NITROGEN AVAILABILITY TO TURFGRASSES FROM UREA-FORMALDEHYDE AND FIVE OTHER FERTILIZERS

A Thesis

Submitted to

The Faculty of Graduate Studies and Research

The University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

R. Scott Reid

January 1967

THE UNIVERSITY OF MANITOBA
ELIZABETH DAFOE LIBRARY

Creeping bentgrass putting greens to study the availability of nitrogen from Uramite and five other fertilizers when all were applied at a rate (six pounds of nitrogen per 1000 square feet) commonly used in the Winnipeg area. The 1965 and 1966 season mean leaf nitrogen response to the Uramite treatment was significantly lower than that to urea, activated sewage sludge (Milorganite), ammonium sulphate, ammonium nitrate, and plastic coated urea. The season mean leaf nitrogen responses to Milorganite, ammonium sulphate and ammonium nitrate did not differ significantly in 1965 or 1966. It was also found that the leaf nitrogen in all fertilizer treatments including the "constant release" fertilizers Milorganite, Uramite and plastic coated urea followed the same general pattern of variation in 1965 and 1966, increasing sharply after all fertilizer applications, then decreasing rapidly approximately two weeks after application.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Turf on special purpose areas such as lawns, golf course greens and fairways, athletic fields and parks, should be maintained at a high quality if full benefit is to be derived from these areas. The characteristics of a good turf are: uniform growth, dark color, a dense weed-free stand, and an ability to resist excessive damage from constant traffic. If these objectives are to be achieved, constant and reasonably adequate levels of nutrients must be available to the plants.

Generally nitrogen is considered to be the most important growth producing element in turf production. It is used in relatively large quantities by turfgrass and, therefore, it is essential that adequate supplies be available at all times. Most soils in the Winnipeg area that have been under turf for several years cannot supply sufficient nitrogen to maintain good quality turf and natural supplies must be continually supplemented to provide adequate nitrogen.

Three main types of nitrogenous fertilizer are used in the Winnipeg area: soluble materials, natural organic materials, and synthetic organic materials.

The soluble materials include ammonium nitrate, ammonium sulphate, and urea. The advantages of using such materials are that the nitrogen is in a form readily available to the plant, the percentage nitrogen content is high and thus there is less bulk carrier to handle. Also the nitrogen in these materials is far less expensive than in any other form. The disadvantages of using such materials on turfgrass are: they require frequent application during the growing season, they cause extreme fluctuations in growth and nitrogen content of the plant leaves, and considerable amounts of nitrogen may be lost to the plants due to leaching.

The natural organic form most widely used in the turf industry is activated sewage sludge. This material is supposedly a slow, constant release nitrogen source, a characteristic that should prevent extreme fluctuations in growth and leaf nitrogen content. Also, it should mean that fewer applications would be necessary during the growing season but this is not possible because the bulk material required to provide adequate nitrogen for a growing season cannot be applied with less than four applications per season. The primary disadvantages of using sewage sludge are; it is the most expensive and bulkiest form of nitrogen, and it has a disagreeable odour.

A synthetic, slow-release organic fertilizer, urea-formaldehyde was developed in an attempt to combine the advantages of soluble materials with the advantages of natural organic materials. Urea-formaldehyde or ureaform, supposedly provides nitrogen for plant growth at a rate that is beneficial for plant life with a long growing season such as turfgrasses. During the past decade this material has come to be used extensively as a nitrogen source for turfgrasses. Turf managers in the Winnipeg area who have used this material claim to have had poor response from applications of urea-formaldehyde fertilizers as compared to other sources of nitrogen. Preliminary studies (14) comparing urea-formaldehyde with the other nitrogen sources, when used at equivalent nitrogen rates on bentgrasses and Kentucky bluegrass in the Winnipeg area have shown that plots treated with urea-formaldehyde had poor visual quality and low fresh weight yields.

The study reported herein was undertaken to determine whether or not soil and weather conditions in the Winnipeg area are suitable for the use of urea-formaldehyde materials. A detailed study of the availability pattern of various commercial sources of nitrogen was also conducted on a bentgrass putting green, using fertilizer rates and dates of application similar to those most frequently used on putting greens in the Winnipeg area.

LITERATURE REVIEW

The term ureaform is actually a general one which includes a host of products which are mixtures of methylene ureas. They range from short-chain, water soluble molecules to long-chain, water insoluble molecules. Since the longer chain methylene ureas constitute the insoluble portion of the ureaform, the agronomic value of the product relates directly to the amount and type of methylene ureas and the amount of unreacted urea in the product.

The possible reactions involved in the production of methylene ureas are given in "Fertilizer Technology and Usage" (30) as:

$$NH_2CONH_2 + CH_2O \longrightarrow NH_2\ CONHCH_2\ OH$$

Urea formaldehyde methylol urea

$$NH_2CONHCH_2OH + NH_2CONH_2 \longrightarrow NH_2CONHCH_2NH\ CONH_2 + H_2O$$

methylol urea urea methylene diurea

methylene diurea + methylol urea ⟶ longer chain methylene ureas

Yee and Love (49) found that nitrification rate, surface area, and solubility of urea-formaldehyde condensation products increase with an increase in the molar ratio of urea to formaldehyde. A slight increase in the mole ratio brings about a marked change in the nitrification characteristics. They also found that the availability of the nitrogen in these materials is roughly proportional to their water solubility.

A method proposed by Morgan and Kravobec (33) is often used to predict the agronomic value of urea-formaldehyde polymers. The procedure requires the determination of cold water insoluble nitrogen, and hot buffered solution insoluble nitrogen. The value involved is termed the Availability Index (A.I.) and is shown as follows:

$$A.I. = \frac{\%\ CWIN - \%\ HWIN}{\%\ HWIN} \times 100$$

This parameter is actually a measure of the availability of the cold water insoluble portion of ureaform and has been shown (9,37,47) to be closely correlated with soil nitrification tests.

Various members of the methylene urea series have been studied by Winsor and Long (48). They found that none of these products possessed all of the properties required for an ideal slow-acting fertilizer. Trimethylene tetraurea was the most promising, methylene diurea and dimethylene triurea decomposed too rapidly, and tetramethylene pentaurea in mixtures with higher members of the series was highly resistant to decomposition in soil.

Microbiological studies on urea-formaldehyde preparations by Fuller and Clark (16) demonstrated that ureaform preparations do not inhibit the activity of the soil microflora even with applications as high as one percent and hydrolytic enzymes of the soil microflora are essential for the liberation of ammonia from urea-formaldehyde preparations in the soil. Strict chemical hydrolysis of ureaform in the soil either does not take place or is too slow to be measured by chemical or vegetative tests. They found also that mineralization proceeds satisfactorily in the presence of ureaform at application rates comparable to, and even greater than those normally used in turf management.

Other laboratory (8,21,34,37,46,47,49), greenhouse (1,2,5,7,27, 40,42) and field (11,25,26,40,41,43) experiments have demonstrated that the rate of mineralization of urea-formaldehyde materials depends on the relative mole ratios of urea to formaldehyde; the method of manufacture, and the physical and chemical properties of the soil such as: pH, microbial activity, nutrient content, structure, and texture.

The agronomic value of urea-formaldehyde condensation products has been studied in several laboratory experiments (8,34,46,49). The conclusions have generally agreed that these materials release enough nitrogen throughout the growing season to be of value as nitrogen fertilizers for long season plantings such as turf. The same general conclusions have been reached in greenhouse experiments (1,2,5,27).

However, field experiments comparing ureaform material to other nitrogen sources have shown considerable disagreement with respect to the agronomic value of these materials. Lantz (24) found that a single application of Uramite[1] at ten pounds per 1000 square feet on Kentucky bluegrass was sufficient to induce moderate growth throughout the season. Milorganite[2] and Uramite proved satisfactory so long as the total nitrogen equalled five to six pounds per 1000 square feet per year. Uramite proved better with three split applications. Musser et al. (35) found urea-formaldehyde formulations showed more uniform rates of nitrogen release throughout the growing season than any other material tested in a three-year trial on a Kentucky bluegrass-Creeping red fescue

---

[1]A urea-formaldehyde fertilizer (38-0-0) manufactured by E. J. DuPont de Nemours and Company (Inc.).

[2]An activated sewage sludge fertilizer (6-3-0) manufactured by The Milwaukee Sewage Commission.

mixture. Single applications of ureaforms, sewage sludge and nitrogenous tankage were adequate to maintain a good quality turf throughout the season, whereas soluble nitrogen fertilizers proved more effective when used in split applications. Duich and Musser (10) reported that ammonium sulphate in the ten split applications increased total growth of Creeping bentgrass putting green turf, but had no significant effect on turf quality over natural organic materials and ureaform compounds. Seasonal growth distribution was more uniform when slowly available nitrogen materials were used, although significant differences in growth rates were evident in the early part of the season. They concluded that the value of any form of nitrogen depends primarily on how it is used. Duich and Musser (11) later reported that ureaform compounds gave the slowest rates of growth, but produced responses over the longest periods, natural organics were intermediate, with responses being influenced to a greater extent by environmental conditions. Killian (23) compared the effects of fertilizers containing various ratios of urea-formaldehyde, to the effect of ammonium nitrate on the rate of growth and nitrogen recovery by Kentucky bluegrass. He found that the largest total yield from the three-year period from annual applications was from mixtures containing 53% or less of their nitrogen as ureaform. Total yields were significantly lower for mixtures containing 88 to 100% of their nitrogen as urea-formaldehyde. However, these mixtures gave the most uniform growth during each of the three years. He concluded that his results suggest that urea-formaldehyde materials can be topdressed on grass at rather heavy rates with the expectation that it will continue to release nitrogen over a period of several years. Litynski (27) found that ureaform materials with U/F mole ratios 1.5 to 2.0 were almost equivalent to ammonium nitrate and were superior to urea as nitrogen sources for potatoes and sugar beets.

Others have been less enthusiastic about the agronomic value of ureaform materials. Escritt (14) found that grass yields throughout the season from plots fertilized with ammonium sulphate in three applications were higher than those from plots which received the same amount of nitrogen in one application of a ureaform fertilizer. He concluded that the use of the ureaform fertilizer was comparable to that of a readily available inorganic fertilizer of relatively low nitrogen content rather than a slow acting organic fertilizer. Goetze (19) found that natural organic materials produced ryegrass turf of better visual quality than either soluble or ureaform fertilizers at comparable rates. On a Creeping bentgrass putting green, soluble and organic fertilizers were found to have better effect on quality than comparable amounts of ureaform material. It has also been reported (17,39,41,45) that ureaforms mineralize too slowly to be of use as a nitrogen source for field crops.

Lunt (39), and Byrne and Lunt (6) have reported that very good slow-release performance can be obtained from ureaform materials on turfgrass under year round growing conditions. The basic requirement for a successful urea-formaldehyde program is the development of a large enough reservoir of the residual ureaform fraction so that the six or seven percent mineralization per month meets the needs of the planting. He estimates that about 20 or 25 pounds of nitrogen in the form of residual urea-formaldehyde per 1000 square feet is required to produce an adequate, steady supply of available nitrogen in putting greens of the Los Angeles area.

In the only study of the effect of temperature on the mineralization of ureaform found in the literature, Basaraba (4) reported that ureaform materials mineralize only very slowly in cool soils. He concluded these compounds could mineralize more rapidly, however, during the summer months when moist soils become warmer.

MATERIALS AND METHODS

This project consisted of one laboratory incubation experiment and two field experiments, which were conducted to determine whether or not soil and weather conditions in the Winnipeg area are suitable for the use of urea-formaldehyde fertilizers and to study the availability of various nitrogen fertilizers to bentgrass putting greens.

Experiment I

A soil-fertilizer incubation experiment was conducted in the laboratory to study the effect of temperature on the mineralization of a urea-formaldehyde fertilizer. Ammonium sulphate was used as a comparative standard and also served to demonstrate the characteristics of ammonium to nitrate oxidation found under these conditions. The amount of nitrate nitrogen produced after the various periods of incubation was used as the criterion for evaluating the amount of mineralization that had taken place. Ammonium nitrogen was not determined because Basaraba (4) found that during a fourteen-week incubation of ureaform, the amount of ammonium nitrogen never exceeded 0.1% of the total nitrogen added.

The urea-formaldehyde material used in this experiment was the same as that used throughout the project. Uramite was selected as the pure ureaform source because it is the brand most frequently utilized in the Winnipeg area. Some of the chemical and physical properties of this material (data supplied by E. I. DuPont de Nemours and Company) are given as follows:

Urea-formaldehyde mole ratio	1.35
Total nitrogen	38.5%
Insoluble nitrogen	27.0%
Urea nitrogen	3.25%
Cold water solubility	9.3%
Hot water solubility	12.9%
Activity Index	55.

The soil used for the study was taken from the top six inches of the field used in Experiment II. The soils of this field are described (12) as imperfectly and poorly drained members of the Red River and Fort Garry soil associations. They are blackearth and meadow soils developed on heavy lacustrine clay. Immediately after sampling the soil was dried and mechanically ground to form particles with less than two millimeters diameter.

The soil was then analysed by the Provincial Soil Testing Laboratory, Department of Soil Science, University of Manitoba. The results of these analyses are presented below:

pH	7.6
Conductivity (mmhos/cm.)	0.6
NO_3 - N (ppm)	6.9
Available P (ppm)	63.5
Exchangeable K (ppm)	585

Soil pH was determined with a Beckman Zeromatic pH meter on a 1:1 water to soil suspension; conductivity on a 1:1 water to soil suspension using a Radiometer conductivity meter, type CDMzd; nitrate nitrogen by a photometric method adapted from Harper (20) and Prince (38) by the Manitoba Provincial Soil Testing Laboratory (22); easily soluble phosphorous by Olsen's Sodium Bicarbonate Method (36) and exchangeable potassium by a flame spectrophotometric method (3) using a Baird Atomic flame photometer.

Twenty-five grams of soil were placed in 360, sixteen-dram prescription vials. One-third of these served as a control and received no further treatment, another third received 100 ppm. nitrogen in the form of sieved particles of Uramite (less than 1 mm. diameter) and the remaining 120 vials received 100 ppm. nitrogen as commercial grade ammonium sulphate (less than 1 mm. diameter). The moisture content was brought up to field capacity (31%) with distilled water and the vials were capped. Holes 0.8 cm. in diameter had been cut in the caps to provide aeration. The vials were arranged in groups of nine, each group having three replicates of the three fertilizer treatments. The treatments were arranged randomly within the groups and the groups removed randomly at the end of each incubation period. The vials were placed in humid incubation chambers at 50, 60, 70 and 85^{o}F. for periods of 1,2,3,4,6,8,10,12 and 14 weeks. During the incubation period the moisture content was checked weekly and adjusted to field capacity as needed. The samples were dried at 40^{o}C. for twenty-four hours immediately after removal from the incubation chambers and then stored at 34^{o}F. until all samples were ready for analysis. The samples were ground to less than two millimeter diameter particles with a mortar and pestle and five grams of a well-mixed sample analysed to determine the nitrate nitrogen content by the method adapted from Harper (20) and Prince (38).

Experiment II

This experiment was conducted to study the availability of a ureaform fertilizer to Kentucky bluegrass (Poa pratensis) turf in the Winnipeg area. In earlier tests (14) and on local putting greens where ureaform fertilizer was applied at a nitrogen rate comparable to that used when applying other nitrogen sources (4-6 lbs N/1000 square feet per season) slow release performance from such materials has always been poor. Lunt (28) claims that the basic requirement for good slow release performance from urea-formaldehyde materials is the development of a large enough reservoir of residual ureaform so that the relatively small percentage of that residual which is mineralized per time unit is great enough to supply the grass with sufficient nitrogen. This theory has been tested only under the year round growing season conditions of Southern California, where it was estimated that a residual of twenty-five pounds of nitrogen per 1000 square feet is required.

For this experiment, rates of application were selected to span a range extending from that recommended by the manufacturer to far in excess of the twenty-five pound nitrogen residual rate estimated by Lunt (28).

The site selected for this experiment was a common Kentucky bluegrass lawn on the University of Manitoba Campus, known to have been seeded in 1959. The experiment was designed with randomized complete blocks, five fertilizer treatments replicated three times. The treatments were as follows: no fertilizer; 11.4 pounds of nitrogen per 1000 square feet; 20 pounds of nitrogen per 1000 square feet; 30 pounds of nitrogen per 1000 square feet and 40 pounds of nitrogen per

1000 square feet. These treatments will be referred to as N0, N1, N2, N3 and N4 respectively throughout the remainder of this paper. The Uramite was broadcast with a calibrated, three-foot, gravity flow Gandy spreader. Dates of application are shown in Table 1.

Table 1. Dates and rates of application of treatments in Experiment II.

Treatment	Date of Application	Rate per Application (lbs. N/1000 sq. ft.)
N1	June 2, 1965	3.8
	August 15, 1965	3.8
	May 30, 1966	3.8
N2	June 2, 1965	10.0
	June 9, 1965	10.0
N3	June 2, 1965	10.0
	June 9, 1965	10.0
	June 17, 1965	10.0
N4	June 2, 1965	10.0
	June 9, 1965	10.0
	June 17, 1965	10.0
	June 24, 1965	10.0

Throughout the 1965 and 1966 growing season the experimental area was mowed to a height of two inches with an eighteen inch reel type mower and the clippings were removed. The area was sprinkler-irrigated only when the plants appeared to be wilting. This was necessary three or four times during each of the two years of testing. In order to facilitate collection of uncontaminated grass tissue, the plot area was cleared of broadleaf weeds by spraying the area with one-half an ounce of 2,4-D amine per 1000 square feet on May 18, 1965.

Leaf tissue samples were taken at approximately weekly intervals during the periods June 29 to October 4, 1965 and May 16 to September 27, 1966. The samples were immediately dried at 104°C. for twenty-four hours, ground for thirty seconds in a Braun, type Mx31 grinder and stored in tins. Samples were dried again at 104°C. for twenty-four hours immediately prior to analysis.

Duplicate one-gram portions of each sample were analysed to determine percentage nitrogen content using the American Association of Cereal Chemists Method 46-12 (29), which is a boric acid modification of the Kjeldhal method. If the results of duplicate determinations differed by more than 0.06% nitrogen, then two more one-gram portions were analysed and all four results were used to calculate the percentage nitrogen content of the samples.

Soil samples were taken August 10, 1965, June 9, 1966 and October 5, 1966. Each sub-plot was sampled from five sites at depths of 0-6, 6-12, 12-24 and 24-36 inches. Composite samples from the five sites at each of the four depths were immediately air-dried, mechanically ground and stored at 42°F. until determinations were made.

The composite samples were analysed to determine the nitrate nitrogen content. The Provincial Soil Testing Laboratory, Department of Soil Science, University of Manitoba, analysed the 0-6 inch samples to determine: conductivity in milimhos per centimeter, pH, easily soluble phosphorous, and exchangeable potassium. The analytical methods were the same as those used in Experiment I.

Constantan-copper thermocouples were set in the centre of the plot at four and eight-inch depths and temperatures read at approximately 8:30 a.m. and 4:30 p.m. daily with a Rubicon temperature calibrated potentiometer, model 2738.

Experiment III

The primary purpose of Experiment III was to compare the rate of availability of a urea-formaldehyde fertilizer with the availability of five other nitrogenous fertilizers when all materials are applied to a Creeping bentgrass putting green at the rate of nitrogen usually recommended and used for such plantings in the Winnipeg area. Availability was studied by determining the leaf nitrogen as percentage dry weight and by recording dry matter yields.

This experiment was conducted on Creeping bentgrass (*Agrostis palustris*) varieties Seaside and Cohansey. Seaside is propagated by seed whereas Cohansey is a vegetatively reproduced variety. Under very short mowing height conditions, such as a putting green, Cohansey generally forms stands denser than Seaside.

The Seaside was seeded and the Cohansey sprigged in August 1963. The experimental area was managed as a putting green throughout the period of the test, mowing height being maintained at 3/16 to 1/4 inch with all clippings being removed.

Seven fertilizer treatments were replicated twice on each of the two varieties. The fertilizers used are given as follows:

Chemical Description	Commercial Name	Manufacturer	Content
ammonium nitrate	Elephant Brand 33.5-0-0	Cominco	33.5%
ammonium sulphate	Elephant Brand 21-0-0	Cominco	21.0%
activated sewage sludge	Milorganite 6-3-0	Milwaukee Sewage Commission	6.0%
plastic coated urea	experimental	Eli-Lily Chemicals	38.0%
urea-formaldehyde	Uramite	DuPont Chemicals	38.5%
urea	Elephant Brand 45-0-0	Cominco	45.0%

All treatments, except Uramite, were applied at the rate of 1½ pounds of nitrogen per 1000 square feet on the following dates: August 18 and September 16, 1964; May 17, June 16, August 16 and September 15, 1965; May 18, June 16, August 15 and September 16, 1966. Uramite was applied at the rate of three pounds of nitrogen per 1000 square feet on August 18, 1964; May 17 and August 16, 1965; May 18 and August 15, 1966.

Clippings from an area 21 inches X 11 feet 5 inches, within each sub-plot, were collected at every mowing. These samples were immediately dried at 104°C. for twenty-four hours. The dry weight was then recorded. At weekly intervals, portions of these dried samples were placed in tins and stored until percentage nitrogen content could be determined.

Composite soil samples from 0-6, 6-12, 12-24 inch depths were taken at five sites within each sub-plot on the following dates: September 16, 1964; May 10, May 31 and August 10, 1965; June 15, August 15 and October 11, 1966. These samples were immediately air-dried. All composite samples were analysed to determine the nitrate nitrogen content. Samples from the 0-6 inch depth taken on September 16, 1964 and October 11, 1966 were analysed by the Provincial Soil Testing Laboratory to determine the conductivity in milimhos per centimeter, pH, easily soluble phosphorous and exchangeable potassium.

The four and eight inch soil temperatures were determined in 1965, by the same method used in Experiment II, and in 1966 they were recorded at the same site by a Brown "Electronik" type 153 multipoint recorder calibrated to record temperatures with copper-constantan thermocouples.

RESULTS AND DISCUSSION

EXPERIMENT I

Each incubation treatment of this soil-fertilizer incubation study was conducted in triplicate, the nitrate nitrogen content was determined for each of these three replicates and the average of these three values was used to calculate the quantity of nitrate nitrogen produced from the ammonium sulphate and Uramite. These quantities of nitrate nitrogen were expressed as the percentage of the total nitrogen added minus the corresponding values for the control soils. The results of this study are presented in Table 2 and Figure 1.

The comparison of means in Table 2 shows that, within the range of 50 to 85°F, increasing temperature increased the amount of nitrate nitrogen produced from Uramite. The results also indicate that the added ammonium sulphate reached a maximum quantity of ammonium oxidized to nitrate after approximately two weeks at 50, 60 and 70°F, and after approximately one week at 85°F. There appears to be a loss of added nitrogen from the ammonium sulphate treatment at 85°F. This is probably due to denitrification and volatilization.

These results compare favorably with those of Basaraba (4). He found that added ammonium reached a maximum quantity of ammonium oxidized to nitrate at 10, 15, 20, 25 and 30°C. after approximately 4, 3 to 4, 3 to 4, 3, and 1 week of incubation respectively. It is possible that the differences in oxidation rate may be due to the fact that Basaraba (4) used a soil with a pH of 7.0 whereas the pH of the soil used for the present experiment was 7.6. Fredrick (15)

Table 2. The quantities of nitrate nitrogen produced from ammonium sulphate and Uramite, expressed as the percentage of the total nitrogen minus the corresponding values for the control soil.

Length of Incubation Period	AMMONIUM SULPHATE Incubation Temperature				URAMITE Incubation Temperature			
	50°F	60°F	70°F	85°F	50°F	60°F	70°F	85°F
1 week	34%	35%	40%	93%	11%	8%	18%	17%
2 weeks	95%	94%	100%	82%	14%	15%	19%	20%
3 weeks	94%	94%	100%	90%	20%	22%	27%	24%
4 weeks	94%	95%	100%	78%	22%	27%	37%	30%
6 weeks	95%	97%	100%	82%	26%	37%	37%	53%
8 weeks	94%	100%	100%	88%	27%	38%	38%	52%
10 weeks	94%	100%	100%	67%	33%	40%	41%	54%
12 weeks	94%	100%	100%	63%	34%	43%	49%	54%
14 weeks	94%	100%	98%	59%	30%	47%	46%	52%
mean	90% ab*	96% b	99% b	79% a	24% a	30% b	34% c	39% d

*Data not identified by the same letter (a,b) are significantly different at the 5% level.

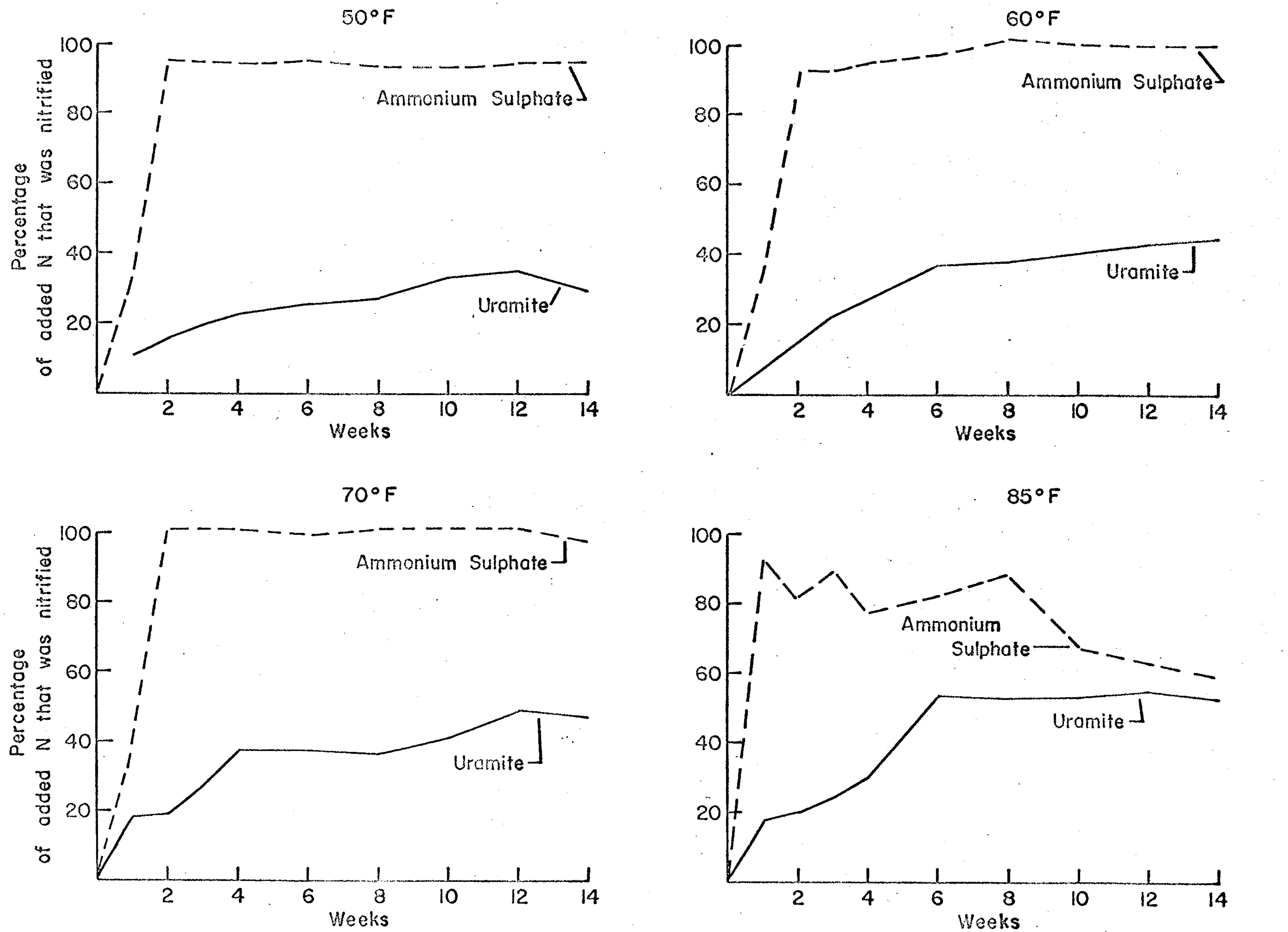


Figure I. The quantities of nitrate nitrogen produced at 50, 60, 70 and 85°F from ammonium sulphate and Uramite expressed as the percentage of the total nitrogen minus the corresponding values.

found that the rate of nitrification decreases with decreases in pH below 7.7. Also, the maximum values of nitrate nitrogen produced from added ammonium were found to be higher than those reported by Basaraba (4). The possible reason for this discrepancy could be that the base exchange capacity of the clay soil used for the present experiment was higher than that of the sandy loam used by Basaraba. According to Gasser (18) and Martin (32) the loss of ammonia by volatilization from the clay soil would be less than from the sandy loam.

It is interesting to note that, while the manufacturer indicates only 29.9% of the nitrogen in Uramite is cold water soluble, the data in Table 2 show 29.9% or more of the Uramite nitrogen was recovered as nitrate nitrogen in incubations at 50, 60, 70 and 85^{o}F. after 8 to 10, 4 to 6, 3 to 4, and 3 to 4 weeks respectively. At all temperatures above 50^{o}F. the percentage of Uramite nitrogen that was recovered as nitrate nitrogen continued to increase during the remainder of the fourteen week incubation period. This result might indicate that at 50^{o}F. the insoluble, longer molecular chain portion of Uramite was not being mineralized.

EXPERIMENT II

In this experiment conducted in the field of study the effect four rates of application would have on the residual long-term availability of Uramite to Kentucky bluegrass, leaf nitrogen as percentage dry weight was used as an indication of this availability.

An analysis of variance was run on data from each sampling date during the 1965 and 1966 growing seasons. Treatments were found to have a significant effect on the variation of leaf nitrogen as percentage dry weight at all dates tested throughout both seasons.

Duncan's multiple-range test was used to separate the means of the treatments at each date. The 5% level of significance was used for this mean separation.

Percentage Nitrogen, 1965

The results of nitrogen determinations made on dried leaf samples taken during the 1965 growing season are shown as percentage nitrogen content in Table 3 and Figure 2. For the sake of clarity, these results are discussed by comparing individual treatments with one another.

Treatment N_0 (no fertilizer) Compared with Treatment N_1 (11.4 lbs N/1000 sq. ft. applied in 3 split applications)

On June 29, twenty-seven days after application, when the first analysis was made, the leaf nitrogen of N_1 was higher (0.05)[1] than that of N_0 and remained so until July 22. Thus, the effect of the first application of treatment N_1 appears to have dissipated after fifty days. The leaf nitrogen once again differed (0.05) after the second application of N_1 on August 15. This difference persisted throughout the remainder of the growing season.

During the early part of the growing season, N_1 probably became less effective when the cold water soluble portion of the Uramite was depleted and the quantity of insoluble material added was not large enough to supply significant amounts of nitrogen through mineralization. After the second application of N_1 on August 15, either the soluble material added was enough to increase and maintain the leaf nitrogen at a significantly higher level for the rest of the season

[1]5.00 percent level of significance.

Table 3. The effect of varying rates of Uramite on leaf nitrogen as percentage dry weight during the 1965 growing season.

Date of Sampling	Treatment N_o	N_1	N_2	N_3	N_4	C.V. %.
June 29	2.26 a*	3.37 b	4.64 c	5.21 d	5.27 d	6.1
July 6	2.16 a	2.84 b	3.42 c	3.93 d	3.88 d	4.4
July 16	2.15 a	2.54 b	3.39 c	3.47 c	3.51 c	3.5
July 22	2.39 a	2.92 a	4.28 b	4.40 b	4.52 b	5.1
July 30	2.27 a	2.58 a	3.57 b	3.63 b	3.97 b	13.2
August 5	2.48 a	2.90 b	4.23 c	4.36 c	4.31 c	5.1
August 13	2.37 a	3.00 a	3.42 b	3.78 b	3.85 b	10.8
August 20	2.13 a	2.70 b	3.74 c	4.11 c	3.82 c	6.2
August 27	2.42 a	3.60 b	4.80 c	4.86 c	5.16 c	9.8
September 2	2.62 a	3.94 b	4.75 c	4.73 c	5.25 c	8.6
September 9	2.65 a	4.61 b	4.59 b	5.01 bc	5.16 c	4.9
September 17	2.84 a	4.97 b	4.87 bc	5.32 cd	5.49 d	4.4
September 27	2.51 a	4.10 b	4.28 b	4.72 c	4.74 c	1.9
October 4	2.13 a	2.87 b	2.89 b	3.28 c	3.20 c	5.4

*Data not identified by the same letter (a,b) at any one date are significantly different at the 5% level.

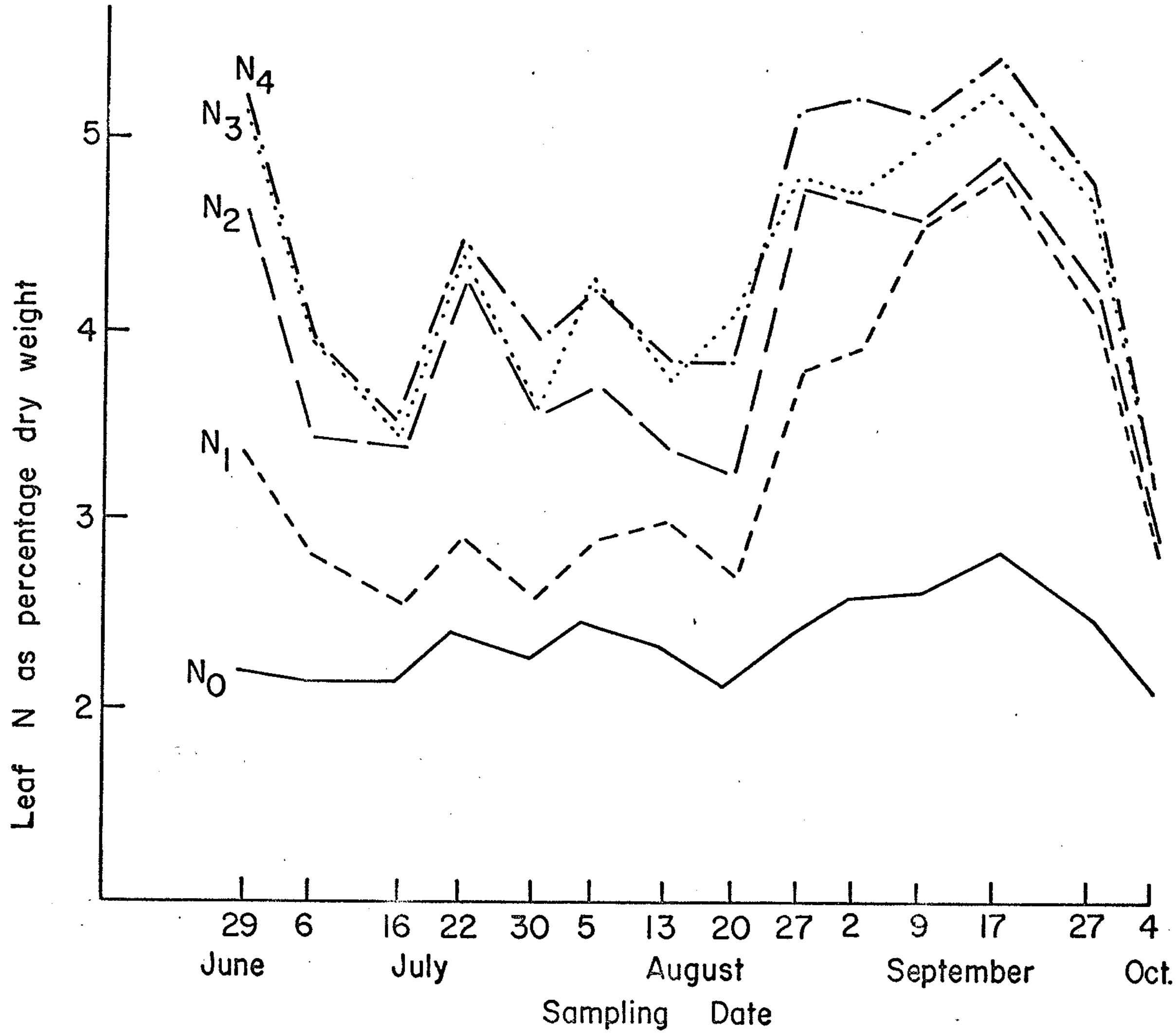


Figure 2. The effect of varying rates of Uramite on leaf nitrogen as percentage dry weight during the 1965 growing season.

or the insoluble portion had been increased to a point where mineralization was providing measurable amounts over and above the unfertilized check (N_o). Actually it is likely that both of these factors were contributing.

Treatment N_o (no fertilizer) Compared with Treatments N_2 (20 lbs N/1000 sq. ft), N_3 (30 lbs N/1000 sq. ft) and N_4 (40 lbs N/1000 sq. ft).

Foliage from treatments N_2, N_3 and N_4 had percentage nitrogen readings that were higher (0.05) than those of the unfertilized treatment (N_o) throughout the entire 1965 growing season.

These results are not surprising for such high levels of nitrogen fertilization. The soluble portion of the Uramite alone could have conceivably caused such differences. According to the manufacturer, 29.9% of the nitrogen contained in Uramite is soluble. Therefore, the grass in treatments N_2, N_3 and N_4 had received 6, 9, and 12 pounds of soluble nitrogen per 1000 sq. ft. respectively. This fact, plus the high nitrate nitrogen content of the soils in these treatments (Table 4) indicate that the consistent differences (0.05) in leaf nitrogen between N_o and treatments N_2, N_3 and N_4 throughout 1965 cannot be attributed, with complete confidence, to the insoluble portion of Uramite alone.

Table 4. The results of nitrate nitrogen determinations on soil samples taken August 10, 1965.

Treatment	ppm. Nitrate Nitrogen — Depth of Sample			
	0-6 inches	6-12 inches	12-24 inches	24-36 inches
N_o	0.0	0.2	0.2	0.2
N_1	0.0	0.2	1.2	1.4
N_2	32.6	13.7	4.5	1.1
N_3	32.6	23.0	10.1	1.4
N_4	31.0	35.0	15.2	1.4

Treatment N_1 (11.4 lbs N/1000 sq. ft. applied in three split applications) Compared with Treatment N_2 (20 lbs N/1000 sq. ft).

The leaf nitrogen of treatment N_2 was higher (0.05) than that of N_1 throughout 1965 except for the period, September 9 to the end of the growing season. However, differences between these two treatments do not necessarily serve to illustrate any difference due to greater residual action in treatment N_2. On the basis of soil test results in Table 4, it is likely that the grass in treatment N_2 has not entirely utilized the water soluble portion of the Uramite.

The non-significant difference in the latter part of the season could probably have resulted from the cooler soil temperatures (Appendix 10) which would reduce the difference in available nitrogen caused by the mineralization of the insoluble residual.

Treatment N_2 (20 lbs N/1000 sq. ft) Compared with Treatments N_3 (30 lbs N/1000 sq. ft) and N_4 (40 lbs N/1000 sq. ft).

Foliage from treatments N_3 and N_4 had higher (0.05) nitrogen than in N_2 during a short period in the early part and again during the latter part of the growing season. However, during most of the season, mid-July and early September, they were not significantly higher in nitrogen content than N_2.

In the early part of the season, the mineralized portion of the insoluble nitrogen in N_2 probably was so small that its effect combined with that of the soluble portion was less than the combined effects of these portions in N_3 and N_4. After mid-July, the insoluble portion may have become more closely associated with soil microorganisms as its incorporation into the soil became more complete. Therefore, the mineralized portion in treatments N_2, N_3 and N_4 would have increased to a point where, combined with the soluble nitrogen, they supplied more than the grass could take up. If this were the case then the leaf nitrogen of these three treatments would not differ. The leaf nitrogen of N_2 was lower (0.05) than N_3 and N_4 in the latter part of the season. This is attributed to the lower fall temperatures (Appendix 10) which would reduce the rate of mineralization of the insoluble portion of the Uramite to a point at which the amount of nitrogen available in N_2 fell below this maximum uptake level.

Treatment N_3 (30 lbs N/1000 sq. ft) Compared with
Treatment N_4 (40 lbs N/1000 sq. ft)

There were no significant differences found between the percentage nitrogen contents of the leaves of these two treatments during the 1965 growing season. This lack of difference between these two treatments is likely due to the amount of nitrogen being made available to the plants exceeding that taken up by them.

Percentage Nitrogen, 1966

The percentage nitrogen determinations made on leaf samples taken during the 1966 growing season are shown in Table 5 and Figure 3.

Treatment N_o (no fertilizer) Compared with Treatment
N_1 (11.4 lbs N/1000 sq. ft. in three split applications)

Leaf nitrogen in N_1 remained higher (0.05) than that of N_o throughout 1966, except on August 2 and September 12. This result indicates that the third application of N_1 on May 30, 1966 combined with the residual of the two 1965 applications provided enough nitrogen to keep the percentage nitrogen content of N_1 higher (0.05) than that of N_o. The fact that this difference lasted almost continuously throughout the 1966 growing season suggests that mineralization of

Table 5. The effect of varying rates of Uramite on leaf nitrogen as percentage dry weight, during the 1966 growing season.

Date of Sampling	Treatment N_o	N_1	N_2	N_3	N_4	C.V. %
May 16	2.49 a*	3.33 b	3.54 b	3.72 b	3.96 b	11.8
May 24	2.69 a	3.48 b	3.90 bc	4.33 c	4.48 c	8.7
May 30	2.26 a	2.88 b	3.34 c	3.85 d	4.14 d	5.4
June 6	2.14 a	3.04 b	2.97 b	3.47 c	3.73 c	6.2
June 14	2.14 a	3.62 b	3.62 b	4.11 b	4.13 b	7.4
June 20	2.11 a	4.13 b	4.02 b	4.15 b	4.41 b	4.2
June 27	2.05 a	2.95 b	3.09 b	3.02 b	3.26 b	10.2
July 4	2.27 a	3.47 b	3.61 b	3.18 b	3.54 b	7.0
July 12	2.12 a	3.76 b	3.91 b	3.76 b	4.00 b	7.0
July 19	2.62 a	4.39 b	4.33 b	4.09 b	4.25 b	6.6
July 25	2.43 a	3.45 b	3.81 c	3.81 c	3.97 c	4.2
August 2	2.25 a	2.66 a	3.44 b	3.39 b	3.25 b	10.3
August 8	2.43 a	3.13 b	3.69 c	3.81 c	3.93 c	8.3
August 16	2.42 a	3.35 b	3.81 c	4.36 d	4.48 d	6.1
August 23	2.63 a	3.05 b	3.53 c	3.85 cd	3.98 d	5.2
August 30	2.24 a	2.72 b	2.94 b	3.61 c	3.67 c	4.7
September 6	2.19 a	2.73 b	3.07 c	3.59 d	4.02 e	4.6
September 12	2.35 a	2.64 ab	2.96 bc	3.44cd	3.78 d	8.6
September 19	2.51 a	3.17 b	3.60 c	4.34 d	4.48 d	6.2
September 27	2.39 a	2.67 b	2.70 b	3.33 c	3.41 c	4.6

*Data not identified by the same letter (a,b) at any one date are significantly different at the 5% level.

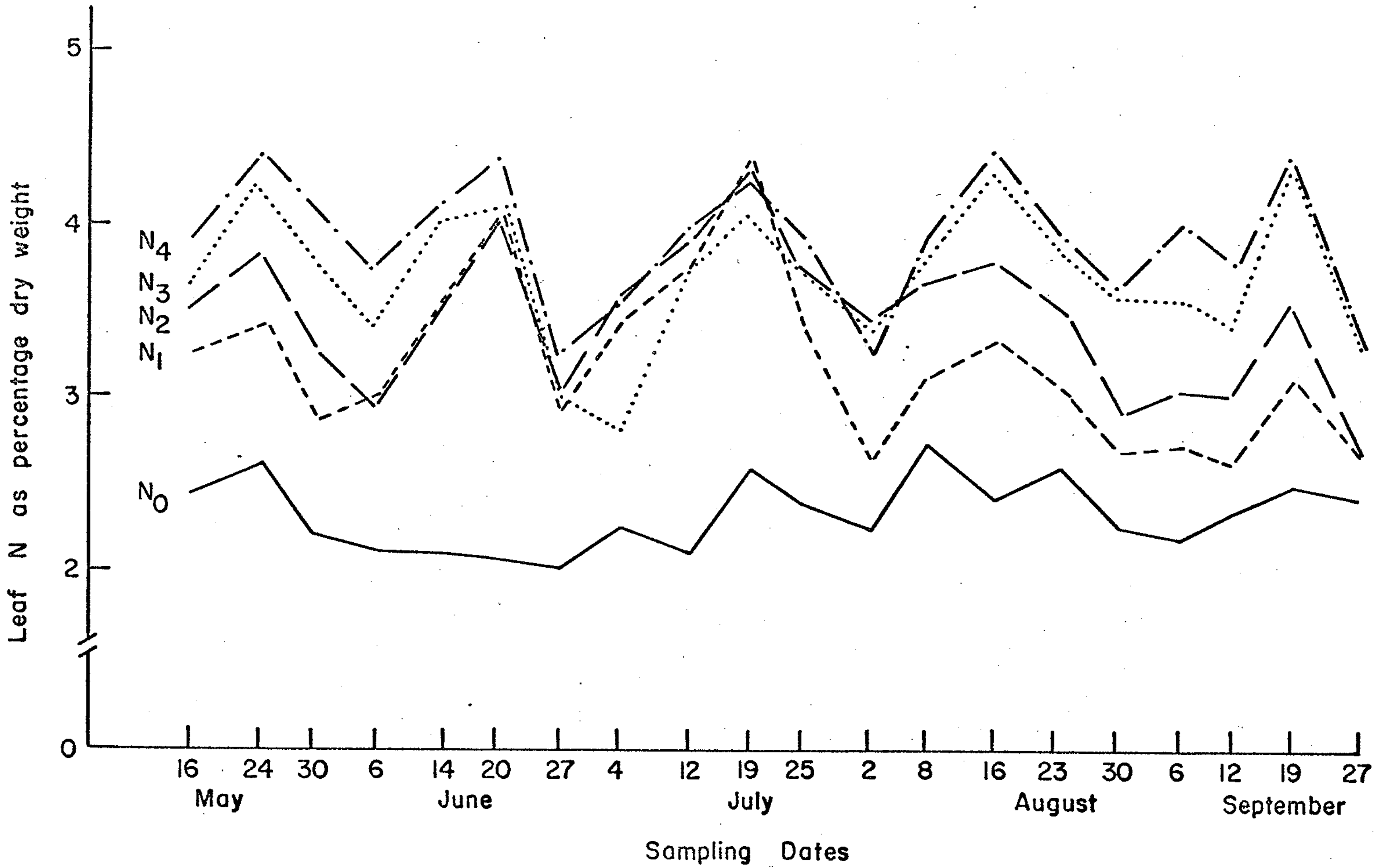


Figure 3. The effect of varying rates of Uramite on leaf nitrogen as percentage dry weight during the 1966 growing season.

the residual ureaform in N_1 provided significant amounts of nitrogen over and above that available in treatment N_o. But, Table 5 and Figure 3 also show that the leaf nitrogen of N_1 falls closer to that of N_o during August and September. This may have resulted from the readily available portion of the Uramite being exhausted by August and the nitrogen taken up by the grass for the remainder of the season being supplied by the residual reservoir that had been built up by the three applications.

Treatment N_o (no fertilizer) Compared with Treatments N_2 (20 lbs N/1000 sq. ft), N_3 (30 lbs N/1000 sq. ft) and N_4 (40 lbs N/1000 sq. ft).

Leaf nitrogen of N_2, N_3 and N_4 remained higher (0.05) than that of N_o, as had been the case throughout 1965. The low nitrate nitrogen in the N_2 soil taken June 9, 1966 (Table 6) indicates that the difference in the leaf nitrogen of N_o and N_2 was due to nitrogen mineralized from Uramite. The fact that this occurred a full year after fertilizer application demonstrates that the environmental conditions during 1965-66 were adequate to cause mineralization of the slow release portion of Uramite.

Treatment N_1 (11.4 lbs N/1000 sq. ft applied in three split applications) Compared with Treatment N_2 (20 lbs N/1000 sq. ft).

Leaf nitrogen of N_2 was not higher (0.05) than that of N_1 during the early part of the 1966 growing season, except on May 30. In mid-July the leaf nitrogen of N_2 became higher than that of N_1 and remained so until August 30. This change is probably due to the effect of the readily available portion of the Uramite applied May 30 being diminished by mid-July. The results of Experiment I indicate

Table 6. The results of nitrate nitrogen determinations on soil samples taken June 9, 1966.

Treatment	ppm. Nitrate Nitrogen			
	Depth of Sample			
	0-6 inches	6-12 inches	12-24 inches	24-36 inches
N_o	0.7	0.6	0.1	0.2
N_1	1.3	0.5	0.0	1.1
N_2	2.1	2.9	4.7	1.1
N_3	8.6	10.0	4.4	1.2
N_4	15.5	31.5	23.5	1.4

Table 7. The results of nitrate nitrogen determinations on soil samples taken October 5, 1966.

Treatment	ppm. Nitrate Nitrogen			
	Depth of Sample			
	0-6 inches	6-12 inches	12-24 inches	24-36 inches
N_o	0.2	0.6	0.2	2.2
N_1	0.5	0.0	0.1	0.9
N_2	0.8	0.9	0.8	1.8
N_3	3.1	7.5	8.3	3.4
N_4	1.0	7.4	19.7	3.8

that at the soil temperature (Appendix 10) encountered during this period (May 30 to July 19) it is quite likely that the soluble portion of the Uramite could have been mineralized and completely utilized over this six-week period. Thus the difference between N_1 and N_2 after mid July probably resulted from the difference in residual, slowly available nitrogen of which N_2 has nearly twice as much. Also, the low nitrate nitrogen in N_2 soil samples taken June 9 (Table 6) indicates that most of the nitrogen taken up by the grass in N_2 during 1966 must have come from the slowly available portion of Uramite.

Treatment N_2 (20 lbs N/1000 sq. ft) Compared with
Treatment N_3 (30 lbs N/1000 sq. ft)

Leaf nitrogen in treatment N_3 was not higher (0.05) than that of N_2 on May 16 and 24, but it became higher on May 30 and June 6. This result could be due to the actual uptake of nitrogen being small or negligible at the first two dates, and the leaf nitrogen of N_3 became higher (0.05) than that of N_2 when the grass had taken up the available nitrogen. From June 14 to August 16 the leaf nitrogen of N_3 did not differ from that of N_2. This could possibly be due to the insoluble nitrogen present in both treatments being more actively mineralized. Thus the quantity being made available to the grass in both treatments was more than the maximum amount that could be taken up. From August 16 to the end of the growing season, N_3 had a nitrogen content higher (0.05) than that of N_2 on five of the seven testing dates. This could have resulted from a gradual reduction of the quantity of residual Uramite to a point at which the amount of nitrogen made available by mineralization per time unit in treatment N_2 was below the maximum uptake rate of the grass, whereas the residual of N_3 had not yet reached this point.

Treatment N_3 (30 lbs N/1000 sq. ft) Compared with
Treatment N_4 (40 lbs N/1000 sq. ft)

There was no difference (0.05) between the nitrogen content of the leaves of these two treatments at all testing dates in 1966, except on September 6. This lack of difference is likely due to the amount of nitrogen being made available to the plants exceeding that being taken up.

Season Mean Percentage Nitrogen, 1965-66

The percentage nitrogen contents for all dates tested during the growing season were averaged for each treatment. Analysis of variance was run on the 1965 and 1966 season averages. The variance of the percentage nitrogen content of the leaves due to treatment was significant at both the 5% and 1% levels in both years. Duncan's multiple-range test was used to separate the treatment means. The results of the season average nitrogen contents during 1965 and 1966 are given in Table 8.

Table 8. The effect of varying rates of Uramite on the 1965 and 1966 season mean leaf nitrogen as percentage dry weight.

Year	Treatment				
	N_0	N_1	N_2	N_3	N_4
1965	2.34 a*	3.23 b	4.08 c	4.30 c	4.31 c
1966	2.35 a	3.24 b	3.49 c	3.76 d	3.95 d

*Data not identified by the same letter (a, b) are significantly different at the 5% level.

Results on the average for the two years of the test were very similar in that leaf nitrogen tended to increase as the amount of Uramite added was increased. The major difference was that in 1965 there was no difference (0.05) on the average between treatments N_2, N_3 and N_4, whereas in 1966 leaf nitrogen was less (0.05) in treatment N_2 than in N_3 and N_4. The nitrate nitrogen content of the soil samples taken from N_2 and N_3 June 9, 1966 (Table 6) seems to indicate that the grass had caught up with soil mineralization and took up nitrogen almost immediately after it had been made available to the plants. If this was actually the case, then the difference between N_2 and N_3 in 1966 was due to the larger residual reservoir in N_3, which provided a greater quantity of mineralized, available nitrogen per time unit than that provided by the residual of N_2.

Soil Analysis Results

The results of analyses by the Provincial Soil Testing Laboratory to determine the pH, conductivity, available phosphorous and exchangeable potassium of soil samples taken on August 10, 1965 and October 5, 1966 are shown in Appendix 7. According to the standards of the Provincial Soil Testing Laboratory (22) the pH of all samples tested ranged from slightly to moderately alkaline, the soluble salt content was very low, the amount of exchangeable potassium was very high and the available phosphorous rating ranged from low to medium.

Although the available phosphorous rating was low the difference amongst the soils of the various treatments was not considered large enough to have affected the treatment comparisons of the experiment.

EXPERIMENT III

Experiment III was a field study conducted on Seaside and Cohansey Creeping bentgrass to compare the availability of Uramite with five other nitrogenous fertilizers. All fertilizers were applied at the common rate of six pounds of nitrogen per 1000 sq. ft. Dry weight yields and leaf nitrogen as percentage dry weight were determined throughout the 1965 and 1966 growing seasons.

Nitrogen Content of Leaf Tissue Expressed as Percentage Dry Weight

The effect of fertilizer treatment on the season mean percentage nitrogen of leaf tissue during 1965 and 1966 is presented in Table 9.

Table 9. The effect of the type of nitrogen fertilizer on the 1965 and 1966 season mean leaf nitrogen as percentage dry weight.

Treatment	Season Mean Leaf Nitrogen	
	1965	1966
no fertilizer	3.83 a*	4.22 a
Uramite	4.20 b	4.54 b
urea	4.48 c	4.77 c
Milorganite	4.75 d	4.75 c
ammonium nitrate	4.78 de	4.81 c
ammonium sulphate	4.85 de	4.86 c
plastic-coated urea	4.88 e	5.06 d

*Data not identified by the same letter (a, b) are significantly different at the 5% level.

The mean leaf nitrogen of the Uramite treatment was higher (0.05) than that of the non-fertilizer treatment during both 1965 and 1966, but it was also lower (0.05) than that of all other fertilizer treatments throughout both years of the experiment. The season mean for leaf nitrogen within the Milorganite ammonium sulphate and ammonium nitrate treatments did not differ (0.05) throughout both years of testing.

There was found to be a highly significant (0.01) interaction between treatments and testing dates during both 1965 and 1966. The interactions are presented graphically in Figures 4 and 5. These graphs show that the leaf nitrogen in the six fertilized treatments increased rapidly after fertilizer application (mid-May, mid-June, mid-August and mid-September) during both years of the experiment, but approximately two weeks later the leaf nitrogen in all treatments started to decrease rapidly and on testing dates immediately preceding the next application date the leaf nitrogen was almost as low as that of the unfertilized check. This consistent pattern of variation indicates that the availability pattern was affected more by the time interval between applications than by the type of nitrogen fertilizer used. The "constant release" fertilizers Milorganite, Uramite and plastic-coated urea did not demonstrate a nitrogen release that was more constant than that of the soluble fertilizers. Figures 4 and 5 show that leaf nitrogen in all fertilizer treatments peaked after fertilizer applications, but in the Uramite treatment these peaks were consistently lower than those of the other treatments. This result indicates that after the soluble portion of the Uramite had dissipated the remaining insoluble portion was not large enough to supply amounts of nitrogen measurably over and above those in the check treatment. Figures 4 and 5 also show that in 1965 from the last week of July to mid-August, and in 1966 from mid-July to mid-August, the leaf nitrogen in all fertilizer treatments differed only slightly from that of the unfertilized check. It appears that the fertilizer applied in June has dissipated to a point where it is no longer effective, and without a July fertilizer application leaf nitrogen cannot be maintained higher than that of the check treatment.

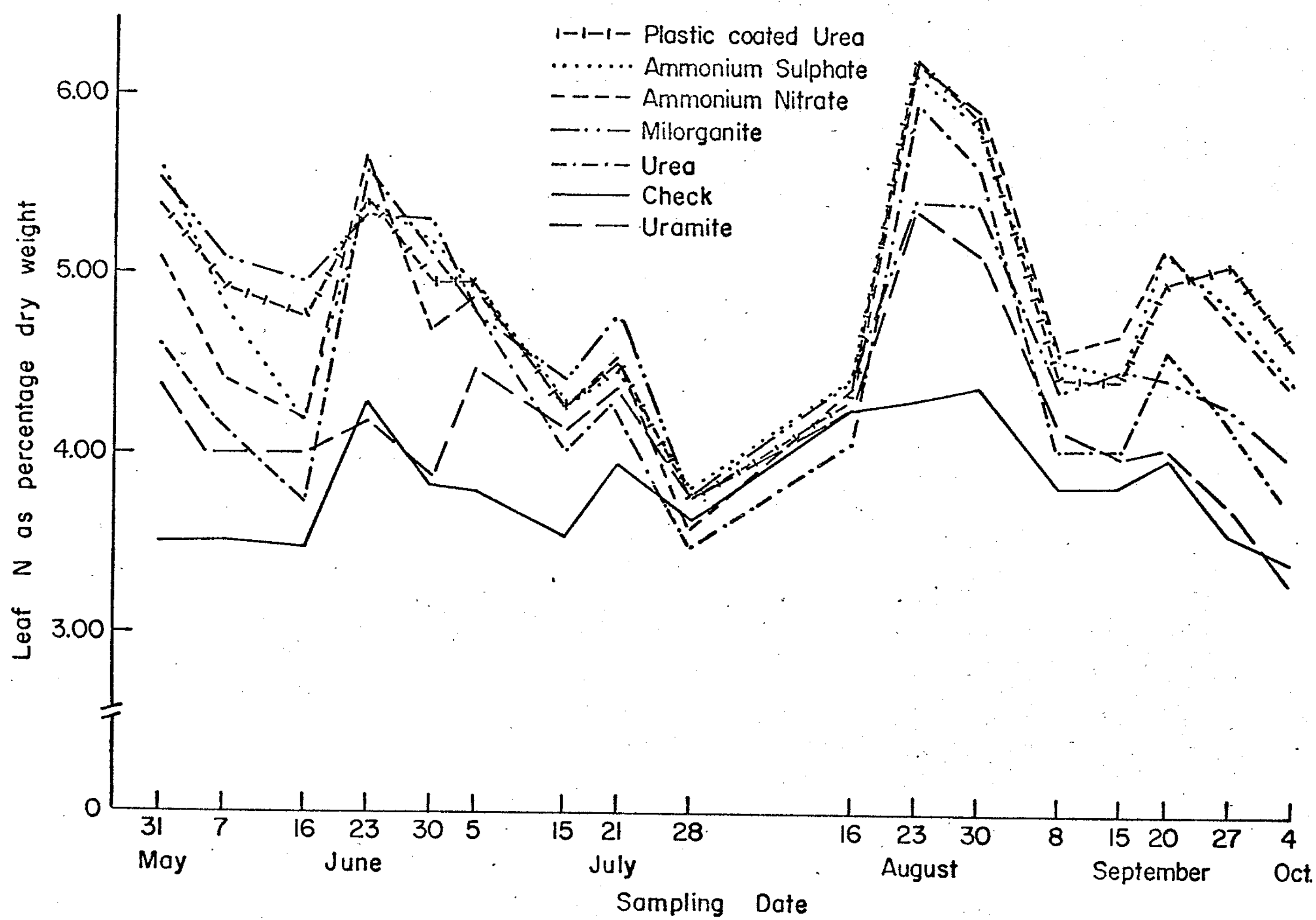


Figure 4. Treatment X date interaction on leaf nitrogen as percentage dry weight during the 1965 growing season.

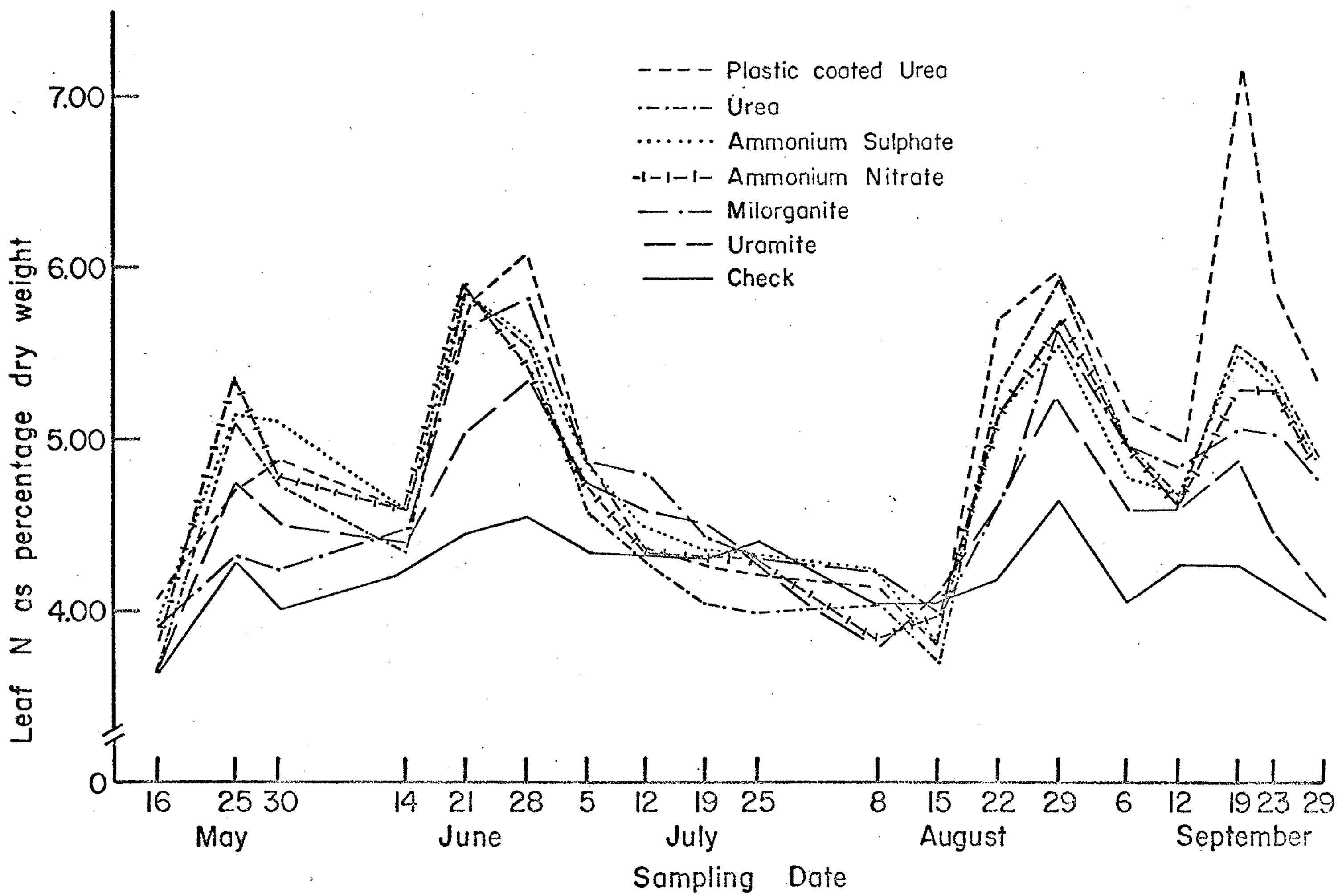


Figure 5. Treatment X date interaction on leaf nitrogen as percentage dry weight during the 1966 growing season.

It was also noted that during both years the September leaf nitrogen peaks were generally lower than they were in August of the same year. Apparently the cooler September temperature had reduced the leaf nitrogen response to fertilizer application.

The interaction between treatments and varieties was significant (0.05) in 1965 and highly significant (0.01) in 1966. These results, presented graphically in Figures 6 and 7, show that Milorganite had less effect on the leaf nitrogen of Cohansey than it did on that of Seaside. The reason for this difference is not apparent.

Dry Weight Yield

The dry weight yield data are not presented because it was felt that their accuracy was reduced by management techniques, such as top-dressing, aerifying, and vericutting, and by winter kill and snow mold. It was concluded that the above factors, which are unavoidable in the management of a putting green, greatly reduce the value of dry weight yield as a measure of putting greens' response to fertilizer.

Soil Analysis Results

The results of analysis for nitrate nitrogen in soil samples taken throughout the period of the experiment are shown in Appendix 9. In all determinations of samples taken throughout the test period the nitrate nitrogen content was found to be very low to low, as described by the Provincial Soil Testing Laboratory's nitrogen rating system. This rating is based on the total nitrate nitrogen to the two-foot depth and is normally used to indicate the amount of nitrogen that is available to crops that are deeper rooted than is putting green bent-grass.

The results of soil sample analysis by the Provincial Soil

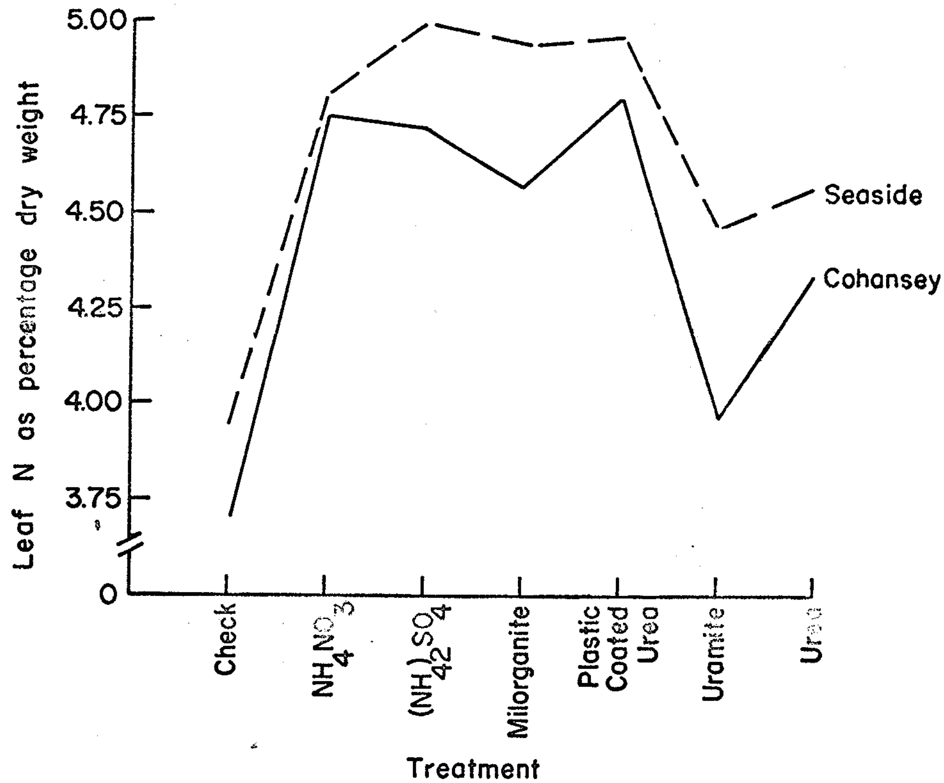


Figure 6. Variety X treatment
Interaction on leaf nitrogen as percentage dry weight during the 1965 growing season.

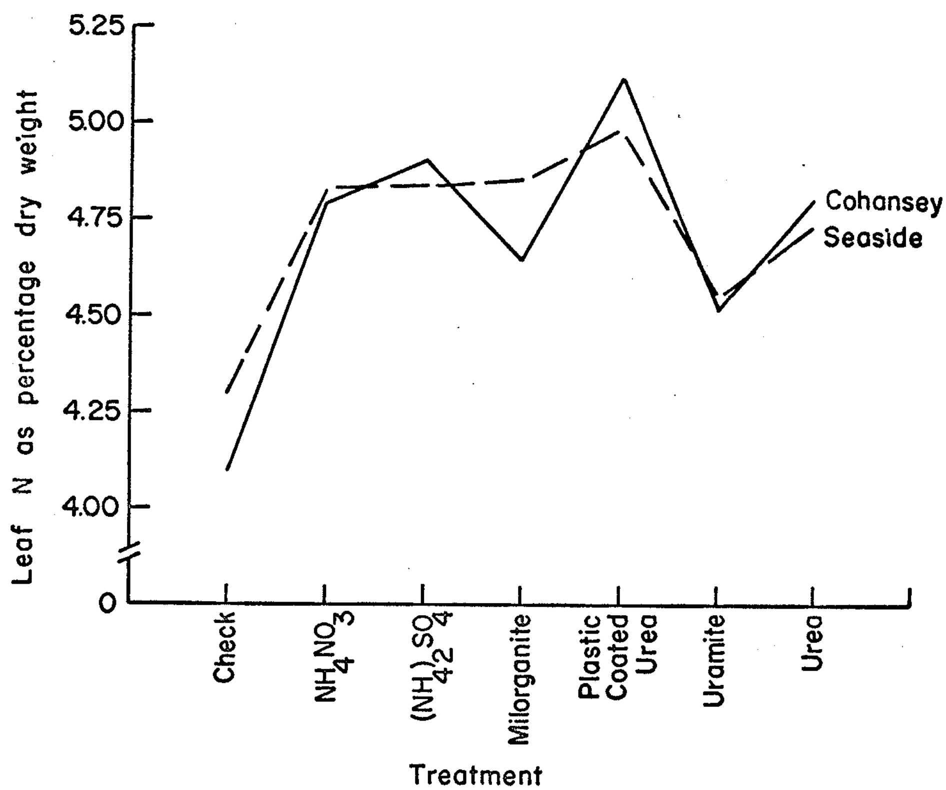


Figure 7. Variety X treatment
Interaction on leaf nitrogen as percentage dry weight during the 1966 growing season.

Testing Laboratory to determine pH, conductivity, available phosphorous and exchangeable potassium are shown in Appendix 8. According to the standards of the Provincial Soil Testing Laboratory (22), the pH of all samples tested was slightly alkaline, the conductivity was very low, the amount of easily soluble phosphorous was very high, and the amount of exchangeable potassium ranged from medium to very high. These results probably indicate that the effects of the nitrogenous fertilizer treatments were not influenced by extremes of soil reaction, high soluble salt content, or a deficiency of potassium or phosphorous.

SUMMARY AND CONCLUSIONS

In a series of experiments in 1965 and 1966 involving a study of the availability of nitrogen from Uramite and five other nitrogenous fertilizers to turfgrasses, the results were as follows:

1. The insoluble portion of Uramite was mineralized in a mixed Red River, Fort Garry clay soil under laboratory incubation conditions.

2. The quantity of nitrate nitrogen produced from Uramite incorporated into this soil and incubated for a fourteen week period at four different temperatures ranged as follows:

$$50^{o}F < 60^{o}F < 70^{o}F < 85^{o}F .$$

3. The leaf nitrogen in treatments that received Uramite at 20, 30 and 40 pounds of nitrogen per 1000 square feet in June 1965, remained significantly higher than that of the unfertilized check throughout 1965 and 1966. The leaf nitrogen in a treatment that received 11.4 pounds of nitrogen per 1000 square feet from three split applications of Uramite on June 2 and August 15, 1965, and May 30, 1966, was significantly higher than that of the unfertilized check throughout 1965 and 1966, except for the period July 22 to August 15, 1965.

4. Uramite applied to Seaside and Cohansey bentgrass putting greens at six pounds per 1000 square feet per year gave a season mean leaf nitrogen response in 1965 and 1966 that was significantly less than that of the urea, Milorganite, ammonium nitrate, ammonium sulphate and plastic coated urea treatments.

5. The season mean leaf nitrogen response to Milorganite, ammonium nitrate, and ammonium sulphate, all applied in four split applications

at six pounds of nitrogen per 1000 square feet per year, did not differ significantly in either 1965 or 1966.

6. The leaf nitrogen in all fertilized treatments increased sharply after each fertilizer application during the two years of the experiment but declined rapidly approximately two weeks later.

7. The Uramite treatment showed a lower leaf nitrogen response after fertilizer application than did all other fertilizer treatments when compared at six pounds of nitrogen per 1000 square feet.

Based on the above results, it was concluded that mixed Red River, Fort Garry clay soil is an adequate medium for the mineralization of the insoluble portion of Uramite; this soil must contain the micro-organisms necessary for the breakdown of this material. The rate of mineralization is affected by temperature and increases with increasing temperature between 50 and 85^{o}F. It was found that the environmental conditions encountered in a field experiment during 1965 and 1966 were sufficient to cause such mineralization when Uramite was applied at 11.4, 20, 30 and 40 pounds of nitrogen per 1000 square feet, suggesting that the residual reservoir theory proposed by Lunt (28) for the fertilization of year around turf may also be applied to areas with a dormant winter season, such as that encountered in the Winnipeg area. However, the rate of reapplication per year required to maintain this residual at a practical level must be determined before a decision can be made as to the commercial feasibility of using urea-formaldehyde as a nitrogen source for turfgrasses in this region.

Conclusions based on the results of a two-year comparison of six nitrogenous fertilizers applied to Seaside and Cohansey Creeping bentgrass putting greens at six pounds of nitrogen per 1000 square feet per year were as follows: The variation of leaf nitrogen in the "constant release" fertilizers, Milorganite, Uramite and plastic coated urea, was similar to that of the soluble fertilizers tested; the time interval between fertilizer applications appeared to be more important than the type of nitrogen source if a constant level of leaf nitrogen is to be maintained during the first two years of such a fertilizer program. Regardless of the fertilizer used, it appeared that four split applications per year were not enough to provide a constant source of nitrogen to Creeping bentgrass putting greens, and therefore the number of applications per year should be increased so as to reduce the length of time between applications to two or at most three weeks. It was also concluded from the relatively poor leaf nitrogen response in the Uramite treatment that this material must be applied at rates higher than those normally used for other nitrogenous fertilizers, in order to build up an effectively large residual reservoir.

LITERATURE CITED

1. Arminger, W.H., Ian Forbes, R.E. Wagner and F.O. Lundstrom, 1948. Ureaform--A nitrogen fertilizer of controlled availability: experiments with turfgrasses. J. Am. Soc. Agron. 40(4): 342-356.

2. Arminger, W.H., K.G. Clark, F.O. Lundstrom and A.E. Blair, 1951. Ureaform: greenhouse studies with Perennial ryegrass. Agron. J. 43: 123-127.

3. Atkinson, H.J., G.R. Giles, A.J. Maclean and J.R. Wright, 1958. Chemical Method of Soil Analysis. Contribution No. 169 (revised). Chemistry Division- Science Service, Canada Department of Agriculture, Ottawa.

4. Basaraba, J., 1964. Mineralization of urea-formaldehyde compounds at different pH levels and temperatures. Can. J. Soil Sci. 44: 131-136.

5. Byczkowski, A. and M. Seidler, 1964. Nutrient efficiency of some urea-formaldehyde products. Pam. Pulawski. 14: 245-265. (Soils and Fert. Abstr. 28: 1221).

6. Byrne, T.G., and O.R. Lunt, 1962. Urea-formaldehyde. Calif. Agr. 16(3): 10-11.

7. Clark, K.G., 1952. Ureaform: a new nitrogen fertilizer. Crops and Soils 418: 14-15.

8. Clark, K.G., J.Y. Yee, F.O. Lundstrom and G. Lamont, 1959. A modified Activity Index procedure for determining the quality of the water soluble nitrogen in mixed fertilizers containing urea-formaldehyde compounds. Assoc. Offic. Agr. Chem. 42: 592-597.

9. Clark, K.G. and G. Lamont, 1960. Correlations between nitrification and Activity Indexes of urea-formaldehyde in mixed fertilizers. J. Assoc. Offic. Agr. Chem. 43: 504-506.

10. Duich, J.M. and H.B. Musser, 1958. Response of Creeping bentgrass putting green turf to ureaform compounds and other nitrogenous fertilizers. Agron. J. 50: 381-384.

11. Duich, J.M. and H.B. Musser, 1960. Response of Kentucky bluegrass, Creeping Red fescue and bentgrass to nitrogen fertilizers. Progr. Rep. Pa. Agr. Exp. Sta. 214.

12. Ehrlich, W.A., E.A. Poyser, L.E. Pratt and J.H. Ellis, 1953. Report of Reconnaissance Soil Survey of Winnipeg and Morris Map Sheet Areas. Soils Report No. 5.

13. Escritt, J.R., and H.J. Lidgate, 1962. An investigation of the suitability of a urea-formaldehyde fertilizer product for use in turf. Turf Res. Inst. Bull. 10: 385-393. (Hort. Abstr. 33: 7792).

14. Ferguson, A.C, 1962. Turf Research Project 1958-1962. Department of Plant Science, U. of Manitoba.

15. Fredrick, L.R, 1956. The formation of nitrate from ammonium nitrogen in soils: I. Effect of temperature. Soil Sci. Soc. Am. Proc. 20: 496-499.

16. Fuller, W.F. and K.G. Clark, 1948. Microbiological studies on urea-formaldehyde preparations. Soil Sci. Soc. Am. Proc. 12: 198-202.

17. Gaspar, L., M. Vegh and D. Szalai, 1957. Development and use of ureaform, a slow-acting nitrogen containing fertilizer. Magy. Tud. Akad. Agrartud. Oszt. Kosl. 13: 113-195. (Soils and Fert. Abstr. 22: 340).

18. Gasser, J.K.R, 1964. Some factors affecting losses of ammonia from urea and ammonium sulphate applied to soils. J. Soil Sci. 15: 258-272.

19. Goetze, N.R, 1960. Heavy nitrogen fertilization of cool season turfgrasses. Diss. Abstr. 21: 23. (Abstr. from Thesis Purdue University).

20. Harper, H.J, 1924. The accurate determination of nitrates in soils. J. Ind. and Eng. Chem. 16: 180.

21. Hays, J.T., W.W. Haden and L.E. Anderson, 1965. Nitrification of fractions from commercial ureaform. J. Agr. Food Chem. 13: 176-179.

22. Jenke, W.E, 1965. Provincial Soil Testing Laboratory, Department of Soil Science, University of Manitoba.

23. Killian, K.C, 1964. Use of urea-formaldehyde and other slowly available forms of nitrogen for grass. Diss. Abstr. 24: 3485. (Abstr. from Thesis U. of Wisc.).

24. Lantz, H.L, 1958. Test fertilizers on turf and bentgrasses. J. Fm. Sci. 13: 43. (Hort. Abstr. 30: 5886).

25. Litynski, T. and K. Mazur, 1964. Ureaform preparations as slow acting nitrogen fertilizers. Roczn. Glebozn. 13 Supp. 277-280. (Soils and Fert. Abstr. 27: 2348).

26. Litynski, T. 1964. Urea-formaldehyde preparations as slow acting nitrogen fertilizers. U. Fertil. Wld. Congr. C. I. I. A. Rapp. Spec. 19: 4. (Soils and Fert. Abstr. 28: 4065).

27. Long, F.L. and G.M. Volk, 1961. Availability of nitrogen contained in certain condensation products of reaction of urea with formaldehyde. Agron. J. 55: 155-158.

28. Lunt, O.R, 1963. Slow release fertilizer materials. Golf Course Reporter 31(4).

29. MacMasters, M.M., chmn. 1962. Cereal Laboratory Methods. Seventh edition.

30. McVickar, M.H., G.L. Bridger and L.B. Nelson, editors, 1963. Fertilizer Technology and Usage. Published by Soil Sci. Soc. Am.

31. Madraimov, J.M. and Z. Tairov, 1965. Preliminary data on trials of new forms of nitrogen fertilizers. Khlopkovodstvo 14(5): 38-39. (Soils and Fert. Abstr. 28: 2642).

32. Martin, J.P., and H.D. Chapman, 1951. Volatilization of ammonia from surface fertilized soils. Soil Sci. 71: 25-34.

33. Morgan, W.A. and R.D. Kravobec, 1953. Chemical method for available fertilizer nitrogen in urea-formaldehyde compositions. J. Assoc. Offic. Agr. Chem. 36: 904-914.

34. Morgan, W.A. and R.D. Kravobec, 1954. Products of urea and formaldehyde as fertilizer with controlled nitrogen availability. J. Agr. Food Chem. 2: 92-95.

35. Musser, H.B., J.R. Watson, Jr., J.P. Stanford and J.C. Harper II. 1951. Urea-formaldehyde and other nitrogenous fertilizers for use on turf. Bull. Pa. Agr. Exp. Sta. 542.

36. Olsen, S.R., C.V. Cole, F. Watanbe and L.A. Dear, 1954. Estimation of available phosphorous in soils by extraction with sodium bicarbonate. U.S D A Circ. 939. Washington, D.C.

37. Pereira, R.L. and J.B. Smith, 1963. Nitrification of urea-formaldehyde fractions insoluble in hot or cold water. J. Assoc. Offic. Agr. Chem. 46: 565-569.

38. Prince, A.L, 1945. Determination of total nitrogen, ammonia, nitrates and nitrites in soils. Soil Sci. 59: 47-51.

39. Scarsbrook, C.E, 1958. Urea-formaldehyde fertilizer as a source of nitrogen for cotton and corn. Soil Sci. Soc. Am. Proc. 22: 442-445.

40. Schmalfuss, K. and S. Michael, 1956. Condensation products of urea and formaldehyde as a nitrogen source in plant nutrition. Z. PhlErnahr Dung. 72: 193-200. (Soils and Fert. Abstr. 19: 1728).

41. Seidler, M, 1964. The nutrient efficiency of urea-formaldehyde compared to other nitrogen fertilizers in field trials. Pam. Pulawski 14: 179-186. (Soils and Fert. Abstr. 28: 1223)

42. Tennille, A.W., 1959. Nitrate production and plant response resulting from soil applications of urea biuret, two urea-formaldehyde compounds and ammonium sulphate. Diss. Abstr. 20: 824. (Abstr. from Thesis U. of Fla.).

43. Turchin, F.V., V.I. Sakalova and B.G. Blyum, 1964. Khim. Sel. Khoz. 61: 6339. (Soils and Fert. Abstr. 28: 1224).

44. Volk, G.M, 1959. Volatile loss of ammonia following surface application of urea to turf or bare soil. Agron. J. 51: 746-749.

45. Volk, G.M., W.H. Kelly and W.G. Blue, 1959. Recovery of nitrogen from several sources by oats and millet. Soil Crop. Sci. Soc. Fla. Proc. 19: 379-385. (Soils and Fert. Abstr. 24: 1000).

46. Winsor, G.W. and M.I.E. Long, 1956. Mineralization of the nitrogen of ureaform compounds in relation to soil pH. J. Sci. Food. Agr. 7: 560-564.

47. Winsor, G.W. and M.I.E. Long, 1957. Urea-formaldehyde compounds as nitrogenous fertilizers. Glassh. Crops. Res. Inst. Rept. 1954-1955: 63-69. (Soils and Fert. Abstr. 21: 703).

48. Winsor, G.W. and M.I.E. Long, 1960. Isolations of some urea-formaldehyde compounds and their decomposition in the soil. J. Sci. Food Agr. 11: 441-445.

49. Yee, J.Y. and K.S. Love, 1947. Nitrification of urea-formaldehyde reaction products. Soil Sci. Soc. Am. Proc. 11: 389-392.

APPENDIX 1.

Analysis of variance for the effect of temperature on the amount of nitrate nitrogen recovered from the ammonium sulphate-soil incubation of Experiment I.

Source of Variance	D.F.	M.S.
Temperature	3	688.520**
Time	8	431.236**
Error	24	127.565
Total	35	

**1.00 percent level of significance.

APPENDIX 2.

Analysis of variance for the effect of temperature on the amounts of nitrate nitrogen recovered from the Uramite-soil incubation of Experiment I.

Source of Variance	D.F.	M.S.
Temperature	3	149.170**
Time	8	238.735**
Error	24	6.940
Total	35	

**1.00 percent level of significance.

APPENDIX 3.

Analysis of variance for the effect of Uramite application rate on Kentucky bluegrass leaf nitrogen as percentage dry weight, 1965. (Experiment II).

Sampling Date	Source of Variance	D.F.	M.S.
June 29	Blocks	2	0.050
	Treatments	4	5.105**
	Error	8	0.064
	Total	14	
July 6	Blocks	2	0.015
	Treatments	4	1.688**
	Error	8	0.020
	Total	14	
July 16	Blocks	2	0.005
	Treatments	4	1.170**
	Error	8	0.011
	Total	14	
July 22	Blocks	2	0.015
	Treatments	4	2.860**
	Error	8	0.036
	Total	14	
July 30	Blocks	2	0.180
	Treatments	4	1.620**
	Error	8	0.178
	Total	14	

**1.00 percent level of significance.

Appendix 3 (cont.)

Sampling Date	Source of Variance	D.F.	M.S.
August 5	Blocks	2	0.025
	Treatments	4	2.418**
	Error	8	0.034
	Total	14	
August 13	Blocks	2	0.105
	Treatments	4	1.120**
	Error	8	0.125
	Total	14	
August 20	Blocks	2	0.025
	Treatments	4	2.135**
	Error	8	0.042
	Total	14	
August 27	Blocks	2	0.005
	Treatments	4	3.940**
	Error	8	0.168
	Total	14	
September 2	Blocks	2	0.185
	Treatments	4	3.162**
	Error	8	0.135
	Total	14	

**1.00 percent level of significance.

Appendix 3 (cont.)

Sampling Date	Source of Variance	D.F.	M.S.
September 9	Blocks	2	0.140
	Treatments	4	3.052**
	Error	8	0.047
	Total	14	
September 17	Blocks	2	0.195
	Treatments	4	3.415**
	Error	8	0.042
	Total	14	
September 27	Blocks	2	0.090
	Treatments	4	2.510**
	Error	8	0.010
	Total	14	
October 4	Blocks	2	0.155
	Treatments	4	0.615**
	Error	8	0.024
	Total	14	

**1.00 percent level of significance.

APPENDIX 4.

Analysis of variance for the effect of Uramite application rate on Kentucky bluegrass leaf nitrogen as percentage dry weight, 1966. (Experiment II).

Sampling Date	Source of Variance	D.F.	M.S.
May 16	Blocks	2	0.050
	Treatments	4	0.950*
	Error	8	0.161
	Total	14	
May 24	Blocks	2	0.170
	Treatments	4	1.560**
	Error	8	0.109
	Total	14	
May 30	Blocks	2	0.100
	Treatments	4	1.708**
	Error	8	0.032
	Total	14	
June 6	Blocks	2	0.005
	Treatments	4	1.105**
	Error	8	0.036
	Total	14	
June 14	Blocks	2	0.110
	Treatments	4	1.995**
	Error	8	0.067
	Total	14	

*5.00 percent level of significance.
**1.00 percent level of significance.

Appendix 4 (cont.)

Sampling Date	Source of Variance	D.F.	M.S.
June 20	Blocks	2	0.210
	Treatments	4	2.622**
	Error	8	0.025
	Total	14	
June 27	Blocks	2	0.015
	Treatments	4	0.670**
	Error	8	0.086
	Total	14	
July 4	Blocks	2	0.070
	Treatments	4	0.913**
	Error	8	0.051
	Total	14	
July 12	Blocks	2	0.065
	Treatments	4	1.845**
	Error	8	0.060
	Total	14	
July 19	Blocks	2	0.015
	Treatments	4	1.670**
	Errors	8	0.066
	Total	14	

*1.00 percent level of significance.

Appendix 4 (cont.)

Sampling Date	Source of Variance	D.F.	M.S.
July 25	Blocks	2	0.005
	Treatments	4	1.172**
	Error	8	0.021
	Total	14	
August 2	Blocks	2	0.025
	Treatments	4	0.818**
	Error	8	0.096
	Total	14	
August 8	Blocks	2	0.040
	Treatments	4	1.158**
	Error	8	0.079
	Total	14	
August 16	Blocks	2	0.005
	Treatments	4	2.120**
	Error	8	0.051
	Total	14	
August 23	Blocks	2	0.065
	Treatments	4	0.955**
	Error	8	0.031
	Total	14	

**1.00 percent level of significance.

Appendix 4 (cont.)

Sampling Date	Source of Variance	D.F.	M.S.
August 30	Blocks	2	0.065
	Treatments	4	1.105**
	Error	8	0.020
	Total	14	
September 6	Blocks	2	0.030
	Treatments	4	1.530**
	Error	8	0.021
	Total	14	
September 12	Blocks	2	0.010
	Treatments	4	1.010**
	Error	8	0.068
	Total	14	
September 19	Blocks	2	0.025
	Treatments	4	2.015**
	Error	8	0.050
	Total	14	
September 27	Blocks	2	0.020
	Treatments	4	0.595**
	Error	8	0.018
	Total	14	

**1.00 percent level of significance.

APPENDIX 5.

Analysis of variance for the effect of Uramite application rate on the season mean Kentucky bluegrass leaf nitrogen as percentage dry weight. (Experiment II)

Source of Variance	D.F.	M.S. 1965	M.S. 1966
Blocks	2	0.015	0.010
Treatments	4	2.200**	1.162**
Error	8	0.138	0.015
Total	14		

APPENDIX 6.

Analysis of variance for the effect of six nitrogenous sources on Seaside and Cohansey bentgrass leaf nitrogen as percentage dry weight. (Experiment III)

Source of Variance	D.F.	M.S. 1965	M.S. 1966
Replicates	1	18.520**	11.639**
Varieties	1	8.699**	0.188
Dates	16	7.245**	7.798**
Treatments	6	10.616**	5.403**
Replicates X Varieties	1	0.216	0.097
Varieties X Dates	16	0.522**	0.330**
Varieties X Treatments	6	0.314*	0.449**
Dates X Treatments	96	0.351**	0.399**
Error	332	0.1227	0.101
Total	475		

*5.00 percent level of significance.
**1.00 percent level of significance.

APPENDIX 7.

Results of Experiment II soil analysis to determine pH, conductivity, available phosphorous and exchangeable potassium.

Treatment	August 10, 1965				October 5, 1966			
	pH	Cond. (mmhos.)	Avail.P (ppm.)	Exch.K (ppm.)	pH	Cond. (mmhos.)	Avail.P (ppm.)	Exch.K (ppm.)
N_o	7.5	0.9	11.5	512	7.8	0.8	11.5	455
N_1	7.6	1.4	9.0	459	7.8	1.0	9.0	376
N_2	7.5	1.2	7.5	531	7.8	0.7	5.5	410
N_3	7.5	1.4	4.0	441	8.0	0.9	8.5	317
N_4	7.3	1.7	14.5	511	7.7	0.6	12.5	429

APPENDIX 8.

Results of Experiment III soil analysis to determine pH, conductivity, available phosphorous and exchangeable potassium.

Fertilizer Treatment	September 16, 1964				October 11, 1966			
	pH	Cond. (mmhos.)	Avail.P. (ppm.)	Exch.K (ppm.)	pH	Cond. (mmhos.)	Avail.P (ppm.)	Exch.K (ppm.)
no fertilizer	7.4	0.5	54.5	238	7.6	0.3	51.0	231
ammonium nitrate	7.4	0.5	57.0	204	7.5	0.4	38.0	128
ammonium sulphate	7.5	0.4	28.5	191	7.6	0.4	34.5	104
Milorganite	7.4	0.4	50.0	227	7.5	0.4	51.0	119
plastic coated urea	7.4	0.5	71.5	242	7.6	0.4	45.0	122
Uramite	7.4	0.4	54.5	238	7.6	0.4	41.5	190
urea	7.4	0.5	71.5	191	7.6	0.5	40.5	125

APPENDIX 9.

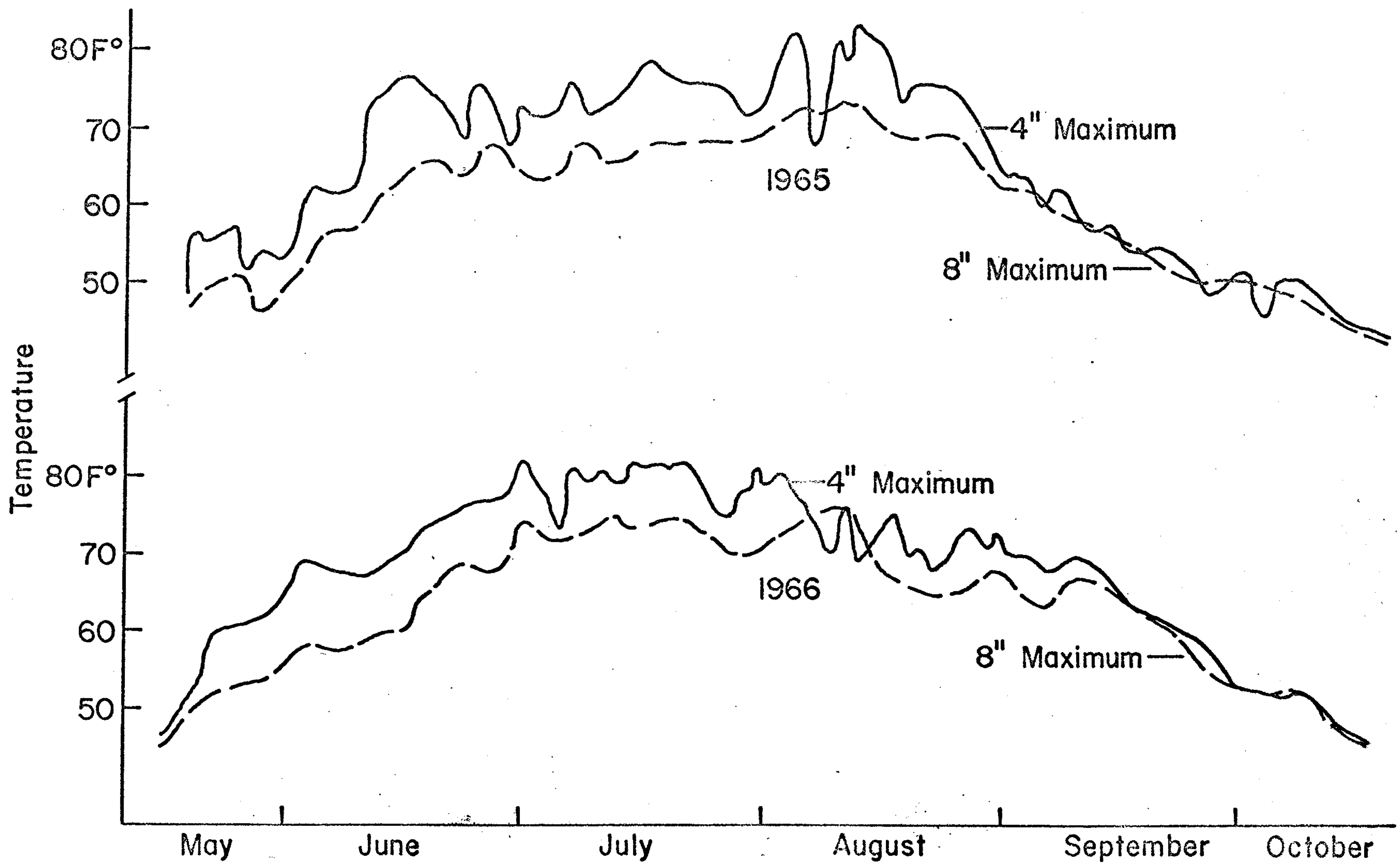
Results of Experiment III soil analysis to determine nitrate nitrogen. (expressed as ppm. NO_3-N)

Fertilizer Treatment	September 16, 1964				May 10, 1965				May 13, 1965				August 10, 1965			
	0-6"	6-12"	12-24"	24-36"	0-6"	6-12"	12-24"	24-36"	0-6"	6-12"	12-24"	24-36"	0-6"	6-12"	12-24"	24-36"
no fertilizer	4.8	5.8	6.1	1.0	3.0	6.1	6.7	1.0	0.0	0.2	0.2	0.0	1.4	2.1	0.2	0.0
ammonium nitrate	6.4	6.7	2.7	0.0	2.7	5.8	3.5	0.0	0.0	0.7	0.2	0.0	0.0	0.2	0.2	0.2
ammonium sulphate	4.2	4.9	2.2	0.2	5.8	5.8	2.2	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.2	0.2
Milorganite	3.7	2.5	1.0	0.5	4.1	4.9	0.2	0.0	0.0	0.5	0.0	0.2	0.0	0.2	0.0	0.2
plastic coated urea	4.4	2.7	0.2	1.0	2.7	1.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.2	0.0	0.0
Uramite	5.9	4.9	1.0	0.5	1.0	0.2	0.7	0.5	0.0	0.2	0.2	0.2	0.2	0.0	0.2	0.2
urea	4.7	4.1	1.0	1.4	1.4	1.4	1.4	2.5	0.0	0.2	0.2	0.2	0.0	0.2	0.2	0.2

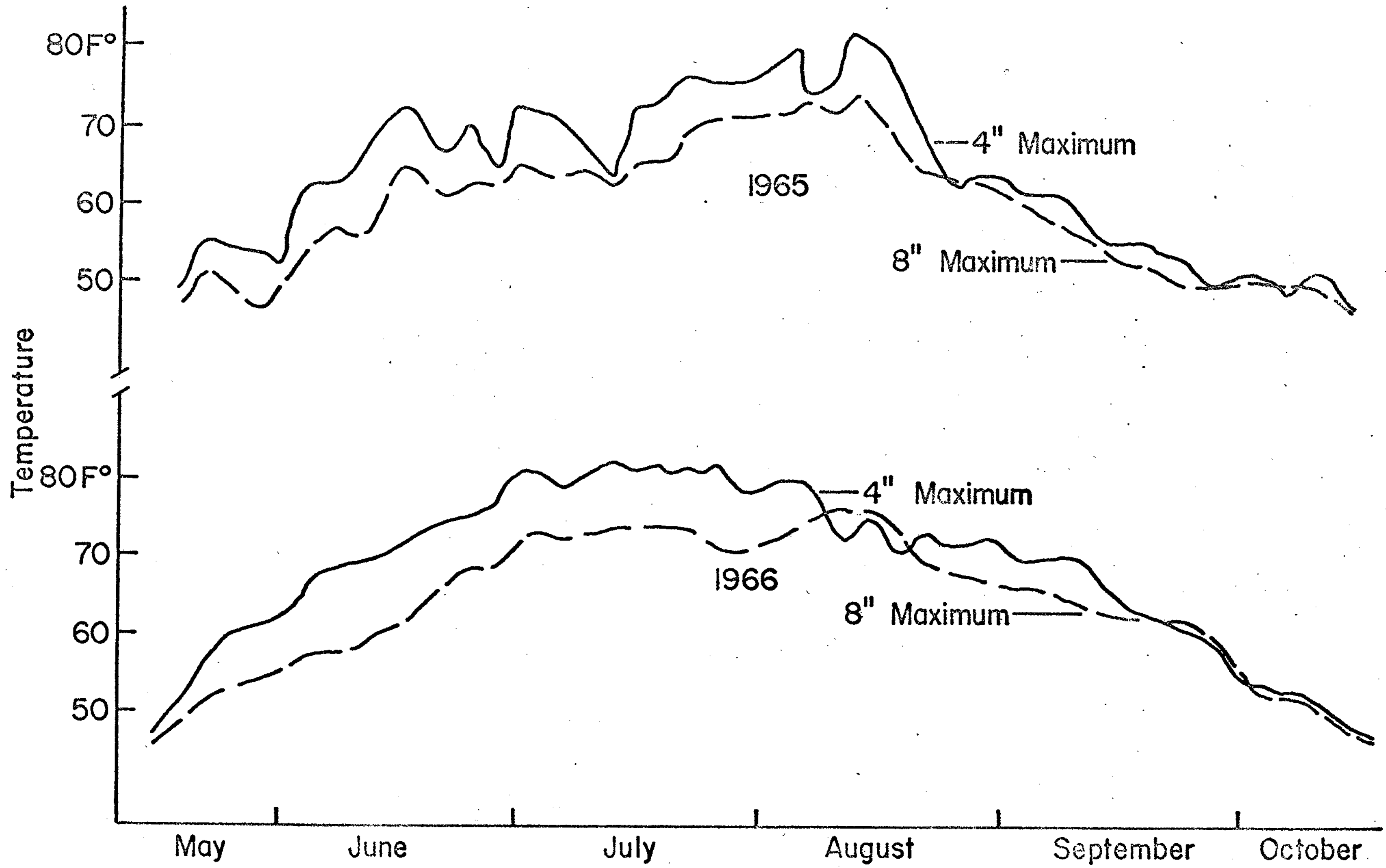
Appendix 9 (cont.)

Results of Experiment III soil analysis to determine nitrate nitrogen. (expressed as ppm. NO_3-N)

Fertilizer Treatment	June 15, 1966				August 15, 1966				October 11, 1966			
	0-6"	6-12"	12-24"	24-36"	0-6"	6-12"	12-24"	24-36"	0-6"	6-12"	12-24"	24-36"
no fertilizer	1.0	0.9	0.2	0.8	0.2	0.2	0.2	0.0	0.9	2.8	0.9	0.0
ammonium nitrate	0.9	0.9	0.2	0.0	0.2	0.5	0.2	0.0	1.8	3.4	0.0	0.2
ammonium sulphate	3.5	1.1	0.0	0.0	0.2	0.4	0.0	0.0	1.4	1.0	0.2	0.2
Milorganite	1.4	1.0	0.2	0.0	0.0	0.2	0.0	0.2	0.8	0.6	0.2	0.0
plastic coated urea	1.5	1.4	0.0	0.2	0.2	0.2	0.2	0.0	5.9	0.8	0.2	0.0
Uramite	1.1	0.5	0.2	0.2	0.2	0.0	0.0	0.2	0.8	0.2	0.4	0.2
urea	1.1	0.5	0.2	0.2	0.5	0.2	0.2	0.0	2.4	0.2	0.2	0.2



Appendix 10. Soil temperatures under Kentucky bluegrass turf (Experiment II.)



Appendix II. Soil temperatures under Creeping bentgrass turf (Experiment III.)