greens with low infiltration rates. Brown et al.[3] have shown that the amount of N lost in the leachate and runoff from golf greens and the concentration in the leachate and runoff depends on the amount and source of the N fertilizer applied.

Large applications of N, particularly from soluble sources, may be leached through the greens by heavy rains or intense irrigations before the N can be taken up or fixed. Definitive data on the influence of management practices on the loss of N have not been reported in the literature.

A technique which may be useful to minimize NO_3 leaching is to regulate the amount of water applied so as to minimize leachate volumes. LaRue et al. (1968) reported that the least amount of water was lost from the root zone when heavy irrigations were applied infrequently. Tovey et al. (1969) found twice-weekly irrigations adequate to maintain a turfgrass with good appearance and condition during the hot part of the growing season if sufficient water was applied to bring the plant root zone to field capacity at each irrigation. Brown and Duble (1975) reported that the water holding capacity of greens with mixtures consisting mostly of sand above a gravel layer is adequate to allow a twice-weekly watering.

Ellis (1969) reported that NO_3 fertilizers applied to lawns in mid-summer could not be detected below a 30 cm depth nor was there any indication of increased NO_3 in the ground water. NO_3 fertilizer applied in October, however, could be traced to the ground water.

This study was undertaken to determine the effect of fertilizer application rate, irrigation rate, and seasons of the year on the loss of N through leaching and runoff from golf greens.

MATERIALS AND METHODS

The materials and methods for this research were described in detail by Duble et al.[4]. Briefly, the treatments were applied to a group of 21 square golf greens, 3 m on a side, separated from each other by plastic barriers and equipped with gravel under-drainage systems which drained into large collection containers. The less permeable soil plots were provided with systems to collect and store both the leachate and the runoff. The volume of water collected in each container was measured three times a week at which time subsamples were collected for analysis.

Four replications of each of the following mixture of materials used to construct golf greens were used: 90% sand-10% peat moss; 80% sand-10% clay soil-10% peat moss; and a fine sandy loam soil. Eight replications of a mixture containing 85% sand-5% clay soil-10% peat moss were also included. An additional single plot of pure sand was included. All plots were planted to Tifdwarf bermudagrass (*Cynodon dactylon* L.) and overseeded with perennial rye grasses in the fall. Irrigations were applied daily May through October and every other day during the rest of the year.

During part of the study, variable irrigation rates were used. Some plots received 0.6-0.8 cm/application; others received 0.8 to 1.0 cm/application and another group received 1 to 1.2 cm/application rates, respectively. During other studies, the rates were 1.0 cm/application. N-containing fertilizers were applied during different seasons and at various rates to 4 replicates as shown in Table 1. All applications but one were applied uniformly over all

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[1] Contribution of the Texas Agric. Exp. Stn. and the U.S. Golf Association, Greens Section. Received 24 Nov. 1976.

[2] Associate professor, extension turf specialist, and research associate, respectively, in the soil and crop sciences Dep., Texas A&M Univ., College Station, TX 77843.

[3] Brown, K. W., J. C. Thomas, and R. L. Duble. 1976. The effect of different nitrogen sources on leaching and runoff losses of nitrate and ammonia from golf greens. Submitted for publication.

[4] Duble, R. L., K. W. Brown, and J. C. Thomas. 1976. Leachate and runoff losses of arsenic from golf greens. Submitted for publication.

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plots. On 2 Aug. 1974, an application of $(NH_4)_2SO_4$, was made at different rates to selected plots. All plots constructed of mixtures were grouped into 4 replicates treated at each fertilizer level. The effects of N sources upon losses of NO_3 are discussed in a companion paper by Brown et al. (1976). The materials applied, their application rates and the seasons are given in Table 1.

Leachate and runoff samples were refrigerated immediately after collection and subsequently analyzed for NO_3 by means of a specific ion electrode (Orion Model 92-07). To determine the amount of N lost as NH_4, some samples were also analyzed by means of a specific ion electrode (Orion Model 95-70).

RESULTS AND DISCUSSION

A. Application Rate Comparisons

Since there were no observable differences in the behavior of the 80-10-10 and 85-5-10 mixtures, the average values for all these will be referred to as the soil mixture plots constructed of 100% fine sandy loam soil will be referred to as the soil plots. The 90-0-10 plots will be referred to as sand since they contain no soil.

N fertilizer in the form of $(NH_4)_2SO_4$ was applied to individual replicates of the soil mixture plots at four different rates on the same date (2 Aug. 1974). The resulting concentrations of NO_3 in the leachate are shown in Fig. 1. Two peaks in concentration are evident, both following heavy rains. The concentrations in the leachate are generally ranked in the order of application rate. The influence of the application rate was most evident immediately after treatment and following dry periods. Some of the NH_4 was apparently converted to NO_3 during the dry period and leached from the green after the first two heavy rains (23 days after application). Heavy rainfall which occurred 25 or more days after application did not result in peak concentrations. It is evident from this data that the concentrations of NO_3 in the leachate following application of NH_4 sources will depend on the application rate and the frequency of heavy irrigation rates or rainfall.

Table 1. Schedule of N source applications to the experimental golf greens.

Source	Date applied	Season	Rate
			kg N/ha
NH_4NO_3	16 Feb. 73	Winter	163
Ureaformaldehyde	6 June 73	Summer	224
12-12-12 ($(NH_4)_2$ SO_4 and urea)	26 July 73	Summer	146
Milorganite	22 Aug. 73	Summer	82
Milorganite	17 Oct. 73	Fall	146
$(NH_4)_2SO_4$	2 Aug. 74	Summer	24
$(NH_4)_2SO_4$	2 Aug. 74	Summer	49
$(NH_4)_2SO_4$	2 Aug. 74	Summer	73
$(NH_4)_2SO_4$	2 Aug. 74	Summer	98
$(NH_4)_2SO_4$	18 Sept. 74	Fall	98
$(NH_4)_2SO_4$	18 Oct. 74	Fall	98
Ureaformaldehyde	25 Jan. 75	Winter	49

N losses from the four rates of $(NH_4)_2SO_4$ are given in Table 2. Losses expressed as a fraction of that applied increased as the application rate decreased from 98 to 24 kg/ha. The trend is evident for both the mixtures and the soils for both the NH_4 and NO_3 components of the loss.

When the data is expressed as kg of N lost per hectare, a different trend is evident. As the application rate increases, there is an increase in the total loss of N per hectare. Thus at the greater application rates, more N was lost, but the fraction of that applied which was lost was smaller.

B. Irrigation Rate Comparison

The influence of irrigation rate on the NO_3 concentration from the greens treated with NH_4 NO_3 can be seen in Fig. 2. The high and medium irrigation rates both resulted in rapid flushing of the NO_3. The peak from the high irrigation rate was earlier and had a greater concentration of NO_3 than did that from the medium rate. The plots which received low irrigation rates showed no peak concentrations of NO_3 at anytime during the study. Water flow through these plots was much less and allowed the N time to be taken up by grass roots, or otherwise transformed, before it was leached.

The leachate concentrations from 12-12-12 treated plots receiving high, medium, and low amounts of irrigation are shown in Fig. 3. The peak concentrations are slightly higher and narrower from the high irrigation rate than from the medium rate. These differences are, however, small. For the low irrigation rate, the peak concentration is about half of that of the higher irrigation rate, is broader and occurs 5 days later, indicating that the NO_3 moved more slowly. This would also allow more time for root uptake and other transformations within the profile. Leachate from the organic N-sources resulted in consistently low concentrations of NO_3 and differences due to irrigation rates were not evident (Fig. 4 and 5).

While heavy rainfall hastened the leaching of NO_3 from the profiles, only occasionally were sharp peaks associated with rainfall events. Concentrations following the application of $(NH4)2$ SO_4, shown in Fig. 1, are one instance where perhaps the rainfall washed the N which had been oxidized to NO_3 from the profile. When organic sources of N were used, no such peaks were observed.

Irrigation rate influenced the concentration and duration of peak concentrations being leached from the plots.

Table 2. N lost in the leachate expressed as a percent of the applied N. Applications were different rates of $(NH_4)_2SO_4$ to plots constructed of mixtures and soil.

	Mixtures						Soil					
Rate	NO_3		NH_4		Total N		NO_3		NH_4		Total N	
kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
98	15.5	15.2	0.8	7.8	16.3	16.0	4.6	4.5	0.3	0.3	4.9	4.8
73	22.0	16.1	0.9	0.7	22.9	16.7	5.0	3.7	0.4	0.3	5.4	3.9
49	24.9	12.7	2.8	1.4	27.7	13.6	--	--	--	--	--	--
24	37.8	9.1	3.6	0.9	41.4	9.9	14.6	3.5	0.8	0.2	15.4	3.7

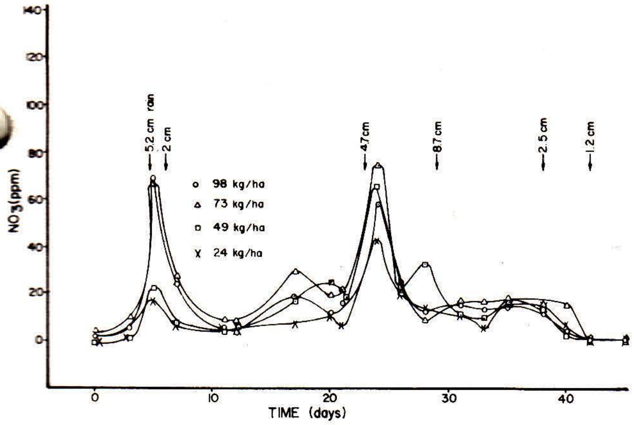

Fig. 1. Concentrations of NO_3 in the leachate from greens constructed of mixtures receiving applications of different amounts of N as $(NH_4)_2SO_4$ on 2 Aug. 1974.

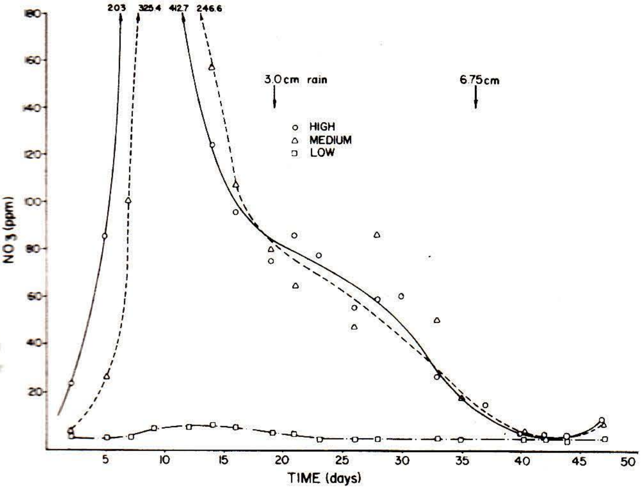

Fig. 2. Leachate loss of N as NO_3 from an application of 163 kg/ha of NH_4NO_3 on 16 Feb. 1973, to field plots irrigated at various rates.

NO_3 leached most rapidly from those plots which received high irrigation rates. When irrigation rates were kept near or below evapotranspiration rates, leachate loss from porous plots fertilized with soluble sources was minimized.

High irrigation rate following application of inorganic N sources resulted in concentrations of NO_3 in the water from porous golf greens which exceeded the drinking water standard of 45 ppm NO_3 (FWPCA, 1972) for periods of as long as 10 days.

Irrigation should be scheduled in such a way as to minimize leaching losses of both water and nutrients. This will not, however, completely eliminate the losses from soluble sources because of occasional heavy storms. Irrigation systems should be adjusted monthly to add no more water than is lost by evapotranspiration. Automatic irrigation systems should be equipped with a bypass system to prevent irrigation for a day or two after heavy rains. In areas where it is necessary to leach salts from the greens and the natural rainfall is not sufficient, the best practice would be to schedule leachings about one month after ap-

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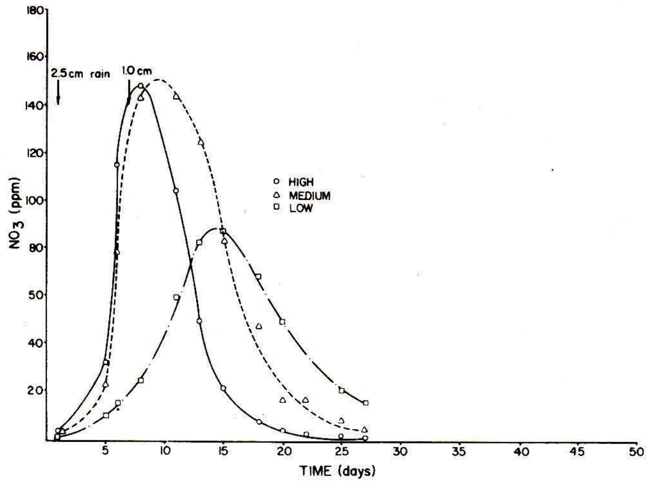

Fig. 3. Leachate loss of N as NO_3 from an application of 146 kg/ha of 12-12-12 on 26 July 1973, to field plots irrigated at various rates.

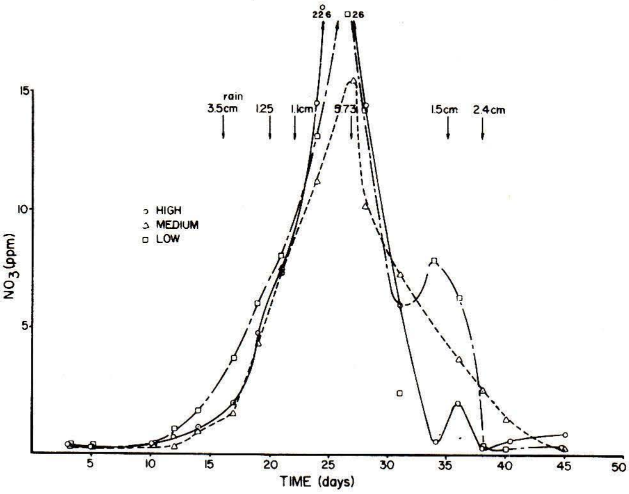

Fig. 4. Leachate loss of N as NO_3 from an application of 146 kg/ha of Milorganite on 17 Oct. 1973, to field plots irrigated at various rates.

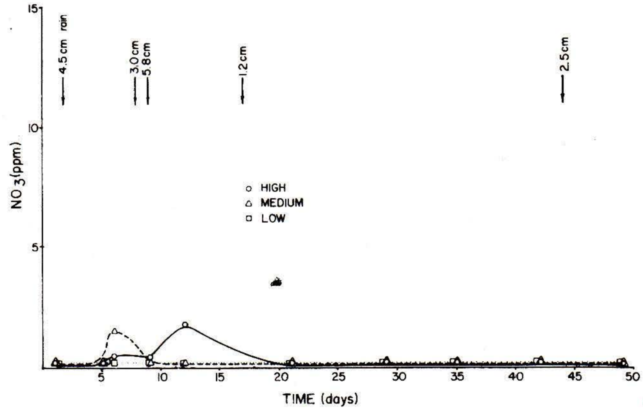

Fig. 5. Leachate loss of N as NO_3 from an application of 244 kg/ha of ureaformaldehyde on 6 June 1973, to field plots irrigated at various rates.

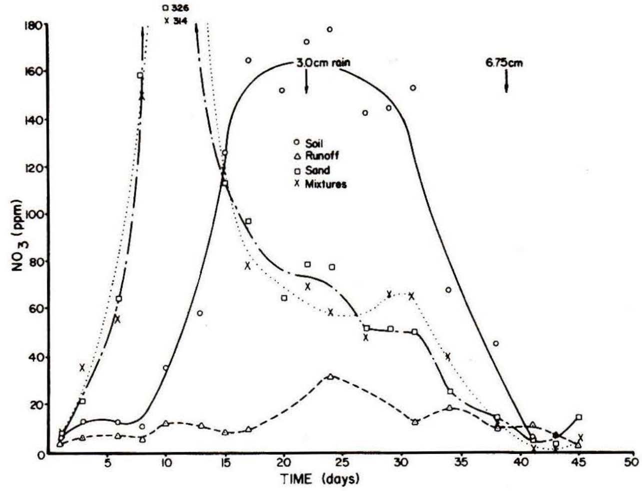

Fig. 6. Concentrations of NO_3 in the leachate and runoff collected from golf greens following an application of 163 kg/ha of N as NH_4NO_3 on 16 Feb. 1973.

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plication of a soluble fertilizer source or two months after the application of an organic or slow release source.

C. Seasonal Comparisons

Seasonal comparisons of the data are difficult at best because different application rates were used during the different seasons. NH4 NO_3 was applied three times; a winter application of 163 kg/ha was made on 16 Feb. 1973. Two applications each of 98 kg/ha were made in the fall of 1974. The results of the latter two applications were similar and thus only one set of data is shown. During the winter, irrigations resulted in peak concentrations (Fig. 6) of 326 and 312 ppm NO_3 in the leachate of the sand and sand-soil mixtures, respectively. The peak occurred 10 days after application. During the fall, the peak concentration of 85 and 50 ppm NO_3 for the sand and sand-soil mixtures respectively occurred 5 days after application (Fig. 7). The peak concentration of 170 ppm NO_3 from the winter application of 163 kg/ha to the soil plots occurred 22 days after application. No peak was evident from the application in the fall. Little rainfall occurred during the early part of either the fall or winter studies and only occasionally did the concentration in the runoff exceed 15 ppm.

From these two sets of data it is evident that the NO_3 did leach out of the sands and sand-soil mixtures during both seasons. The initial peaks are slightly higher and may be slightly earlier from the sands than the sand-soil mixtures. Rather than appearing as a perfectly symmetrical breakthrough curve, the concentrations after the peak remain high, as can be seen in Fig. 6, indicating that NO_3 continues to leach perhaps as the oxidation of other forms proceeds.

Since water moves slower through the sandy loam soil than the sand or sand-soil mixtures, the concentration peaks are broader and not as high as from the sands or sand-soil mixtures. Apparently, following the fall N application the application rate was low enough and the rate of water movement was slow enough that no peak concentration was found in the soil leachate. However, some N was lost from the soil plots in the form of NO_3 in the runoff. Rains were generally light and the concentrations in the runoff were low compared to the leachate.

Another comparison can be made between the summer and fall applications of 82 kg-N/ha and 146 kgN/ha as Milorganite. The lower application rate on 22 Aug. 1973, did not result in any mean concentrations greater than 2 ppm NO_3, and most of the samples were below detection limits. Thirty days following the application on 17 Oct. 1973, a peak concentration of 49.3 ppm NO_3 was reached in the sand plots (Fig. 8). This peak was undoubtedly stimulated by the 5.75 cm rain which fell 2 days earlier. Concentrations from the mixture peaked at the same time, but did not exceed 10 ppm NO_3. Runoff concentrations from the soil plots exceeded 10 ppm only once during the study and was 5 ppm or less for all the other samples.

Ureaformaldehyde applications of 244 kg N/ha and 49 kg N/ha were made on 6 June 1973, and 25 Jan. 1975. The data are shown in Fig. 9 and 10, respectively. Follow-

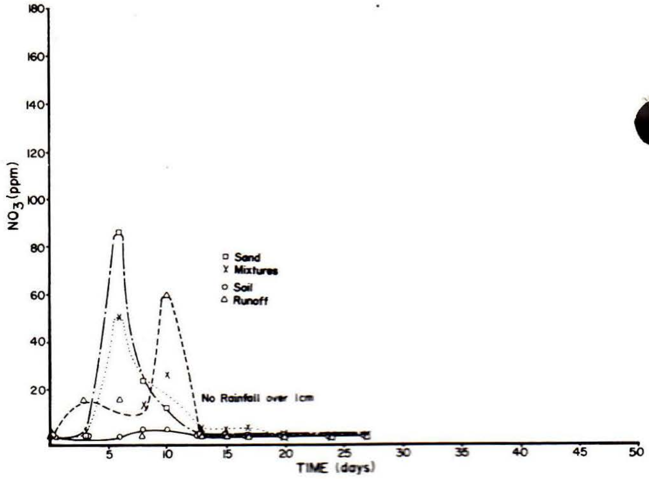

Fig. 7. Concentrations of NO_3 in the leachate and runoff collected from golf greens following an application of 98 kg/ha of N as NH_4NO_3 on 18 Sept. 1974.

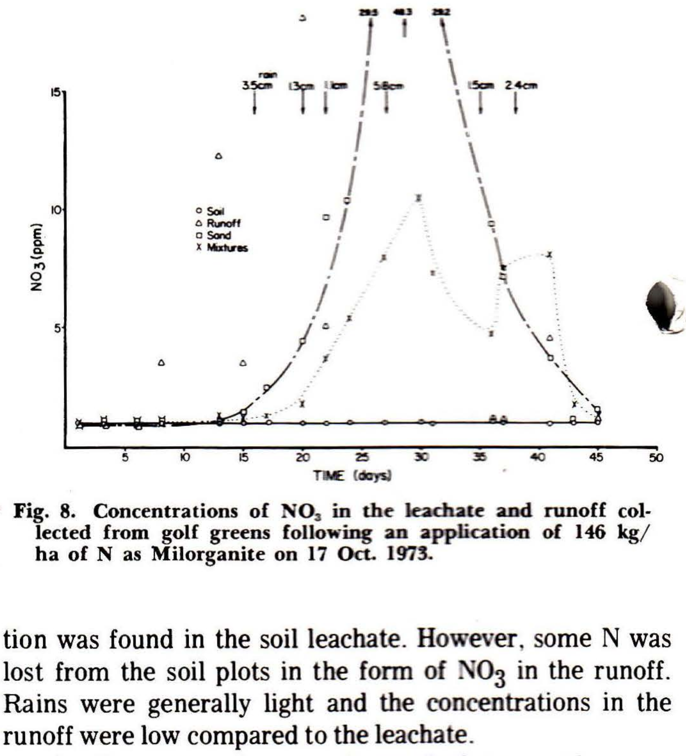

Fig. 8. Concentrations of NO_3 in the leachate and runoff collected from golf greens following an application of 146 kg/ha of N as Milorganite on 17 Oct. 1973.

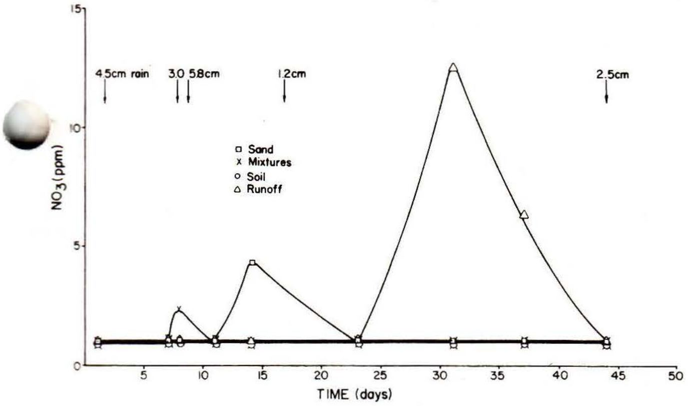

Fig. 9. Concentrations of NO_3 in the leachate and runoff collected from golf greens following an application of 244 kg/ha of N as ureaformaldehyde on 6 June 1973.

ing the heavy application during the summer all concentrations were low. One sampling date for the mixtures and one for the soil yielded concentrations above the detector limit; the runoff concentrations were above those limits on only two occasions and did not exceed 15 ppm in either case. The much lower application rate during the winter did result in detectable concentrations, but they were all too low. A peak of 18 ppm from the sand-soil mixtures occurred 8 days after this application. The concentrations from the sand peaked at 9 ppm on the same day and never exceeded 5 ppm. The soil concentrations were always less than 10 ppm and showed a broader, delayed peak. Runoff concentrations from all cases were at or below the detection limits.

The data from this study indicate that N losses from organic and slow release N sources are low and of small economic importance throughout all seasons and irrigation rates. When soluble inorganic N sources are used, however, it was found that greater amounts were lost and the potential for environmental pollution was greater. The potential for pollution was greatest for these sources during periods of low plant N use and heavy rainfall or irrigation.

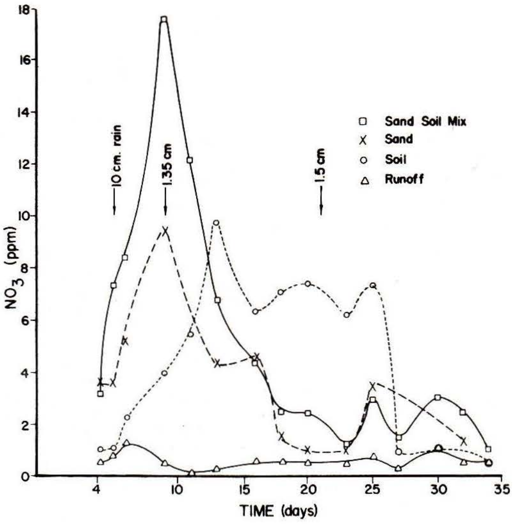

Fig. 10. Concentrations of NO_3 in the leachate and runoff collected from golf greens following an application of 49 kg/ha of N as ureaformaldehyde on 25 Jan. 1975.

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Potassium: The Mystery Element

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In terms of quantities taken up by crops and the total amount present in many soils, potassium is one of the most important of the nutrient cations. Potassium is one of the essential elements in the nutrition of plants and one of the three that are commonly in sufficiently short supply in the soil to limit crop yield (3, 8, 9).

Potassium is absorbed in the plant in larger amounts than any other element excluding nitrogen. Upon analysis potassium is found in all plant parts in relatively large quantities, particularly in the leaves and growing points. Potassium is also present in comparatively large quantities in most soils and constitutes 2.4 per cent of the earth's crust. The importance of potassium in crop production has been recognized since the beginning of the nineteenth century. (3, 7, 9).

Despite its widespread presence, potassium could well be described as the mystery element of plant nutrition. Although many studies have been made on the metabolic role of potassium in plants, its specific functions in plant growth have yet to be fully described and understood (7).

While potassium does play an important role in many of the vital physiological processes in the plant, it is not a constituent of living cells or part of the molecular structure of any of the important plant components such as proteins, carbohydrates, or chlorophyll. Also, the exact nature of the mechanism by which potassium functions is not definately known (6).

Potassium is essential in all cell metabolic processes and apparently has a specific role in influencing the uptake of certain other mineral elements, in regulating the rate of respiration, in affecting the rate of transpiration, in aiding the synthesis and translocation of carbohydrates, amino acids and proteins, and in numerous enzymatic reactions including nitrate reduction where it functions in the role of a catalyst. (3, 6, 8).

In relation to photosynthesis, potassium participates in at least two ways. While not entering prominently into the molecular structure of chlorophyll as does nitrogen, potassium is necessary for the development of this pigment. Its importance in the photosynthetic process is further indicated by the fact that potassium shortages in leaves are commonly considered to lead to reduced rates of carbon dioxide assimilation (7, 8).

Potassium is also involved in the regulation of water absorption and uptake and in this respect greatly influences the heat, drought, and cold tolerances of turfgrasses. Tissue hydration decreases as potassium levels increase, and a distinct reduction in heat and cold tolerance will be noted under conditions of potassium deficiency. Moderate to high levels of potassium in the plant will increase leaf turgor pressure which reduces wilting tolerance of the plant. Increased rooting development, particularly branching, at higher potassium levels also contributes to improved drought tolerance (3, 7).

Higher levels of potassium will reduce the incidence of several turfgrass diseases as *Helminthosporium* app., brown patch, *Ophiobolus* patch, *Fusarium* patch, red thread, and dollar spot. Increased susceptibility to disease at low or deficient potassium levels can result from: a) an

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excessive accumulation of nitrogen and carbohydrates which creates a favorable medium for pathogen activity; b) a thin, delicate cell wall structure that is easily injured during mowing operations and provides ideal penetration sites; c) changes in the reaction and composition of cell sap which enhances pathogen activity; d) reduced plant vigor (3, 7).

Casual observations imply that turfgrass wear tolerance increases proportionally with the level of potassium nutrition. Under high potassium conditions cell walls are thicker, cellulose content is higher, turgor pressure is increased, and the plant exhibits increased vigor and wear tolerance. Turfgrasses grown under conditions of adequate potassium nutrition are healthier, more vigorous plants with reduced susceptibility to disease and environmental stress.

Equally important as the absolute level of potassium nutrition is the relationship which exists among potassium, nitrogen, and phosphorus. Potassium can act as a corrective factor to the harmful effects of nitrogen such as increased disease incidence, reduced drought tolerance, and reduced rooting depth (8).

A proper balance of potassium and phosphorus in relation to nitrogen is important in achieving maximum high and low temperature hardiness. A nitrogen: potassium ratio of 2:1 or 3:1 has been shown to result in maximum cold temperature hardiness of Kentucky bluegrass. In agricultural crops potassium delays maturity and works against the undue ripening influences of phosphorus. It is in these ways that potassium exerts a balancing effect on nitrogen and phosphorus (3, 4, 8).

This relationship involving nitrogen, phosphorus, and potassium can cause problems under field conditions. For example, potassium levels in the soil may be adequate for crops growing under conditions of low nitrogen and phosphorus; but as nitrogen and phosphorus levels are increased that supply of potassium becomes inadequate. Therefore, signs of potassium deficiency are often seen only after nitrogen and phosphorus fertilizers have been applied to a crop (8).

Plants grown under conditions of potassium deficiency are stunted and exhibit yellowish leaf margins. The most characteristic sign of potassium deficiency is "leaf scorch", which is frequently mistaken for burning or firing and is often ascribed to a deficiency of moisture during periods of dry weather. (2, 6).

Potassium deficiency on turf appears initially as drooping of leaves. Moderate yellowing then develops in the interveinal areas, especially at the tips of older leaves. This is followed by rolling and withering of the leaf tips, which retain blotches of green coloring. As the deficiency progresses, yellowing extends to the midvein which remains green even though the leaf margins become scorched and the leaf tips severely scorched. As a result of such leaf deterioration photosynthesis is greatly impaired and the synthesis of starch is brought to a virtual standstill (3, 7).

Under ordinary conditions and with adequate nutrient supply, the crop removal of potassium is high, often equalling that of nitrogen. When large amounts of potassium are in a readily available form plants tend to take up soluble potassium far in excess of their needs. This capacity is termed luxury consumption as the excess potassium absorbed by the plant does not appreciably increase crop yields or plant vigor.

Luxury consumption can prove to be a problem under field conditions. For example, in order to save on labor costs a turfgrass manager may be tempted to apply potassium once in a two to three year period. Much of the added potassium would probably be absorbed wastefully by the turf during the first season and the amount of potassium available for subsequent seasons would be low (3).

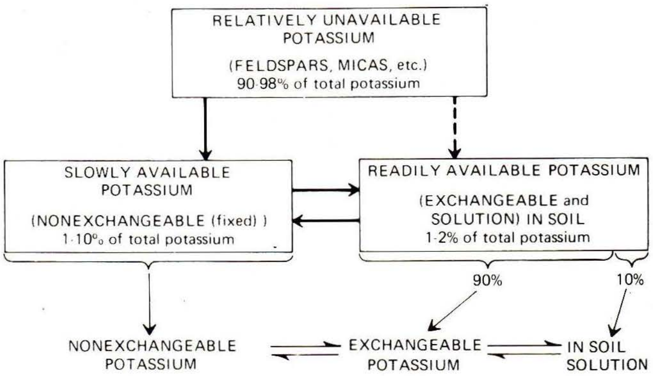
Much potassium can be lost by leaching. In extreme cases the magnitude of potassium loss on mineral soils as measured by examination of drainage water can approach that of potash removal by the crop.

Leaching losses on intensively fertilized sandy soils, such as golf greens, can be quite high. Organic soils, while exhibiting a high exchange capacity, have a comparatively low bonding strength for cations such as potassium and are susceptible to potassium losses. The use of nitrogen carriers with ammonium increases potassium loss by leaching as the ammonium ion readily replaces the potassium ion on the exchange sites of colloids (3, 4, 7).

SOIL POTASSIUM AND ITS AVAILABILITY

Most mineral soils, except those of sandy nature, are comparatively high in total potassium. In fact, the total quantity of this element is generally greater than that of any other major element. Fine-textured soils formed from rocks high in potassium-bearing minerals can contain quantities of potassium as high as 50,000 pounds per acre furrow slice, a quantity approaching 1,200 pounds per thousand square feet (7, 9).

Of the total potassium contained in a soil, only a fraction can be immediately utilized by plants. The forms of potassium in soils can be classified on the basis of their availability: a) unavailable, b) readily available, c) slowly available. Most of the soil potassium is in the unavailable form. The relationship among the three general categories are shown below (4).



These equilbrium tendencies are of vital importance, especially with regard to the slowly available and readily available forms. A slow change from one form to another can and will occur. This allows for the fixation and conservation of added soluble potassium and a subsequent slow release of this element when the readily available supply is reduced (4).

Clearly, most soil potassium contained in a mineral soil exists in relatively unavailable forms. Primary minerals such as the micas and feldspars contain most of this form of potassium and supply relatively insignificant quantities of potassium over a given growing season as a result of their resistance to weathering. There does exist a continuous but slow transfer of potassium from the primary minerals to the exchangeable and slowly available forms (4, 9).

The readily available form of potassium comprises only one to two per cent of the total potassium in an average mineral soil. Readily available potassium exists as potassium in the soil solution and as exchangeable potassium absorbed on soil colloidal surfaces, and constitutes that fraction of soil potassium that can be readily absorbed by growing plants and readily leached through the soil profile. These two forms of readily available potassium exist in dynamic equilibrium, as earlier illustrated, and this relationship assumes great significance from a practical

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standpoint. Plant absorption of soil solution potassium will temporarily disrupt this equilbrium. In order to restore this balance, a portion of exchangeable potassium immediately moves into the soil solution until the equilbrium is again established. Conversely, when water soluble forms of potassium are added, the reverse adjustment takes place (4).

Slowly available potassium becomes available to plants over longer periods of time. However, it is much more available to plants than the potassium present in the primary minerals.

In the presence of 2:1 expanding type minerals such as vermiculite and illite, potassium ions can fit in between the crystal units of the clays and become an integral part of the crystal. Potassium in this form is referred to as non-exchangeable, for it is not readily available to higher plants. However, this form is in equilbrium with the available forms and creates an important source of slowly available potassium.

This amount of "fixed" potassium in some soils can be quite large, and is continually released to the exchangeable form in amounts large enough to be of practical importance. For example, Bray and DeTurk found the release of as much as 300 pounds of potassium per acre from an Illinois soil in a six month period (4, 5).

The exact mechanisms concerning potassium fixation and release are still not clearly understood; but it is surely known that several soil conditions greatly influence potassium fixation. Clays of the 1:1 type such as kaolinite do not fix potassium in the manner described for the 2:1 types. Applications of lime often result in an increase of potassium fixation in soils, but with normal liming practices this is considered beneficial as potassium is conserved against leaching losses which are more severe in acid soils. Large amounts of fertilizer potassium additions over a period of time will result in less fixation of subsequent applications and an increase in the content of exchangeable potassium. Research to date indicates that the level of exchangeable potassium increases as temperatures increas Generally speaking, drying field-moist soils usually increases the level of exchangeable potassium. This fact is of particular interest in regard to soil tests where air drying samples prior to analysis could lead to high soil test values of potassium and a resulting low recommendation for potassium fertilization. (4, 8, 9).

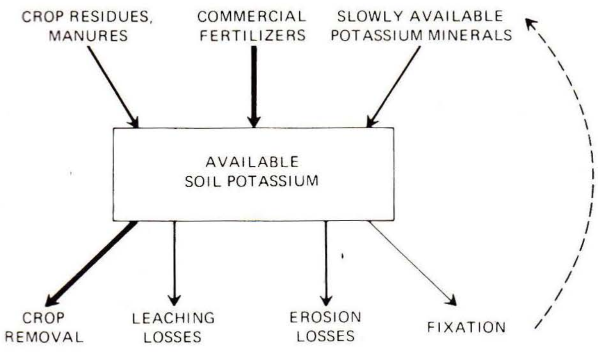
In relation to fixed or native potassium it has been shown that plants with roots of relatively low exchange capacity values are best able to absorb native soil potassium. Plants with low exchange capacities such as grasses and cereals will exhibit small response to applications of fertilizer potassium when compared to plants such as clover which have higher root exchange capacity. Keeping this in mind, it becomes obvious that grasses are much better able to survive at low levels of potassium (9).

Practical Implications in Respect to Potassium

One suggestion that is evident from the material considered thus far is that frequent, light applications of potassium are superior to heavier, less frequent applications. Heavier applications lead to excess leaching, luxury consumption by crops, and an increase in potassium fixation. While fixation does exhibit a beneficial capacity in regard to potassium conservation, in most situations this is outweighed by the disadvantages of excess leaching and luxury consumption.

Another valuable suggestion is that full advantage be taken of the potassium supplying power of soils. For example, A. S. Ayres grew 16 crops of Napier grass in Hawaii over a four and one-half year span without adding potassium fertilizer. Each cropping removed 250 pounds of potassium per acre but the exchangeable potassium in the soil remained nearly the same over the duration of the experiment. The idea that each pound of potassium lost from the soil by leaching or plant uptake must be supplemented by the addition of fertilizer potassium is not always correct. In many cases large quantities of moderately available forms of potassium are present in the soil and can be utilized for plant uptake (1).

According to Brady, the problem associated with the maintenance of soil potassium can be outlined as follows (4).



SUMMARY

The problem of potassium economy can be summarized: a) a very large proportion of this element at any given time is relatively unavailable to higher plants; b) because of the solubility of its available forms, it is subject of wasteful leaching losses; c) the removal of potassium by crops is high, especially when luxury quantities of this element are applied (4).

Bearing these ideas in mind, along with the accelerated use of sand in topsoil mixes, one must expect an increased use of commercial potassium if optimum turf quality is to be maintained. The contemporary turfgrass manager certainly must develop a comprehension of the interactions encountered by different forms of potassium in the soil environment; he can not afford to overlook the role of potassium in relation to disease incidence and the general hardiness of grasses to withstand many adverse environmental conditions.

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Effect of IBDU and UF Rate, Date, and Frequency of Application on Merion Kentucky Bluegrass[1]

By J. F. Wilkinson[2]

ABSTRACT

IBDU (isobutylidene diurea) and UF (ureaformaldehyde) are two popular synthetic, slow-release nitrogen sources for use on turf. IBDU-N release is a dissolution process, whereas N release from UF is dependent upon microbial activity. As a result, different turf responses to the two sources are expected. The objective was to compare IBDU coarse and fine, UF, and AN (ammonium nitrate) applied to 'Merion' Kentucky bluegrass *(Poa pratensis* L.) grown on Brookston silt loam, a member of the fine-loamy, mixed, mesic Typic Argiaquolls, with a pH of approximately 7.3. Each N source was applied at 1, 2, or 3 kg N/are. The 1 and 3 kg N rates were applied in April. The 2 kg N rate was applied either in April, September, split between April and September, or split between April, June, July, and September. Treatment response was measured monthly by turf quality ratings, clipping weights, and N uptake. Turf response to coarse and fine IBDU was very similar. Single spring applications of IBDU produced a poor initial turf response compared to UF. IBDU provided a much better turf response than UF at low temperatures, whereas there was relatively little difference in turf response to IBDU nd UF during the summer months when applied at the same rate and date. Frequency of application affected turf quality response more with IBDU than UF. Two IBDU applications were required for most uniform turf quality response. Uniformity of response improved only slightly with multiple UF applications.

Additional index words: Isobutylidene diurea, N recovery, *Poa pratensis,* Turf quality, Urea-formaldehyde.

Slow-release nitrogen sources are used extensively by turf managers to decrease fertilizer application frequency and labor costs. Ureaformaldehyde (UF) and isobutylidene diurea (IBDU) are two synthetic, slow-release N sources commercially available for use on turf. N release from UF is dependent upon microbial degradation, and consequently, soil temperature is a major factor affecting turf response. IBDU-N release is a dissolution process and less dependent on temperature than release of UF-N. Since N release from UF and IBDU follow different principles, different turf responses are anticipated throughout the growing season.

UF normally contains 25 to 35% of its total N in the water-soluble form (11% water-soluble N). A rapid initial response is produced, especially if applied at higher rates. A residual response results from the water-insoluble N fraction.

IBDU contains 3% water-soluble N (10% of its total N). It has been found to produce a slow initial response (2). N release rate is reported to be faster with finer particle sizes and in acid soils (1). Earlier studies have indicated better N recovery and cold temperature response from IBDU than UF (2, 4, 5). There is some indication that high rates of IBDU may produce temporary turf discoloration (3).

The objective of this research was to compare in detail the response of 'Merion' Kentucky bluegrass (*Poa pratensis* L.) to different rates, dates, and frequencies of application of IBDU and UF.

MATERIALS AND METHODS

The research was conducted at the turfgrass research plots at The Ohio State Univ. in Columbus on a 6-year-old stand of Merion Kentucky bluegrass. The soil was Brookston silt loam, a member of the fine-loamy, mixed, mesic Typic Argiaquolls, with a pH of approximately 7.3. P and K were applied at 1.7 and 0.9 kg/are/year, respectively. The turf was irrigated throughout the growing season to prevent wilt and was moved twice weekly at 3.8 cm with clippings returned. A randomized complete block design was used with three replications and a plot size of 1.21 X 2.42 m.

The treatments (Table 1) included IBDU coarse (1 to 2 mm particle size), IBDU fine (0.25 to 0.5 mm) and UF (71% water-insoluble N). Each was applied at three rates and three frequencies of application. Ammonium nitrate (AN) was included as an additional treatment at 0.5 kg N/are in April, June, July, and September for comparative purposes. Monthly precipitation and temperature data are presented in Fig. 1.

Table 1. Rate and frequency of application of coarse and fine IBDU and UF.

	Application	
Total N	Rate	Date
kg N/are		
1	1	April
2	2	April
2	2	Sept.
2	1	April, Sept.
2	0.5	April, June July, Sept.
3	3	April

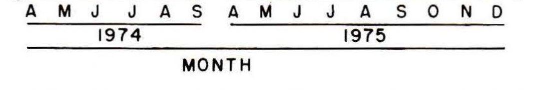

Fig. 1. Monthly precipitation and temperature data for Columbus, Ohio, in 1974 and 1975.

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Treatments were initiated in April 1973, and terminated in September 1975. Fertilizer was applied each year on 15 April, 1 June, 15 July, and 1 September. Turf quality data were taken monthly during 1974 and 1975. Plots were rated 1 to 9, 1 being dead turf and 9 being the highest possible quality, not the highest on any particular rating date. Using this system, a value of 6.5 or higher was considered acceptable turf quality. Clippings were collected monthly during 1975 from one 2.42 m pass of a mower over the plots (1.6 m2) after 7 days of regrowth. Clippings were dried at 70 C, weighed, and ground in a Wiley Mill for Kjeldahl analysis of total N. Nitrogen determinations were made on the clippings in early and late spring, mid-summer, and early fall.

RESULTS AND DISCUSSION

Turf response to coarse and fine IBDU in most cases was very similar, especially at the 1 and 2 kg N/are rates. A more rapid N release rate normally is expected from the finer material, however, this was observed in only a few instances at the 3 kg N/are rate. Similar turf response to the two particle sizes may be due, in part, to the alkaline soils used in this study. Hughes (1) has shown IBDU-N release may be delayed in alkaline soils. As a result, pH may have negated IBDU particle size effects. Results reported in this article compare only IBDU coarse with UF and AN.

Both IBDU and UF produced higher turf quality and greater clipping weights with increasing N levels (Fig. 2). Turf response (both quality and clipping weights) to spring-applied IBDU was slow compared to UF, regardless of the rate of N application. This was especially true of the turf quality response in 1974. The best turf response from IBDU was reached 3 months after a single spring application. As expected, spring applied UF provided a much more rapid turf response owing to its water-soluble N fraction. The UF water-soluble N fraction apparently was utilized rapidly as turf quality and clipping weights peaked within 1 month of the spring application. A second UF peak occurred sometime between June and August, probably in response to N from all the water-insoluble fraction released as a result of higher soil temperatures. When applied only in spring, at least 2 kg N/are would be required from either IBDU or UF to produce an acceptable turf quality (rating $>$ 6.5) throughout the growing season.

The results of spring vs. fall-applied IBDU and UF at 2 kg N/are may be compared in Fig. 3. Spring application of IBDU produced a slow turf response, but did not provide an acceptable turf quality through the summer and early fall. IBDU applied in September provided an excellent response in the fall and also produced an excellent response in early spring. This low temperature response was expected, because IBDU-N release is a dissolution process and soil temperature is not a primary factor affecting release rate. As the spring progressed, turf quality and clipping weights from the single IBDU fall application decreased, and an additional N application would be required to maintain an acceptable turf quality through the summer months. IBDU would be an excellent N source for use on cool-season turfgrasses in locations having relatively mild winters where turf areas are utilized into late fall and again in early spring.

Spring-applied UF at 2 kg N/are produced a rapid

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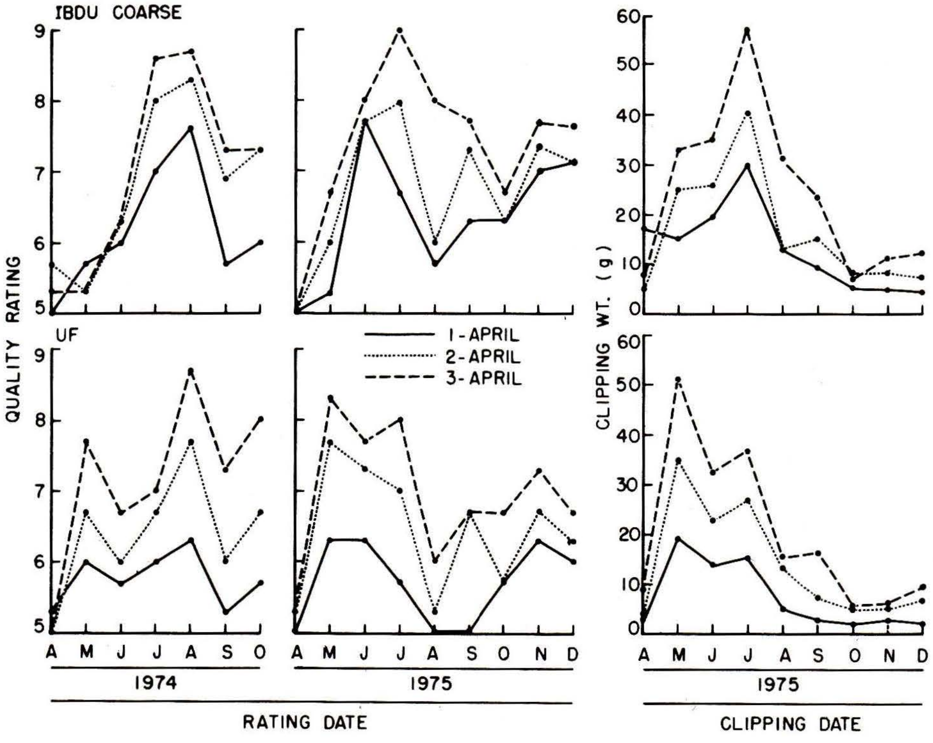

Fig. 2. Effect of IBDU coarse and UF at 1, 2, and 3 kg N/are applied in April on turfgrass quality and clipping dry weights.

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response from the water-soluble N fraction, with turf quality generally being maintained at an acceptable level through the summer and early fall (Fig. 3). Fall-applied UF also provided an excellent turf response in September due to the water-soluble N fraction. This fraction apparently was utilized in the fall, and compared to fall-applied IBDU, fall-applied UF was unable to produce an acceptable turf quality in early spring (April rating date). However, in contrast to the fall-applied IBDU, fall-applied UF provided a turf quality and clipping weight response through the late spring of 1974 and 1975 and summer of 1975 similar to the single UF spring application. This most likely is attributable to the residual water-insoluble N fraction which was not used during the winter months because of low soil temperatures.

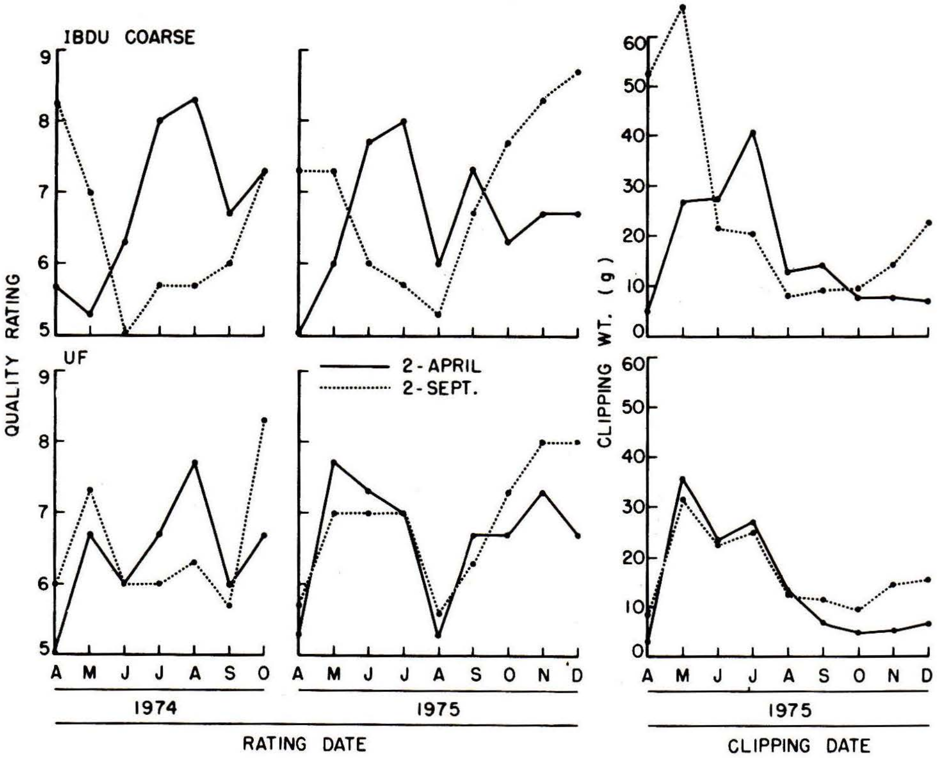

Fig. 3. Effect of IBDU coarse and UF at 2 kg N/are applied in April or September on turfgrass quality and clipping dry weights.

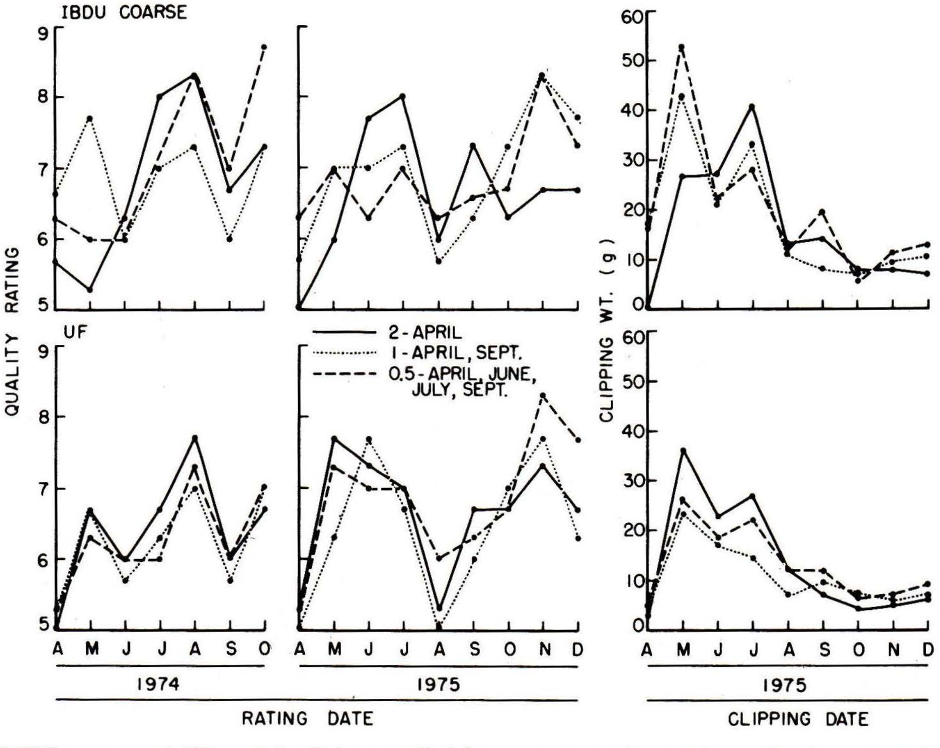

Fig. 4. Effect of IBDU coarse and UF at 2 kg N/are applied in one, two, or four split applications on turfgrass quality and clipping dry weights.

Turf quality response to UF was similar throughout the growing season whether applied in one, two, or four applications (Fig. 4). Although clipping weights reveal more uniform growth from two and four UF applications compared to a single spring application, turf quality response to application frequency followed the same trends throughout the growing season. IBDU application frequency influenced turf quality response to a greater extent than UF. Single spring applications of IBDU provided slow spring greenup, but excellent turf through the summer. A minimum of two IBDU applications produced a more uniform turf quality response than a single spring application. In 1974, it appeared four IBDU applications did not provide sufficient N for carryover from fall to spring to produce acceptable turf quality in early spring. Two or four IBDU applications provided a more uniform turf quality response than one, two, or four UF applications during 1975.

This limited effect of UF frequency of application is confirmed by N recovery in clippings (Table 2). At 2 kg N/are applied in the spring, frequency of UF application significantly influenced N recovery on one date only, whereas IBDU application frequency affected N recovery on all four dates.

Note that in Fig. 2, 3, and 4 turf quality and clipping weights are not strongly related. Clipping weights generally peaked in response to maximum N release from either source. For example, in Fig. 2, IBDU clipping weights peaked 3 months after spring application. In the case of UF, an initial peak occurred 1 month after application in response to the water-soluble N fraction, and a second occurred in mid-summer, apparently in response to N release from the water-insoluble N fraction. Turf quality responded differently, with quality directly related to the prevailing growing conditions. This was especially true in late summer, when clipping weights from a single spring application were decreasing, while turf quality was improving due to better growing conditions. These figures point out that clipping weights, often used as a measure of turf growth rate, may not always be a true indicator of turfgrass quality in response to fertilizer applications.

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Table 2. Effect of IBDU coarse and UF rate, date, and frequency of application of N recovery in clippings on early and late spring, mid-summer, and fall dates.

N Sources	Total N	Rate and Date	Date				
			1 April	1 June	1 Aug.	1 Oct.	Mean
	kg N/are				% N		
IBDU Coarse	1	1 —April	3.23	4.11	4.32	4.26	4.03
	2	2 —April	3.07	4.48	4.66	4.18	4.10
	2	1 —April, Sept.	3.76	4.28	4.27	4.80	4.27
	2	0.5—April, June, July, Sept.	3.63	3.70	4.50	4.69	4.13
	3	3 —April	3.13	4.70	4.96	4.38	4.29
UF	1	1 —April	3.22	3.54	4.35	4.06	3.79
	2	2 —April	3.12	3.87	4.63	4.28	3.98
	2	1 —April, Sept.	3.09	3.59	4.26	4.29	3.81
	2	0.5—April, June, July, Sept.	3.14	3.69	4.62	4.53	4.05
	3	3 —April	3.13	4.10	4.67	4.45	4.09
AN	2	0.5—April, June, July, Sept.	3.34	3.60	4.73	4.52	4.05
		L.S.D. (0.01)	0.29	0.38	0.35	0.33	0.29

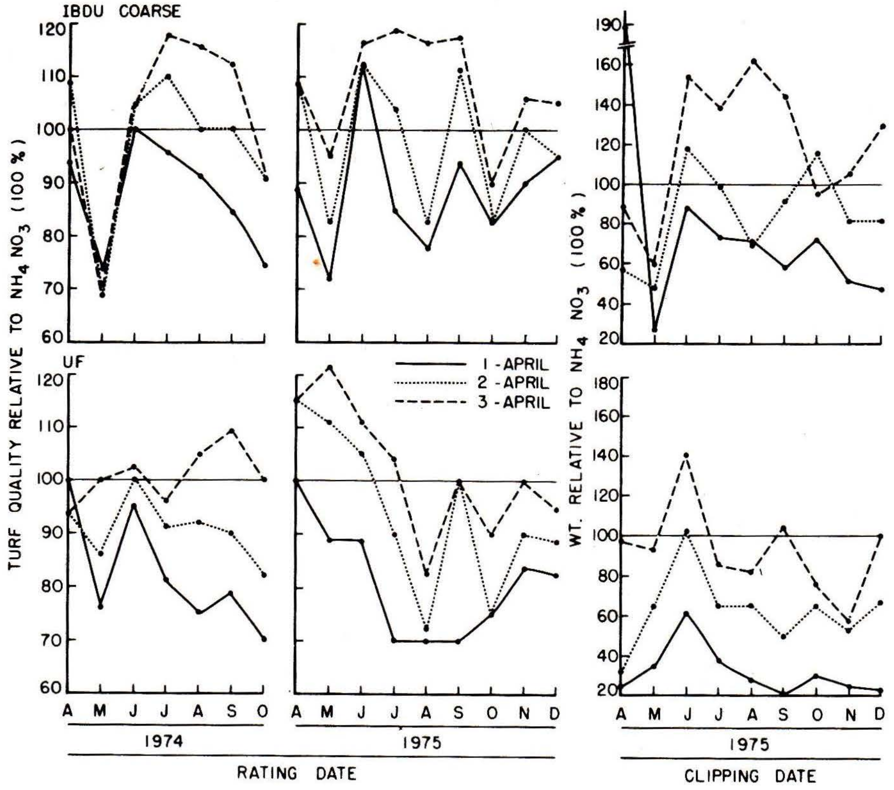

Fig. 5. Effect of IBDU coarse and UF at 1, 2, and 3 kg N/are applied in April on turfgrass quality and clipping dry weights compared to AN at 2 kg N/are applied in four split applications.

Continued from Page 17)

When compared to the AN treatment of a relative value of 100%, N utilization appears more efficient from IBDU than UF (Fig. 5). Except for the initial spring period, IBDU, applied at 2 and 3 kg N/are in a single spring application produced turf quality and clipping weights comparable to or better than AN applied at 2 kg N/are in four applications. In contrast, UF produced lower turf quality and clipping weights than AN at comparable rates (2 kg N/are), except during the initial spring period when the water-soluble N fraction was available. Three kg N/are from UF were required to provide as high a turf quality or clipping weight as 2 kg N/are from AN.

Improved N efficiency from IBDU compared to UF is confirmed by N analysis of clippings (Table 2). When applied at the same rate and time, IBDU provided for equal or better N recovery than UF. Previous studies have also indicated better N recovery from IBDU than UF (2).

Poor N recovery from UF compared to IBDU may be the result of two factors. First, the UF used in this study contained 29% of its total N in the water-soluble form, whereas the IBDU N was 97 to 98% insoluble. Once the water-soluble N fraction of UF was utilized and/or leached from the root zone, the remaining amount of N providing for a residual turf response would be small compared to IBDU. Second, UF contains a hot water-insoluble N fraction which may not be available, at least within the first growing season after application. This may be as high as 25% of the total N in UF.

CONCLUSIONS

Under the conditions of this study the following conclusions can be drawn regarding turf response to IBDU and UF:

a) Turf response to coarse and fine IBDU was very similar. This may be due, in part, to the alkaline soils used in this study.
b) IBDU, having a small water-soluble N fraction, produced a poor initial response compared to UF.
c) When applied in the fall, IBDU produced a much better low temperature turf response than UF.
d) Turf response to IBDU and UF was similar during the summer months.
e) Frequency of application affected turf response more with IBDU than UF.
f) Two IBDU applications produced the most uniform turf quality response of all treatments.
g) N recovery was better than IBDU than UF.

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