THE GROWTH AND QUALITY OF 'PENNCROSS' CREEPING BENTGRASS (*AGROSTIS PALUSTRIS HUDS.*) AS INFLUENCED BY SEVERAL NITROGEN SOURCE MATERIALS ON HIGHLY AMENDED PUTTING GREEN SOIL MIXTURES

A Thesis

Presented to

the Graduate School of

Clemson University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

Horticulture

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by

Charles Benjamin White

August 1980

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To the Graduate School:

Herewith is submitted a thesis written by Charles Benjamin White entitled "The Growth and Quality of 'Penncross' Creeping Bentgrass *(Agrostis palustris Huds.)* as Influenced by Several Nitrogen Source Materials on Highly Amended Putting Green Soil Mixtures." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Horticulture.

A. D. Mayer
Thesis Advisor

We have reviewed this thesis
and recommend its acceptance:

A. D. Mayer

T. V. Hein

Horace D. Skipper

Steven S. Hayasaka

Accepted for the Graduate School:

Farrell P. Brown

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ABSTRACT

The high annual applications of nitrogen (N) on putting greens with amended rootzone media prompted investigations to determine the influence of various mixtures on nitrifier and denitrifier populations; mineralizations of ureaformaldehyde (UF), sulfur-coated urea (SCU), isobutylidene diurea (IBDU) and urea under controlled laboratory conditions, and under actual putting green conditions; and to determine the leaching losses from these N source materials and their effects on creeping bentgrass (*Agrostis palustris* HUDS. 'Penncross') establishment and quality. Two mixtures [70% (vol.) sand + 30% peat mixture and a 70% sand + 20% peat + 10% Cecil sandy loam soil] were used that reflect the current trend in putting green construction.

Initially the mixture containing soil had *Nitrosomonas* and *Nitrobacter* populations 500 x and 40 x higher, respectively, than the mixture without soil. In laboratory studies Urea-N levels decreased in both soil and soilless mixtures with IBDU with time and for all N sources to a trace in 2 weeks except SCU which increased to 80 ppm at 1 week. Urea and SCU showed similar trends in NH_4^+-N accumulations with 56, 101 and 90 ppm for urea and 22, 103 and 115 ppm for SCU at the 1, 2 and 4 week periods, respectively. The accumulation of $(NO_2^- + NO_3^-)$-N in the IBDU treatments followed similar trends with 36 and 71 ppm at 4 and 8 weeks with soil and 25 and 75 ppm at 8 and 16 weeks without soil. The accumulation of $(NO_2^- + NO_3^-)$-N was 79 ppm in the urea treatment at 8 weeks and 100 ppm in the SCU treatment at 16 weeks.

After 16 weeks of incubation only one-third of the N from UF had been converted to $(NO_2^- + NO_3^-)$-N while three-fourths of that in the IBDU treatment without soil was similarly transformed.

In the field studies N sources were applied at the rate of 0.61 kg N/a/mo. Sept.-Feb. for urea and 2.93 kg N/a in Sept. for the slowly soluble and slow release N sources.

After 1 month in the field no differences were found in nitrifying bacterial populations. Denitrifier bacterial populations had increased dramatically with time and remained higher at all sampling dates in the soil mixture.

Little if any Urea-N or NH_4^+-N was found in the leachate samples. The influence of percolating water was most evident on leaching losses in the SCU and the IBDU in the soilless mixture treatments. The SCU treatment showed excessive leaching losses of $(NO_2^- + NO_3^-)$-N of 94, 38, and 76 ppm at the fourth, fifth, and seventh week of sampling respectively and 20, 12, and 30 ppm for IBDU in the soilless mixture for the same periods. These materials showed greater leaching losses due to the broken coating with the SCU and hydrolysis of IBDU. The lower leaching losses for urea despite its solubility [17 ppm of $(NO_2^- + NO_3^-)$-N at 4 weeks] are due to lower application rates.

The establishment of bentgrass was most rapid in the IBDU treatments in the mixture with soil with 50% coverage 4 weeks after seeding and 83% coverage after 9 weeks. Even in the soilless mixture establishment rate of bentgrass was greater at 4 weeks with IBDU (22%) than with urea (7%) or UF (8%) but not greater than SCU (18%). The increased establishment in the soil mixture as compared to the soilless mixture with IBDU is attributed to the reduced leaching losses of N.

Turf injury was observed in the SCU treatment during the maintenance due to broken fertilizer particles. These broken particles resulted in significant releases of N thus a high salt index.

Dedicated to the man

I respect most --

my Father

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INTRODUCTION

Nitrogen (N) is the soil nutrient used in greatest amounts by turfgrasses and is the nutrient that influences turf quality to the greatest degree. Nitrogen serves many functions in plant growth. It is an important constituent in the synthesis of amino acids, proteins and nucleic acids. Despite the fact that most N available to plants is in the NO_3^- form, organic nitrogen compounds are synthesized from NH_4^+. The initial step in nitrogen metabolism in plants is the reduction of NO_3^- to NH_4^+. Amino acids are synthesized in plants when ammonium (NH_4^+) is combined with various carbon skeletons. Amino acids are the building blocks of proteins and serve to regulate metabolism as well as transport and store N in the plant. The nucleic acids, another product of N metabolism, function principally to control hereditary characteristics and transfer genetic messages to all parts of the cell.

The soil medium is the principle source of nitrogen for plant growth and contains nitrogen in various organic and inorganic forms. Organic compounds are readily metabolized to ammonium and then nitrate by the process of mineralization. The initial phases are accomplished by heterotrophic organisms while the final phases are the result of chemosynthetic autotrophic bacteria.

Nitrogen source materials are divided into the broad categories of soluble, slowly soluble, and slow-release. The soluble materials, usually inorganic salts or urea, are immediately available for plant

utilization; however, they can be readily lost through leaching. Slowly soluble materials are natural or synthetic organics such as activated sewage sludge, ureaformaldehyde or isobutylidene diurea. These materials must be mineralized to convert them to soluble forms that are available for plant assimilation. This process generally requires varying lengths of time depending on nature of the material, moisture, temperature, and pH. Slow-release N sources are soluble materials that have been encapsulated in a substance that controls the release of these materials such as osmocote and sulfur-coated urea. The nature and thickness of the coating determines the desolution rate or the time required for the N to become available to plants.

Nitrogen utilization or loss is greatly influenced by the cation exchange capacity of the soil medium and/or percolating water. Normally putting greens are maintained at moisture levels optimum for plant growth which are also the levels where compaction is most severe. The recent trends in putting green construction have been toward the use of high sand content mixtures (usually 70-90% by volume). These mixtures are designed to minimize the influence of compactive forces under conditions of intensive management, heavy equipment and foot traffic. High sand mixtures characteristically have poor nutrient and moisture retaining properties. The successful establishment and growth of turf on highly amended putting greens require the use of controlled release nitrogen fertilizer materials and/or water management practices. Highly amended golf greens require from 10 to 12 .24-.49 kg/a applications of N per year, when soluble N sources are

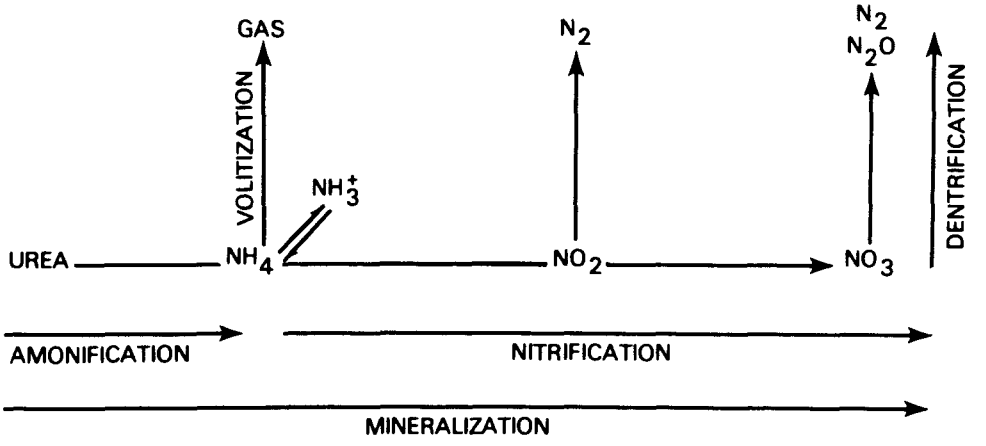
used. As labor is the greatest single expense in a golf course budget (32), reducing applications and associated labor costs would result in considerable savings. The use of slowly soluble or slow-release materials on putting greens twice per year rather than bi-weekly, would solve this problem; providing there was no corresponding reduction in turf quality. This study was initiated 1) to investigate the nitrifier and denitrifier populations of two highly amended putting green mixtures; 2) to measure the mineralization of UF, SCU, IBDU, and urea under controlled laboratory conditions, and under actual putting green conditions; 3) to determine the leaching losses of these nitrogen source materials and their effects on turfgrass establishment and quality.

REVIEW OF LITERATURE

Nitrogen Mineralization

Biological Factors

Mineralization of nitrogen is an essential process occurring in soils. It is a twofold process involving ammonification and nitrification.



There are many biological factors which influence rates of mineralization such as type of microorganisms, soil moisture, temperature, aeration, and reaction.

Ammonification seldom becomes a rate limiting step in mineralization. This process utilized a diverse group of heterotrophs which are active over a wide variety of conditions (78).

Nitrification can become rate limiting because only two genera of obligate autotrophs are involved, *Nitrosomonas* and *Nitrobacter* (78).

Populations of *Nitrosomonas* and *Nitrobacter* were reported to increase with increasing applications of N (85).

Inhibition or retardation of nitrification has been found to reduce leaching losses of NH_4^+-N (31). However, Mazur and Hughes (58) found that soils treated with various s-triazines and dithiocarbamates had a stimulatory effect on N mineralization in the soil.

Basaraba (8) and Kilian (48) found the mineralization of urea-formaldehyde (UF) too slow for optimum turfgrass growth. Beaton (10) observed UF to be mineralized slowly at first but it was an acceptable N source as time progressed. The mineralization rate of UF was about 6-7% per month and about 25% of the material was water soluble (18).

Mixtures high in organic matter or soil also showed an increase in nitrifier populations which in turn increased nitrification rates (15).

Chemical and Physical Factors

Losses of N from turfgrass areas due to leaching was shown to be greatly affected by the N source material. Extremely high NO_3^--N losses from putting greens were incurred when soluble N source materials were used (15, 63). These higher N losses were greatest during periods of heavy rainfall and/or low plant growth. This increased loss of N from soluble, inorganic sources also poses an environmental pollution threat (16).

Duble (23) stated that on highly permeable golf greens, there could be a 50% or greater loss of applied N from organic sources. These significant losses of N were drastically reduced when N was applied as IBDU (23).

Nitrate-N losses from IBDU were not detected until two to four months after first application, but increased rapidly once detectable NO_3^--N was found (27). UF showed NO_3^--N losses immediately after application and levels peaked 9-12 days afterwards (27). Under bermudagrass putting green conditions, about 30% of the UF had leached out three weeks after application and about 65% in 15 weeks (80).

Urea was found to have the greatest N losses six to nine days after application. In about 30 days, NO_3^--N levels were comparable to unfertilized areas (27, 76). This is similar to findings by Bredakis and Steckel (12) which showed that 75% of the N from urea leached out in 3 weeks with an additional 13% leaching the next 3 weeks. Benson and Barnette (11) observed no Urea-N in leachates following applications of urea. They also concluded that all N applied as NO_3^--N was leached from the soil.

Ishizuka and Takagishi (41) concluded the mineralization rate of UF was governed by the urea:formaldehyde ratio and a ratio of 1.5:3 possessed reasonable nitrification. The high percent of combined urea in UF accounted for decreased nitrification and leaching losses (37). Nitrification of UF has been further summarized by Hays (36) and Yee and Lowe (95).

In lysimeter studies, about 37% of applied soluble N was found to be leached under grass situations where 54% of the applied N leached under clover (43). When a fall fertilization of grass was observed, about 12% of the soluble N was leached the first year. Virtually none of the fertilizer was leached the first year when applied to grasses in February (44). Menn et al. (60) observed

NO_3^--N leaching in putting greens to be the greatest with inorganic N sources and lowest with synthetic organic sources. Skogley and King (73) found under turfgrass situations that 21-35% of the applied N from urea was recovered where only 9-12% of the N from UF was recovered.

Increased rates of N fertilization on putting greens increased leaching losses (5, 14). Allen and Mays (3) state that the slow-release fertilizers significantly decreased the leaching losses incurred with readily available N sources.

Soil pH plays a very significant role in mineralization as well as leaching losses of N. Soil pH was found to increase in sandy soils by the leaching of soluble N (11). Urea had the greatest effect of raising the pH. Decreased soil acidity caused an increase in leachable N. Ureaformaldehyde in the 3-15 weeks period produced more leachable N at soil pH 6.7 and 5.5 than urea (12). The rate of NO_3^--N produced from UF was 2-5% higher in soils with pH 5.7 as compared to soils with a pH of 7.0 (8).

In alkaline soils, IBDU delayed plant response which was attributed to the reduced release rate of N at the higher pH. The amount of N recovered after 10 weeks was equivalent to 65-70% of the IBDU added compared to a 98% recovery from urea. This low N recovery was attributed to incomplete release of N in alkaline soils rather than N loss (40). Lunt and Clark (54) reported efficient plant use of IBDU in a pH range of 5-8. The conversion of IBDU to urea-N, NH_4^+-N, and NO_3^--N was not as fast in alkaline soils as acid soils (40). Hughes (39) also found the release of N most rapid at pH 5.7 to 7.7.

The release of N from SCU also increased in limed versus acid soils (29). Two weeks after application, losses of N from urea were reported to be 29% on limed areas and 36% on unlimed areas (79). Pearson et al. (66) stated that ammonium fertilizers tend to acidify soils and increase leaching of NO_3^--N as well as cations.

Putting green soil textures greatly influence turfgrass quality, mineralization of N, and leaching losses (19). Green mixtures containing no organic matter exhibited very high NO_3^--N losses from soluble N sources (15). There was less than 2% loss from IBDU and UF, and only 14% from Milorganite. Green mixtures containing organic matter had less NO_3^--N losses with the soluble and slowly soluble N source materials (15). Mitchell et al. (61) reported NO_3^--N levels higher than NH_4^+-N levels in putting green soils after an application of slowly soluble fertilizer. This was noted in soil and soilless mixtures. Nash and Johnson (64) observed soil texture to have no effect on NO_3^--N recovery but did influence NH_4^+-N recovery. When used as an organic matter source, peat was reported to have no signifcant effect on turfgrass growth (74).

Particle size directly influences the release rate of slowly soluble N source materials. Several studies have indicated a delay in the release of N from IBDU (20, 62, 79, 84). Hughes (39) concluded that N release from IBDU is dependent on particle size which is second only to soil moisture. Release of N from IBDU was faster with a finer particle size (40). The dissolution of IBDU was the rate limiting factor in the conversion of N to plant available forms (33). During a controlled-release period, the decrease in N uptake

was greater with IBDU than with UF or SCU (82). A period of a few weeks after application the availability of N from UF was less than from ammonium sulfate or urea on silty soils (52). Brown and Volk (17) found UF had no delayed availability compared to ammonium nitrate. Release of N from SCU has been found to be directly related to particle size and thickness of the sulfur coat (29). In summer fertilization of 'Tifdwarf' Bermudagrass SCU, at the 9% dissolution rate, exhibited better controlled-release characteristics than UF or IBDU (81). Coated N sources were found to have greater longevity in the soil than non-coated N source materials. The non-coated N sources showed greater N loss from the root zone (38). This residual N exists largely in the NO_3^--N form (87). Lunt (53) proposed that the SCU release rate average was about 1% per day.

Environmental

Moisture levels in soils have varied effects on the release and leaching of N, especially with readily available N source materials. According to Smika et al. (75) the amount of NO_3^--N lost below the root zone of corn grown on sandy soils was proportional to the amount of water that percolates through the root zone. Similar results were also observed by Stout and Burau (78). They found leaching losses of N were usually small on well-drained silt loam soils with moderate rainfall. Under similar conditions, most of the NO_3^--N not taken up by the crop was found in the root zone (67). Edwards et al. (25) reported little or no NO_3^--N movement below the root zone with proper water management.

Nitrate N was not detected below a 30 cm depth under lawn fertilizer conditions in the summer; however, nitrate applications in October were traced to the ground water (26). The timing of fertilizer application as noted by Edwards et al. (25) showed that NO_3^--N moved with the water front in dry soils but not in saturated soils. UF materials gave greatest soil N levels in the top 2.54 cm of soil. No differences occurred in the 2.54 to 19.78 cm range, and levels in the lower depths were directly related to the solubility of the N materials (21). Raney (72) observed N removal from loamy soils was affected very little by the amount of water percolating through the profile. Losses incurred were primarily NO_3^--N, therefore, control of NO_3^--N concentrations might effectively control leaching losses.

Under high water applications negligible amounts of N leached from UF in lysimeters with sandy soil (17). The N availability from UF was found to be proportional to its solubility in water (94). During dry periods, IBDU showed lower NO_3^--N losses than UF but comparable losses under heavy rainfall conditions (76). Hughes (39) concluded that soil moisture was the primary factor in the release of N from IBDU. Isobutylidene diurea gave excessive turfgrass growth in periods of heavy rainfall after a single application (86). The mineralization rate of IBDU increased in water-logged conditions over field capacity moisture levels (71). The stability of the SCU coating was also greater in water-logged (anaerobic) conditions than aerated (aerobic) soils. This reflected a faster N release from SCU in aerobic conditions (29).

Results contradictory to these were reported by Prasad (69) which stated an increased release of N from SCU with increased

moisture levels. Maximum N release occurred at medium soil moisture levels. Under severe leaching regimes, SCU was much more effective at reducing NO_3^--N leaching than a single application of soluble N source materials (4).

Temperature has also been found to influence leaching losses and N mineralization in soils. Losses of NO_3^--N increased with increased soil temperature under putting green conditions (61). Soil temperature has also been found to drastically affect the mineralization rate of UF (8). During the growing season of the crop, UF had limited value at soil temperatures less than 15°C.

Hawes and Decker (35) observed coverage of creeping bentgrass was more dependent on soil temperature than the application rate of fertilizer. The fastest coverage and optimum fertilizer utilization occurred at 21°C.

Plant Responses

Response of turfgrasses varied with respect to N source materials, application rate, timing of application and season of the year.

Turfgrasses respond very slowly to low rates of slow-release N sources (34,46,63,81). On Kentucky Bluegrass, poor spring green-up resulted when IBDU was applied only in the spring, compared to UF (89); although when applied in the fall, White and Pesek (88) reported that IBDU gave better turf response than UF. After a single spring application, IBDU was found to give poorer fall color than UF or SCU due to greater turf stimulation in early summer (82). Turf responses were slower with UF than inorganic or soluble fertilizer (73, 91, 93).

Jagschitz and Skogley (42), Mays (56), and Davis (22) all reported as much turf response with UF as SCU or soluble N sources.

Readily available materials were most effective in the spring and fall while UF had less seasonal response (55). At increased rates on actively growing turf, UF showed superior longer lasting effects during the summer only according to Goetze and Daniel (30). Winsor and Long (91) found UF to give the best results on turfgrasses with a long growing season. Other studies showed UF applied in the fall lasted no longer than ammonium nitrate (23).

During the first growing season, urea and ammonium nitrate gave the best turf color and density, but in the second growing season UF produced an equal quality of roadside turf (65). On Kentucky Bluegrass UF promoted uniform growth and gave consistently higher density ratings than urea (45,48,49). UF produced less total seasonal clipping yields than inorganic sources but had no less turf quality (24). The UF materials also encouraged greater root and crown development than soluble N sources (7).

Higher yields were obtained from soluble N fertilizers than from SCU for early forage cuttings; while the opposite results were obtained from later cuttings (57). Clipping yield from Kentucky Bluegrass was greater with IBDU than with UF or Milorganite according to Wilkinson (89). Spring color from the fall application was found to be better with urea than with IBDU (83).

Kentucky Bluegrass responded well to N applied as ammonium nitrate, Osmocote or SCU (20% dissolution rate), but responded poorly to UF, Milorganite and SCU (14% dissolution rate). IBDU, Osmocote and SCU

(20% dissolution rate) were found to provide superior turf growth, density and color (50). Mays (56) observed promising results with SCU on bermudagrass turf with the exception of putting greens. Applying soluble N fertilizers in combination with natural and synthetic organic N sources provide immediate as well as long term turf responses (51).

Soluble and slowly soluble N source materials have exhibited a potential for turf injury when applied at high application rates. In tests on bermudagrass with high rates of N, urea nearly killed turf where SCU gave the maximum response with no sign of burning (70). Treatments UF and IBDU showed little or no burning effect on turfgrass (62,68,90). Hays and Haden (37) reduced burning potential of UF to the fact that over 90% of the N was combined urea.

The selection of a single vs. split application regime is a problem requiring much investigation to determine which program will provide the best turf quality. Beard (9) stated that a single application of UF did not produce adequate turf quality throughout an entire growing season. Wisniewski and DeFrance (92) showed UF to give higher turf quality when applied alone or as a component in mixtures. Powell and McKee (68) observed UF to give best winter color on bentgrass when applied in combination with biweekly applications of soluble N.

Kentucky Bluegrass responses in the summer were similar with UF and IBDU; however, frequency of application affected turf response more with IBDU than with UF (89). Tests by Moberg et al. (62) showed IBDU and UF to possess controlled-release characteristics. Uniform turf quality was obtained with three applications of UF or two

applications of IBDU per season. This complies with Wilkinson (89) who found IBDU to give the most uniform turf response to Kentucky Bluegrass when two applications were made in April and September. Split applications of IBDU did not improve uniformity of growth but did give better early spring green-up. In contradiction Wilkinson et al. (90) found split applications of IBDU or UF did not improve turf quality over a single spring application. Waddington and Duich (83) found a single spring application of IBDU was better than a single fall application on creeping bentgrass.

On Italian ryegrass, a single application of IBDU produced a 24-53% increased effectiveness over four split applications of urea based on equalivalent N rates. Isobutylidene diurea was also observed to give better turf quality than urea when used as 2/3 of the N in a 18-6-12 fertilizer analysis (59). However, there was no indication of the adjustment of phosphorus and potassium on the urea treatments.

Fall performance of cool season sports to turfgrasses was improved when spring-summer split applications of SCU were followed (94). This concurs with Waddington (82) who found split applications of SCU to give the best results on cool season turfgrass.

Waddington and Duich (83) concluded that SCU, UF and IBDU all need split applications to minimize growth peaks following applications and to provide good fall color to creeping bentgrass.

MATERIALS AND METHODS

Two highly amended mixtures were prepared for these studies which reflect "current trends in putting green mixtures." The first mixture consisted of 70% (vol.) sand + 30% peat; the second contained 70% sand + 20% peat + 10% Cecil sandy loam topsoil (clayey, kaolinitic, thermic typic Hapludults) (Appendix Table 12).

The accumulation of nitrogen (N) in the two mixtures was observed weekly after applications of four different N source material. The N source materials were ureaformaldehyde (UF), sulfur-coated urea (SCU), and isobutylidene diurea (IBDU) which are slowly soluble and urea, which is a readily available N source (Appendix Table 13).

Determinations for Urea-N, NH_4^+-N, and (NO_2^- + NO_3^-)-N in all experiments were conducted by the methods outlined by Bremner and Kenney (13,47). Extractions of 20g soil samples were made by adding 100 ml of 2M KCl and shaking on a wrist action shaker for one hour then filtering through Whatman No. 42 filter paper. The filtrates were either analyzed immediately or frozen at -18°C for later analyses.

All experiments were designed in a randomized complete block design with three replications. The individual flasks in the lab incubations, and the lysimeters in the field studies were the experimental units (77).

Laboratory Incubations

The laboratory incubations were initiated to investigate mineralization activities in the two mixtures treated with the four N source materials under controlled conditions.

The pH of the mixtures was adjusted to 7.0 with solid $Ca(OH)_2$ thoroughly mixed with air-dried soil. The mixtures were moistened and allowed to equilibrate for 48 hours prior to addition of N source materials. Mixtures were weighed into 250 ml Erlenmeyer flasks to give 20g of soil per flask on an oven-dry wt. basis. Granular N source materials were added so as to provide 100 ppm N per flask. The N source materials were mixed with the soil then moistened to 30 $\pm$ 1% moisture by weight. The flasks were incubated at 20 $\pm$ 1°C and distilled water was added daily to maintain prescribed moisture levels. Mixtures were extracted after 0, 1, 2, 4, 8 and 16 weeks of incubation.

Field Studies

Field studies were conducted with the use of lysimeters (Figure 1) to investigate the leaching losses from the prescribed nitrogen sources and their effect on bentgrass establishment and quality. Each lysimeter was constructed utilizing 76.3 L galvanized tubs with a one and one-half inch hole cut in the bottom. A kitchen sink drain system was installed in each, and was extended out with drain pipe to empty into a collection carboy. A six mil plastic liner was placed in each lysimeter to prevent any reactions that might occur between the mixtures and the surface of the metal tubs. To insure proper lateral movement of soil water, a gravel base of 2.5 cm washed and sieved gravel was placed in the bottom of each lysimeter. Small gravel (1% 6.3 mm sieve, 3.7% 1 mm sieve and 95.2% 2mm sieve) was used to prevent mixtures from filtering into the gravel base.

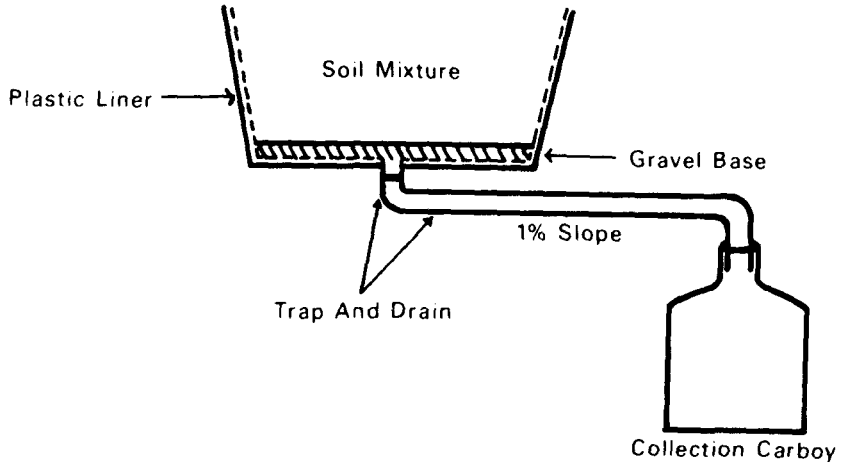


Figure 1. Leachate collection system schematic.

All mixtures placed in lysimeters were blended in a cement mixer for five minutes each. Equal amounts of water were added to assure even and consistent mixing of the components. The mixtures for each lysimeter were mixed separately to prevent bias and error that might occur from bulk mixing. The mixture depth in each lysimeter was 27.5 cm.

The lysimeters were installed in a bentgrass putting green to simulate normal maintenance conditions. Cement blocks served as foundations for the tubs. The blocks were leveled and aligned in a continuous row. The pit area was wide enough to accommodate the lysimeters, plus an area for the 16 L collection carboys.

A 10.16 cm perforated drain was placed at the base of the lysimeters to prevent any excess seepage from the green that might disrupt the lysimeter foundations.

Canvas was used to cover the drains and carboys to prevent exposure to sunlight.

The area surrounding the lysimeters was then back filled with a mixture of 60% sand and 40% softwood bark. The entire area was leveled, raked and rolled to provide a smooth and firm seedbed. The area was seeded 5 May 1978 with creeping bentgrass (*Argostis palustris* HUDS. 'Penncross') at 0.49 kg/a. Light raking and rolling insured proper seed and soil contact. The area was mulched to improve establishment. The lysimeters were hand watered to insure adequate moisture for germination. Germination occurred after 10 days.

During the establishment period the lysimeters received 4 biweekly applications of their respective N sources at 0.49 kg N/a.

Those applications were made to provide available N, and to determine the influence of these materials on establishment.

On 1 September 1978, the fall fertilizations were applied at the rates shown in Appendix Table 14. The applications were applied by hand to insure exact amounts on each lysimeter and materials were watered in to prevent foliar damage.

After germination the bentgrass seedlings were treated with chloroneb at 0.15 g/a weekly for the first month to prevent Pythium (*Pythium* spp.).

After 30 days the area was mowed 3 times weekly at a 1.27 cm height of cut with a single unit, reel-type mower. The lysimeters received normal cultural practices which included mowing, watering, and preventative fungicide sprays.

Percent cover ratings were taken throughout the study to measure the rate of establishment. The ratings were always taken by two persons to avoid bias in ratings.

Weekly leachate samples were collected and determinations of pH and volume were recorded. Samples were either analyzed immediately or frozen at -18°C for later analysis. Soil temperatures were also taken for each lysimeter at the 10 cm depth. An inhibitor was added to the collection carboys to prevent any nitrification or denitrification from occurring in the carboys. The material used was a 1 M Boric acid solution added at 10 ml/L (6).

Soil core samples were taken from each lysimeter at the application date and extracted with 2M KCl as previously described.

Nitrifier and denitrifier populations were measured in the IBDU treatments with and without soil by the methods outlined by Alexander and Clark (2), and Focht and Joseph (28) respectively. Population counts were estimated by the Most Probable Number Method for microbial populations (MPN) as described by Alexander (1).

RESULTS AND DISCUSSION

Nitrifying and denitrifying bacterial populations measured initially indicated that *Nitrosomonas* and *Nitrobacter* populations were higher in the mixture with soil (Appendix Table 1) than in the soilless mixture. These higher bacterial populations in the mixture with soil were attributed to the soil component. Soils have higher bacterial populations than sands, peat or bark due to more favorable environmental conditions. These higher populations concur with Brown et al. (15) who stated an increase in soil content also increased nitrifier populations between the two mixtures (Appendix Table 1).

Laboratory Incubations

Laboratory incubations indicated that the levels of Urea-N (Figure 2, Appendix Table 2) decreased in mixtures with and without soil with time and for all nitrogen materials except SCU. The behavior of SCU is dictated by the thickness of the sulfur coating on the particle. Only a trace (3 ppms of Urea-N) was observed at the initial extraction due to the intact sulfur coating. The Urea-N levels in SCU increased to over 80 ppm after 1 week of incubation and then decreased to 9 ppm after 2 weeks. This nearly total release of Urea-N from SCU after 1 week reflects the total disolution of the sulfur coat. This would not be expected from a material with only a 27.6% disolution rate in 7 days as 80% is approximately 2.5 times this rate. After 4 weeks the Urea-N had decreased to a trace in all treatments.

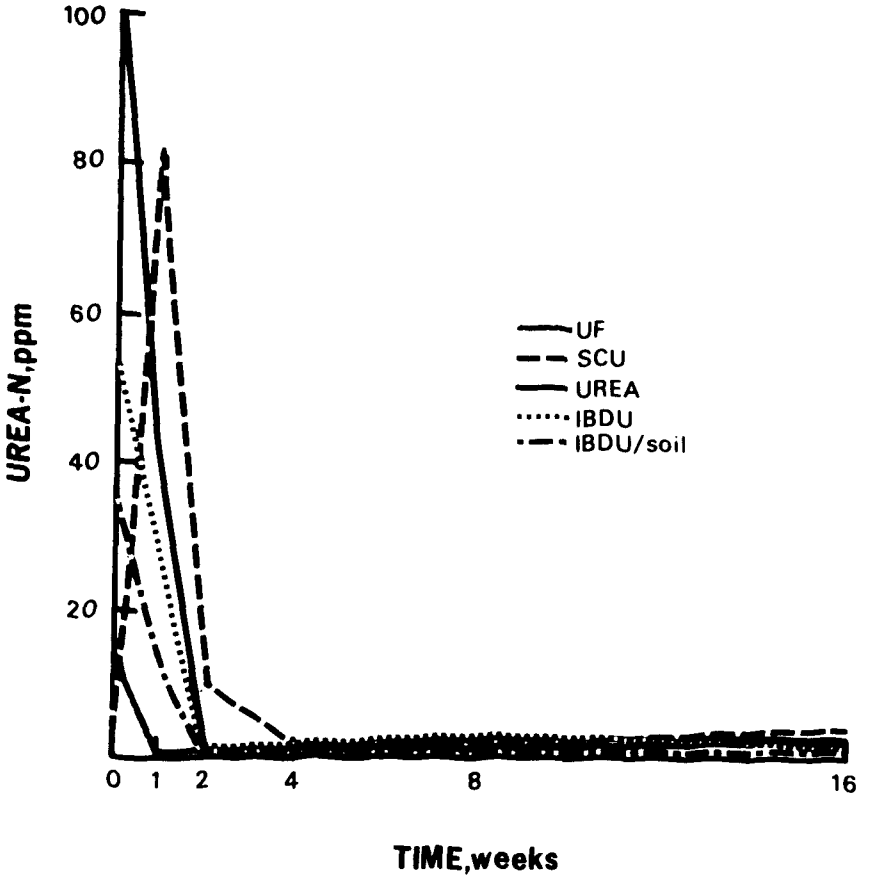


Figure 2. Accumulation of Urea-N from UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures with time; laboratory incubations.

The initial recovery of 100 ppm of Urea-N in the urea treatment indicates the accuracy of the procedures. As Hughes (40) reflected in his paper the free Urea-N extracted at time 0 from the IBDU treatments (55 and 36 ppm Urea-N) is believed to be due to the extraction procedure and not actually free urea in the soil.

No differences were found in the NH_4^+-N levels between the putting green mixtures with and without soil and IBDU until the fourth week (Figure 3, Appendix Table 2). At this time the mixture containing soil exhibited lower levels of NH_4^+-N; however, by the eighth week no differences were evident. The lower NH_4^+-H levels in the soil mixture at time 0 reflected a greater mineralization potential with a proportionately higher (NO_2^- + NO_3^-)-N concentration. The SCU and urea treatments behaved in a similar manner (Figure 3, Appendix Table 2). This is indicated by the rapid accumulation of 56, 101, and 90 ppm at 1, 2, and 4 weeks, respectively, by urea and 22, 103, and 115 ppm by SCU for the same period. A slight lag in NH_4^+-N accumulation was observed at week 1 in the SCU treatment. After 8 weeks of incubation all differences in NH_4^+-N levels among treatments disappeared.

Greater amounts of (NO_2^- + NO_3^-)-N were observed in the mixture containing soil at the 2 week period and continuing for the remainder of the 16 week incubation period (Figure 4, Appendix Table 2). The greater amounts of (NO_2^- + NO_3^-)-N in the soil mixture are attributed to greater nitrifying bacterial populations in the mixture. The accumulation of (NO_2^- + NO_3^-)-N showed a similar pattern in the IBDU treatments with and without soil with a 2 week delay in the soilless mixture. The 2 week lag in the soilless mixture reflects the greater potential of the soil mixture for N mineralization. The major accumulation started at 2 weeks

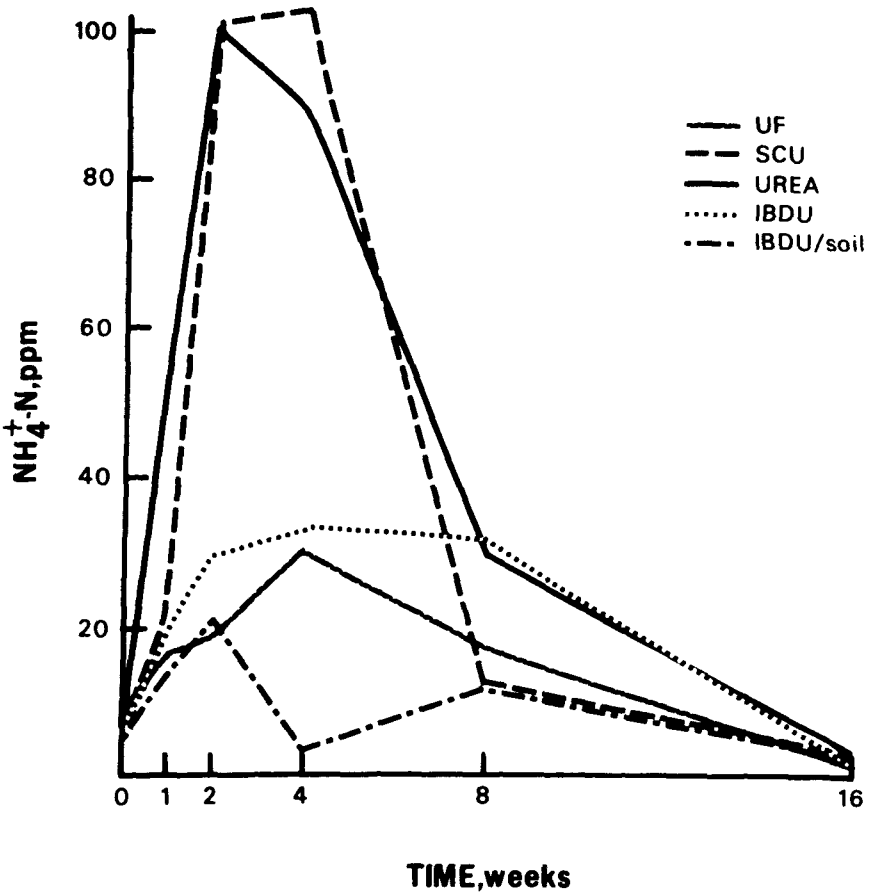


Figure 3. Accumulation of NH_4^+-N from UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures with time; laboratory incubation.

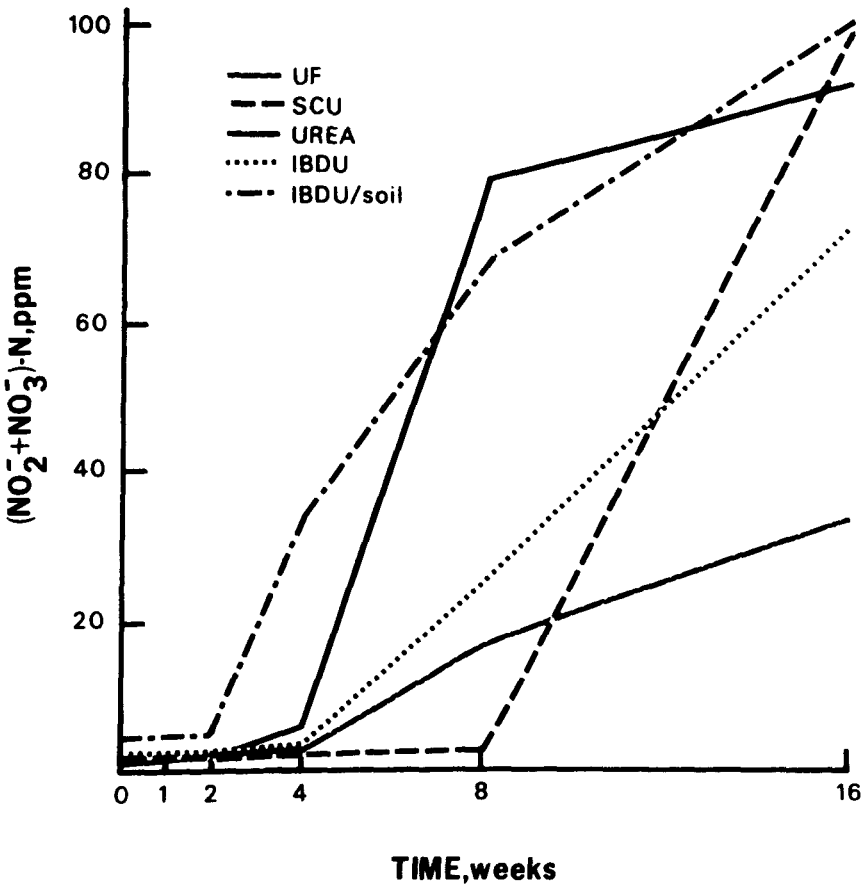


Figure 4. Accumulation of $(NO_2^-+NO_3^-)$-N from UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures with time; laboratory incubation.

in the mixture with soil and 4 weeks in the soilless mixture. The urea and SCU treatments showed similar trends with major accumulation starting at 4 weeks for urea and 8 weeks for SCU. The delay in $(NO_2^- + NO_3^-)$-N accumulation with SCU compared to urea is attributed to the disolution of the sulfur coat which must occur before mineralization of the exposed urea can occur. It was observed that after 16 weeks of incubation only one-third and three-fourths of the N was converted to $(NO_2^- + NO_3^-)$-N in the UF and IBDU treatment without soil, respectively.

Field Lysimeter Studies

Extracts from mixtures one week after application indicated the IBDU treatment with soil had higher Urea-N accumulation than the treatment without soil (Figure 5, Appendix Table 3). In the field, as in the lab, the mixture with soil showed a greater potential for nitrogen mineralization, despite the fact that differences were not observed in the nitrifier population (Appendix Table 6). This difference was again observed 3 weeks after application. No differences were observed in extracts for Urea-N levels for various N source materials in soilless mixture until the third week of the field study. At this time the IBDU had greater Urea-N levels than the other materials.

No differences in NH_4^+-N levels were found between the extracts from IBDU treatments with and without soil during the field study (Figure 6, Appendix Table 3). The SCU treatment had higher concentrations of NH_4^+-N than IBDU at 1 week and all treatments at 2 and 3 weeks.

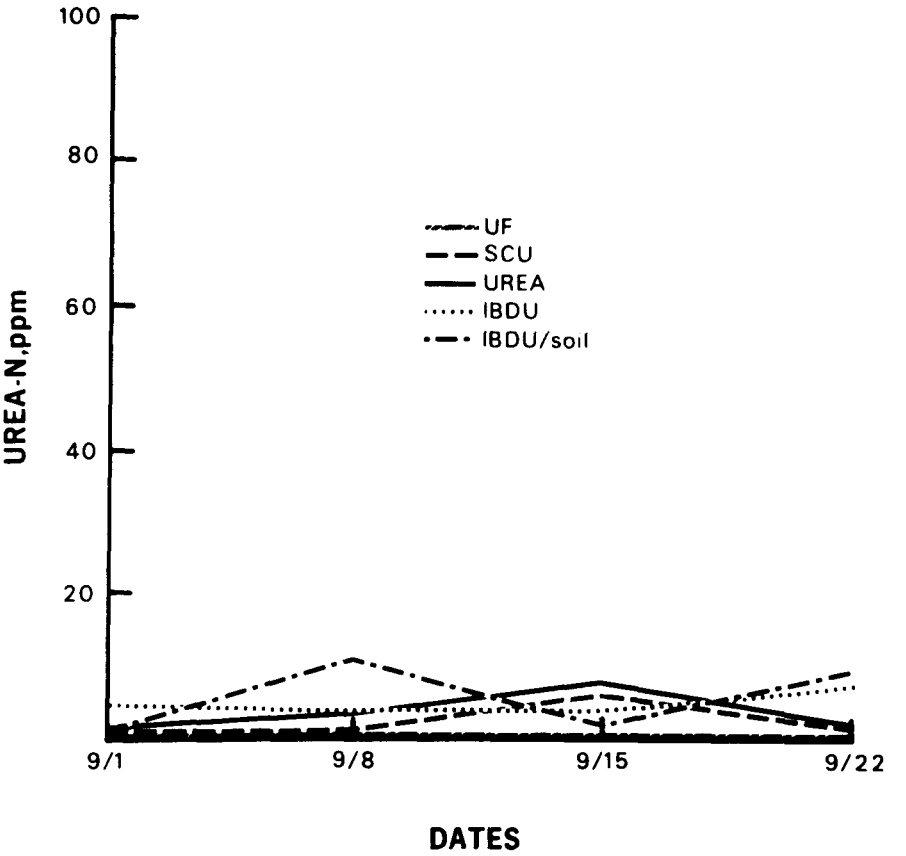


Figure 5. Accumulation of Urea-N from UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures; Lysimeters.

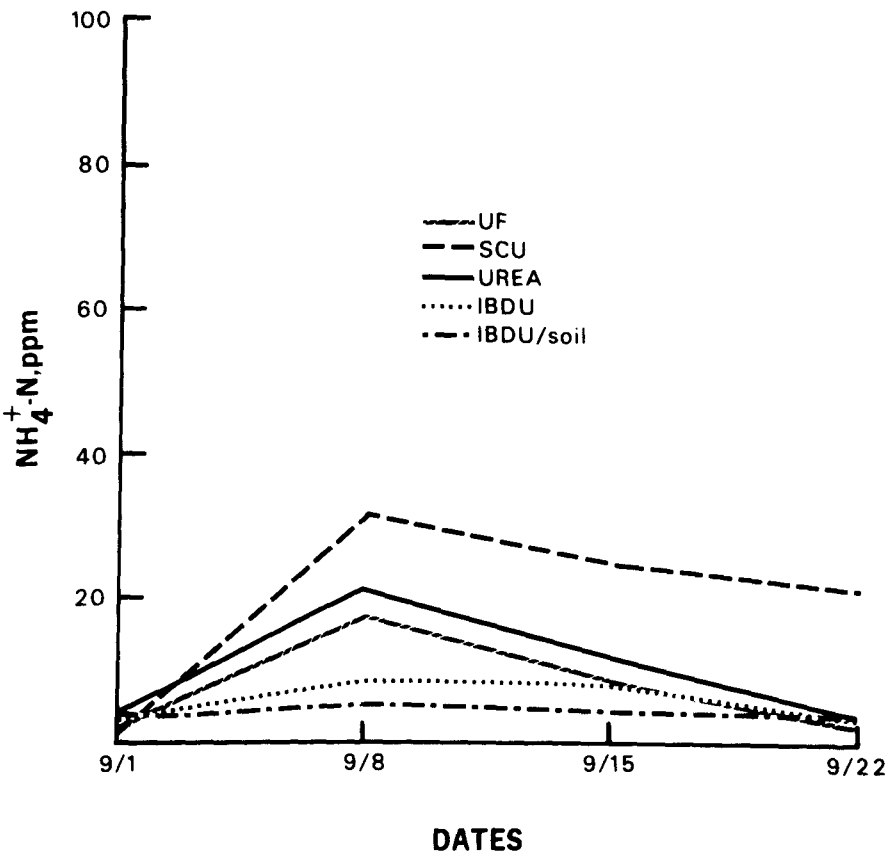


Figure 6. Accumulation of NH_4^+-N from UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures; Lysimeters.

The only difference in $(NO_2^- + NO_3^-)$-N levels in soil extracts between the IBDU treatments with and without soil were observed during the second week of field studies when extracts from the soilless mixture exhibited greater levels (Appendix Table 3). The SCU treatment under field conditions had higher levels of $(NO_2^- + NO_3^-)$-N than UF and IBDU at 1 week and all other treatments for the remainder of the study (Figure 7, Appendix Table 3).

Lysimeter leachates were found to contain essentially no free urea during the duration of the study (Appendix Table 4). Greater amounts of NH_4^+-N were observed in leachates in the SCU treatment than the IBDU mixture at 1 week and than all other treatments during the fourth, fifth, and seventh weeks (Appendix Table 4). High levels of NH_4^+-N in leachate from the SCU treatment correlates with the high levels found in extracts from the rootzone mixtures.

The only differences in $(NO_2^- + NO_3^-)$-N levels in leachates between the IBDU treatments with and without soil occurred at the 5 and 7 week samplings when the soilless mixture retained higher concentrations (Figure 8, Appendix Table 4). The higher levels of $(NO_2^- + NO_3^-)$-N in the leachate from the IBDU in the soilless mixture may be due to greater nitrifying bacteria populations in that mixture although these levels were not significantly higher by the MPN method. The urea treatments had greater concentrations of $(NO_2^- + NO_3^-)$-N in leachate than the IBDU treatment at both 1 and 2 weeks and the UF treatment only at 2 weeks. These higher levels of $(NO_2^- + NO_3^-)$-N in the leachate from urea would be expected due to the more rapid mineralization of the smaller organic molecules. As urea is readily leached out of the soil no $(NO_2^- + NO_3^-)$-N was observed in the leachate to any extent after a 4 week period. Only

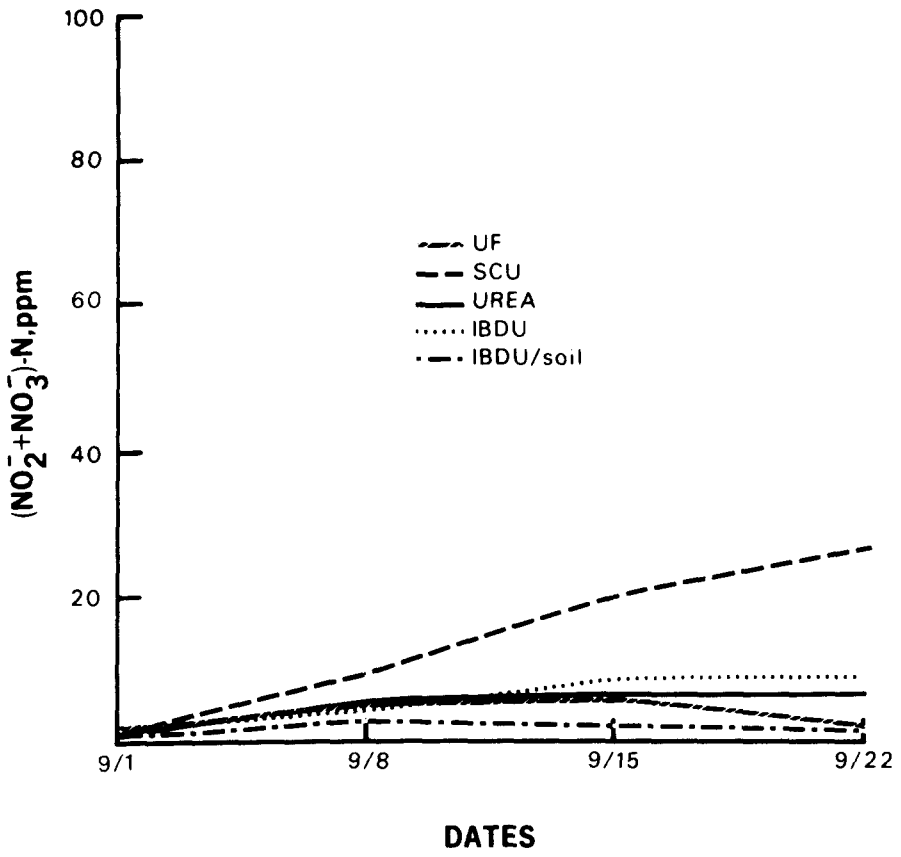


Figure 7. Accumulation of $(NO_2^-+NO_3^-)$-N from UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures; Lysimeters.

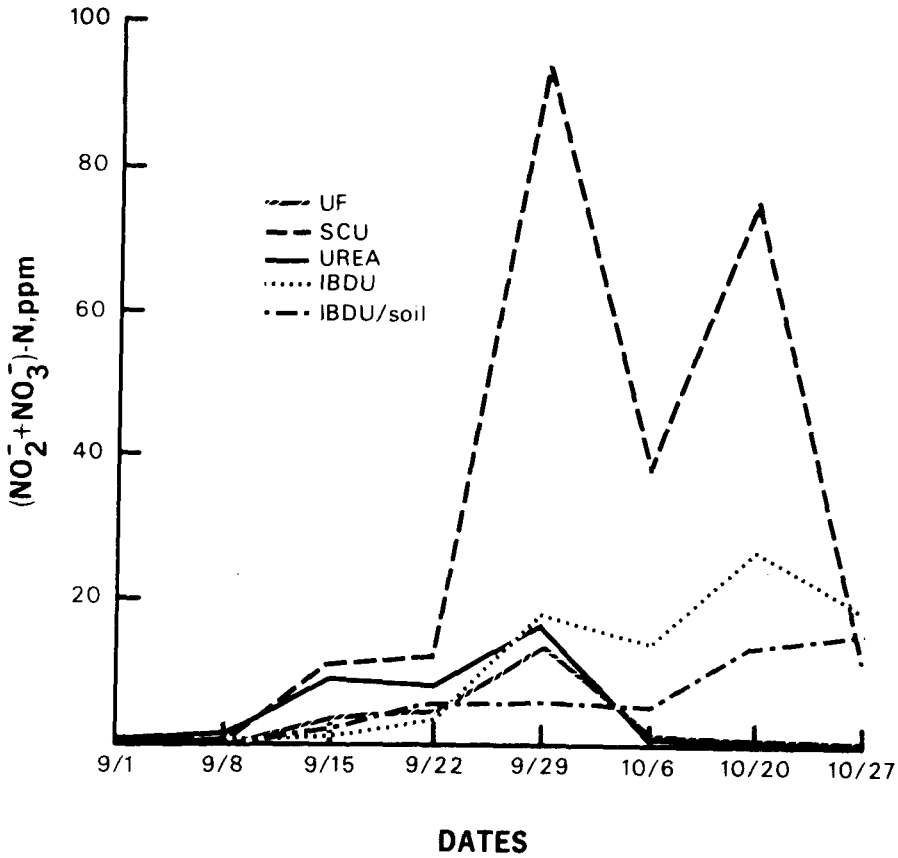


Figure 8. Accumulation of $(NO_2^- + NO_3^-)$-N from UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures in Leachate; Lysimeters.

one application of urea was applied to observe its residual. English et al. (27) and Snyder et al. (76) reported similar results when the greatest losses from urea occurred 6-9 days after application. The SCU treatment had greater concentrations of $(NO_2^- + NO_3^-)$-N than the UF and IBDU treatments at 2 weeks and greater than all other treatments during the fourth, fifth and seventh weeks of the study. The $(NO_2^- + NO_3^-)$-N levels in leachates from SCU had the same pattern as the NH_4^+-N levels. The higher levels of $(NO_2^- + NO_3^-)$-N observed during the fourth and seventh weeks were attributed to the large volumes of water that passed through the lysimeters during those periods (Figure 9, Appendix Table 5). The minimal amounts of $(NO_2^- + NO_3^-)$-N in leachates agree with observations by Brown and Volk (17) that showed negligible amounts of N leached in UF treatments. The influence of percolating water through the mixtures stresses the importance of controlled irrigation programs on putting green turf to minimize leaching losses particularly when SCU and IBDU are used in fertility programs. The SCU behaved in a similar manner to urea because of the more rapid mineralization of the smaller organic molecules. Nitrogen losses from all materials except UF were a direct function of water movement through the soil profile. These results are in complete agreement with those of Smika et al. (75) and Stout and Burau (78) who found that the amount of NO_3^--N lost below the root zone was proportional to the amount of water percolating through the root zone. The results obtained in this study contradict the results of Heilman et al. (38) which state that the residual of N was greater with coated than non-coated N sources. These studies show at the 2.93 kg N/a rate SCU was the N source most readily leached from the soil.

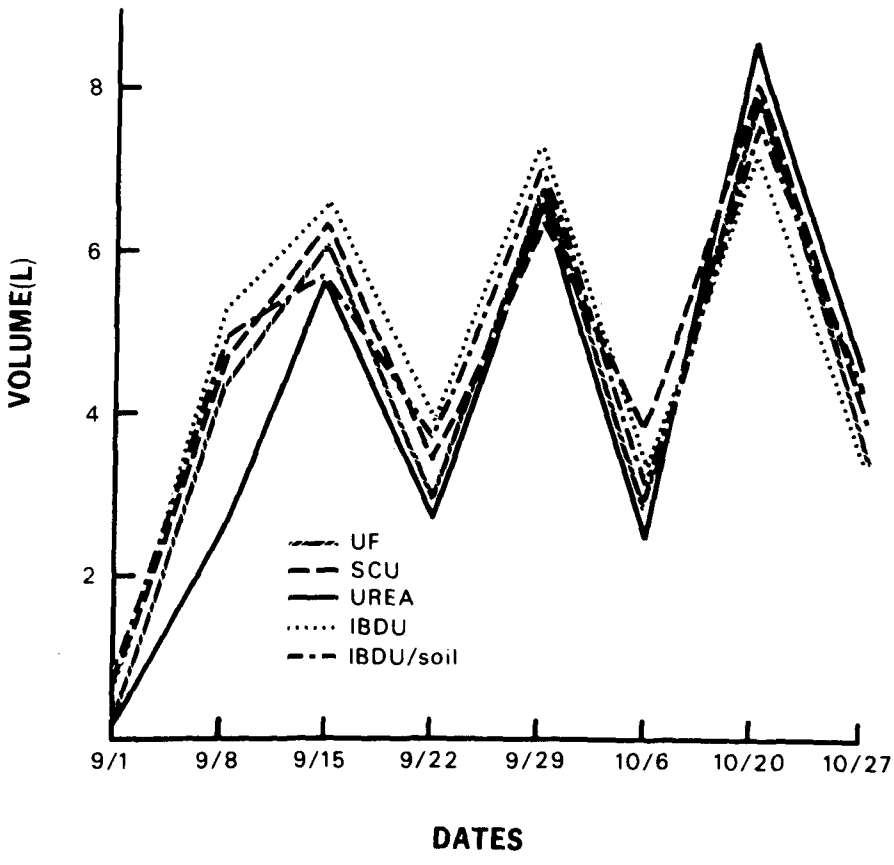


Figure 9. Total Leachate volume at sample date; Lysimeters.

The dissimilar results under field conditions and those observed in the laboratory incubations appear to be due to the differences in the nitrifying bacteria populations (Appendix Table 6). A general increase in nitrifyer populations in the field was attributed to constant inoculation of the mixtures with omnipresent nitrifying bacteria. Although much greater numbers of bacteria were found in the mixture containing soil, these differences were not significantly greater than in the mixtures without soil. This suggests that a greater number of replicates might be in order when using the most probable number method of estimating the bacterial populations. The physical limitation in large numbers of test tubes and time required for reading the tubes did not permit greater replication in these studies.

Recorded temperature did not show any differences between lysimeters (Appendix Table 7) and, therefore, did not have any effect on N accumulation or leaching losses during the study.

The only consistant trend in pH was observed for leachates from the SCU treatments which were lower at 4, 5 and 7 weeks. This can be explained by the oxidation of sulfur to sulfuric acid (Appendix Table 8).

The IBDU without soil and SCU treatments exhibited essentially the same rate of creeping bentgrass coverage at the biweekly establishment rate of 0.98 kg of N/a for the period 35 through 114 days after seeding (Figure 10, Appendix Table 9). The IBDU and the SCU treatments had 95 and 90% coverage respectively by 114 days. While the rate of cover of the UF treatment was not different from the SCU treatment, it was less than the IBDU treatment at 35, 53, and 114 days. The urea treatment had less coverage than the SCU treatment for the period 71 through 114 days

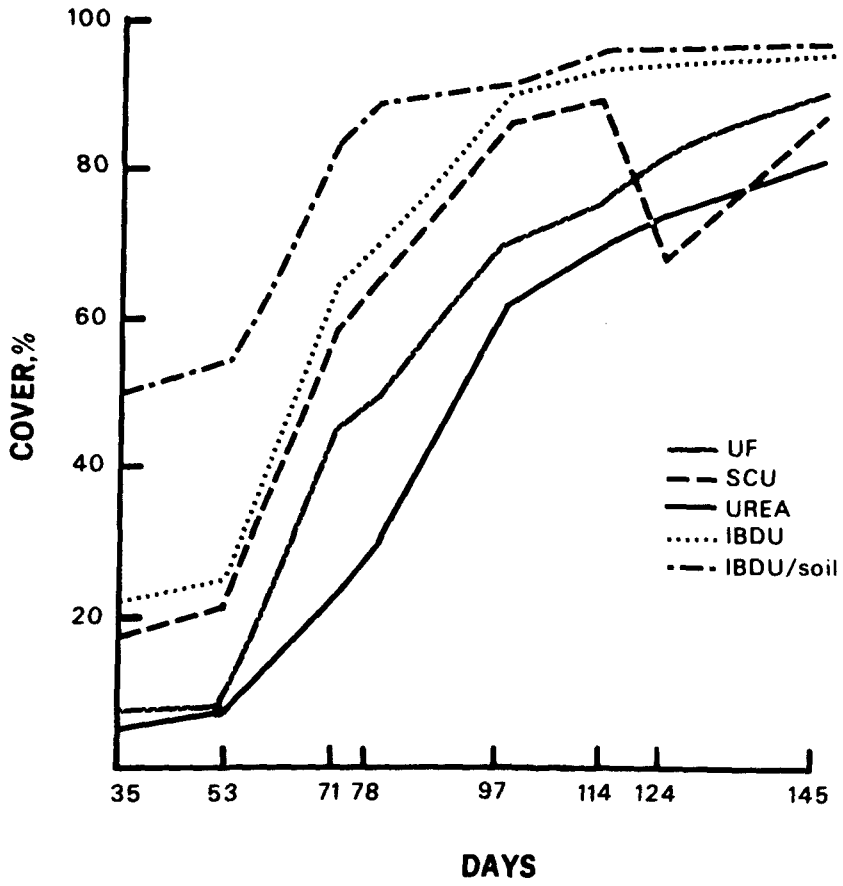


Figure 10. Bentgrass cover as influenced by UF, SCU, urea, IBDU in the soilless, and IBDU in the soil mixtures; Lysimeters.

and less than IBDU for the entire period 35 through 114 days. This would be expected as soluble fertilizer materials are quickly lost in high sand content greens. It is also interesting to note the effectiveness of SCU at these lower rates showing the desirable influence of the sulfur coat on urea.

The IBDU treatment with soil had the most rapid establishment rate with 83% coverage by 71 days. This was greater than the IBDU treatment without soil both at 35 and 53 days. The increased establishment rate by IBDU might be partially due to increased capillarity in the mixture with soil; however, it is most probably due to reduced leaching losses of N, thus a more efficient utilization of the N by the developing seedlings in this treatment. The IBDU in both mixtures and the SCU treatment were the only treatments with sufficient coverage for the fall application of the N source materials.

During the maintenance application phase of the study, when 2.93 kg N/a of slow release materials were applied in a single application on 1 Sept. 1979, there was a significant reduction in the percent cover of turf on the SCU treatment (Figure 10, Appendix Table 9). This injury was due to the high percentage of broken particles that occurred during mowing operations. The physical breakdown of the sulfur coating on the particles resulted in salt injury. This would eliminate the use of SCU on golf greens due to repeated traffic with machinery and golfers. This agrees with the findings of Mays (56) who stated that SCU was a promising N source for turfgrasses except putting greens. This injury is contradictory with the results obtained by Prasad et al. (69) who found no burning from SCU even at higher application rates but can be explained

by the comparatively lower rates and absence of traffic in those studies. There was considerable recovery in the SCU treatment during the period 124 to 145 days, with coverage equal to the UF and urea treatments but inferior to both IBDU treatments after 145 days. Although this damage was relatively short term, the degree of severity of the injury would limit SCU use at these high rates; however, as noted in the establishment data when SCU was used at the lower .98 kg/a rate, it performed in a very acceptable manner.

CONCLUSIONS

The importance of soil in putting green mixtures is evident from the results obtained in these studies. Although nitrifying bacterial populations were found to be greater initially in the mixture with soil, these differences did not persist under field conditions. The inoculation of the soilless mixtures by the omnipresent nitrifying bacteria eliminated any differences in populations under actual putting green conditions. The more rapid establishment rate of turf observed in the soil mixture was associated with the higher initial populations. The IBDU in the mixtures with and without soil gave comparable results, but the mixture with soil had a more rapid rate of establishment. The increased establishment rate may be in part due to increased capillarity but most probably is due to a more effective utilization of N resulting from the reduced N losses through leaching.

Under the conditions of these studies SCU when applied at 2.93 kgN/a was not an effective source of N for putting green turf. The high potential for turf injury due to salt damage from the high percentage of particles that were broken or crushed by routine maintenance operations and concurrent excessive leaching losses would severely limit its use as the lysimeter area did not receive as much traffic as a putting green. The potential for injury would be even greater when used on golf course greens.

The uncontrolled release of N from SCU resulted in the high levels of $(NO_2^- + NO_3^-)$-N in the lysimeter soils as it did with the high NH_4^+-N levels.

From these studies we conclude that when soil was used in small amounts (10% by volume) it provided an improved media for turfgrasses. The higher initial cost of this media should be offset in a short time by the reduction in fertilizer leaching losses at an estimated 50%.

APPENDIX

TABLE 1. Microbial, Populations in Soilless and Soil Mixtures, Initially.

TRT	MPN/g		
	Nitrosomonas	*Nitrobacter*	*Denitrifier*
Soilless	0 a*	1300 a	1100 a
Soil	490 b	54000 b	4900 a

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 2. Accumulation of Nitrogen from UF, SCU, Urea, IBDU in the Soilless, and IBDU in the Soil Misture with Time; Laboratory Incubations.

TRT	Time, Weeks 0	1	2	4	8	16
	Urea-N, ppm					
UF	13.5 d*	0.0 d	0.0 b	0.0 a	1.4 a	4.4 ab
SCU	3.3 e	81.9 a	9.2 a	0.0 a	2.0 a	6.0 a
Urea	100.3 a	43.6 b	1.2 b	0.0 a	4.3 a	4.4 ab
IBDU	54.7 b	32.6 b	0.0 b	0.0 a	4.9 a	5.5 a
IBDU/Soil	36.1 c	16.1 c	0.0 b	0.0 a	1.0 a	2.7 b
	NH_4^+-N, ppm					
UF	9.8 a	17.9 b	21.4 b	30.7 c	17.1 a	2.8 b
SCU	8.9 b	21.7 b	102.6 a	115.0 a	12.6 a	4.3 a
Urea	8.9 b	55.8 a	100.6 a	88.9 b	29.2 a	4.2 a
IBDU	8.5 b	20.2 b	27.2 b	33.3 c	31.0 a	4.4 a
IBDU/Soil	7.7 c	15.0 b	22.8 b	5.3 d	12.6 a	3.5 ab
	$(NO_2^- + NO_3^-)$-N, ppm					
UF	2.3 ab	1.6 a	2.9 ab	3.7 bc	18.5 b	35.7 c
SCU	1.3 c	2.2 a	2.5 ab	2.4 c	2.2 b	103.3 a
Urea	1.2 c	2.7 a	2.7 ab	6.6 b	79.4 a	91.4 a
IBDU	1.4 bc	2.7 a	1.5 b	2.7 c	24.7 b	74.7 b
IBDU/Soil	2.7 a	3.6 a	6.8 a	36.1 a	70.8 a	104.2 a

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 3. Accumulation of Nitrogen from UF, SCU, Urea, IBDU in the Soilless, and IBDU in the Soil Mixture; Lysimeters.

TRT	Dates 9/1	9/8	9/15	9/22
	Urea-N, ppm			
UF	0.0 a*	0.0 b	0.0 a	0.0 c
SCU	0.0 a	0.0 b	1.8 a	0.0 c
Urea	0.0 a	0.9 b	3.3 a	0.0 c
IBDU	3.9 a	1.2 b	0.0 a	5.5 b
IBDU/Soil	0.0 a	12.8 a	0.5 a	11.4 a
	NH_4^+-N, ppm			
UF	4.6 a	16.9 ab	8.5 b	3.9 b
SCU	4.4 a	35.9 a	27.3 a	25.4 a
Urea	5.1 a	20.8 ab	12.5 b	4.7 b
IBDU	4.8 a	9.1 b	8.1 b	4.7 b
IBDU/Soil	4.8 a	6.3 b	5.3 b	5.2 b
	$(NO_2^- + NO_3^-)$-N, ppm			
UF	2.4 ab*	4.7 bc	5.3 bc	2.9 b
SCU	1.5 b	7.2 a	21.3 a	29.7 a
Urea	1.3 b	6.5 ab	6.3 bc	6.6 b
IBDU	2.7 ab	4.5 bc	8.4 b	8.7 b
IBDU/Soil	3.5 a	3.9 c	2.0 c	2.6 b

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 4. Accumulation of Nitrogen from UF, SCU, Urea, IBDU in the Soilless, and IBDU in the Soil Mixture in Leachate; Lysimeters.

TRT	Dates							
	9/1	9/8	9/15	9/22	9/29	10/6	10/20	10/27
	Urea-N, ppm							
UF	0.0 a*	0.6 a	0.0 a	0.2 a	0.0 a	0.0 a	0.0 a	0.0 a
SCU	0.0 a	9.2 a	0.0 a	0.2 a	0.0 a	0.0 a	0.0 a	0.0 a
Urea	0.0 a	1.4 a	0.0 a	0.2 a	0.0 a	0.0 a	0.0 a	0.0 a
IBDU	0.0 a	0.8 a	0.0 a	0.1 a	0.0 a	0.0 a	0.0 a	0.0 a
IBDU/Soil	0.0 a	0.6 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
	NH_4^+, ppm							
UF	0.0 a	0.4 ab	0.6 b	0.0 a	0.0 b	0.1 b	0.5 b	0.1 a
SCU	0.0 a	1.1 a	1.7 a	0.5 a	8.1 a	5.4 a	5.0 a	0.2 a
Urea	0.0 a	0.4 ab	0.7 b	0.2 a	0.9 b	0.2 b	0.6 b	0.2 a
IBDU	0.0 a	0.1 b	0.5 b	0.3 a	0.5 b	0.1 b	0.6 b	0.2 a
IBDU/Soil	0.0 a	0.2 ab	0.4 b	0.0 a	0.2 b	0.1 b	0.7 b	0.3 a
	$(NO_2^- + NO_3^-)$-N, ppm							
UF	0.0 a	0.4 ab	3.9 b	4.7 a	14.2 b	1.3 c	0.5 c	0.2 b
SCU	0.0 a	0.4 ab	12.1 a	13.0 a	94.3 a	38.3 a	76.0 a	10.3 ab
Urea	0.0 a	0.6 a	9.9 a	7.4 a	17.4 b	1.5 c	0.4 c	0.2 b
IBDU	0.0 a	0.1 b	2.2 b	2.5 a	19.5 b	12.1 b	30.2 b	17.1 a
IBDU/Soil	0.0 a	0.1 b	1.2 b	5.9 a	6.2 b	3.9 c	12.4 c	13.8 a

*Means within the same colum followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 5. Total Leachate Volume at Sample Date; Lysimeters

TRT	Dates							
	9/1	9/8	9/15	9/22	9/29	10/6	10/20	10/27
	Liters							
UF	0.2 a	4.5 ab	6.4 a	2.8 a	7.1 a	2.5 a	8.3 a	3.3 ab
SCU	0.5 a	5.3 a	6.3 a	3.0 a	7.2 a	2.5 a	8.1 a	2.5 b
Urea	0.2 a	2.5 b	5.8 a	2.6 a	6.6 a	2.4 a	8.6 a	4.6 a
IBDU	0.2 a	5.4 a	6.6 a	3.3 a	7.4 a	2.8 a	7.7 a	2.9 ab
IBDU/Soil	0.5 a	5.7 a	5.9 a	2.6 a	6.9 a	2.5 a	8.0 a	3.2 ab

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 6. Changes in Microbial Populations as Influenced by Soilless and Soil Mixture; Lysimeters

TRT	9/1	9/8	9/15	9/22
	MPN/g			
	Nitrosomonas			
Soilless	2433 a*	766667 a	2183333 a	47700000 a
Soil	840153 a	983333 a	108400000 a	3240000 a
	Nitrobacter			
Soilless	185983 a	191333 a	1403333 a	643333 a
Soil	983333 a	766666 a	1083333 a	2333333 a
	Denitrifier			
Soilless	44400 a	313667 a	57533333 a	79333333 a
Soil	603333 a	1210000 a	102000000 a	117333333 a

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 7. Soil Temperature at 10 cm Depth; Lysimeters

TRT	Dates							
	9/1	9/8	9/15	9/22	9/29	10/6	10/20	10/27
	°F							
UF	81.6 ab*	78.3 a	75.0 a	82.1 a	67.8 a	65.6 a	57.3 a	73.3 a
SCU	81.8 a	78.5 a	74.6 a	82.1 a	68.0 a	65.6 a	57.6 a	73.1 a
Urea	81.3 b	78.5 a	74.6 a	82.1 a	67.6 a	65.3 a	57.3 a	73.0 a
IBDU	81.8 a	78.3 a	74.6 a	82.3 a	68.0 a	65.6 a	57.6 a	73.0 a
IBDU/Soil	81.5 ab	78.5 a	74.3 a	82.0 a	68.0 a	65.6 a	57.6 a	73.0 a

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 8. Changes in Leachate pH as Influenced by UF, SCU, Urea, IBDU in the Soilless, and IBDU in the soil mixture; Lysimeters

	Dates							
TRT	9/1	9/8	9/15	9/22	9/29	10/6	10/20	10/27
	pH							
UF	4.8 a*	7.3 b	7.4 a	7.0 ab	7.1 ab	7.3 a	7.3 a	7.3 a
SCU	5.1 a	7.4 a	7.4 a	7.0 ab	6.8 b	6.6 b	7.1 b	7.2 a
Urea	5.3 a	7.2 b	7.2 a	6.9 b	7.2 a	7.2 a	7.3 a	7.3 a
IBDU	5.0 a	7.3 ab	7.5 a	7.1 a	7.1 a	7.2 a	7.3 a	7.3 a
IBDU/Soil	5.7 a	7.3 ab	7.5 a	7.0 ab	7.3 a	7.3 a	7.4 a	7.5 a

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

TABLE 9. Bentgrass Cover as Influenced by UF, SCU, Urea, IBDU in the Soilless, and IBDU in the Soil Mixture; Lysimeters

	Days							
	Establishment						Maintenance	
TRT	35	53	71	78	97	114	124	145
	%							
UF	8.3 c*	8.3 c	45.6 bc	50.0 bc	71.6 bc	75.0 bc	81.6 ab	88.3 ab
SCU	18.3 bc	21.6 bc	58.3 ab	65.0 ab	86.6 ab	90.0 ab	68.3 b	86.6 b
Urea	6.6 c	7.3 c	20.3 c	28.3 c	61.6 c	68.3 c	75.0 ab	80.0 b
IBDU	21.6 b	25.0 b	63.3 ab	68.3 ab	91.6 ab	94.6 a	96.0 a	96.6 a
IBDU/soil	50.0 a	55.0 a	83.3 a	89.0 a	93.3 a	97.3 a	98.6 a	97.6 a

*Means within the same column followed by the same small case letter do not differ significantly at the 5% level by the Duncan's multiple range test.

Nitrifying Bacterial Media

TABLE 10. Ammonium-calcium Carbonate Medium for *Nitrosomonas*

$(NH_4)_2\ SO_4$	.5 g
K_2HPO_4	1.0 g
$FeSO_4 \cdot 7H_2O$	.03 g
NaCl	.3 g
$MgSO_4 \cdot 7H_2O$	.3 g
$CaCO_3$	7.5 g

TABLE 11. Nitrite-calcium Carbonate Medium for *Nitrobacter*

KNO_2	.006 g
K_2HPO_4	1.00 g
NaCl	.3 g
$MgSO_4 \cdot 7H_2O$	.1 g
$FeSO_4 \cdot 7H_2O$	.03 g
$CaCO_3$	1.0 g
$CaCl_2$	.3 g

Both the *Nitrosomonas* and *Nitrobacter* media are prepared in the same manner. Each list of materials is dissolved in 1000 ml water. Three ml quantities of the media are transferred to individual test tubes, plugged with cotton and autoclaved at 15 lbs pressure for 15 minutes (2).

The nitrifier broths are very sensitive and easily contaminated. After much trial-and-error work, a simple method was established to prevent impure mixing of broths.

All materials used in nitrifier broths were completely pure and any suspected of contamination were discarded. Each chemical was tested separately for purity by mixing in water, autoclaving and Griess-Ilosvay reagent added. If negative tests resulted with all chemicals, the sources were considered pure and acceptable for use with the nitrifier broths.

Root Zone Component Properties

TABLE 12. Soil and Sand Texture and Identification

Texture and Classification	% Sand					
	V. Coarse	Coarse	Med.	Fine	V. Fine	Total
Cecil sandy loam member of the clayey, kalolinitic, thermic family of Typic Hapludults	2.1	12.9	17.3	21.3	8.0	61.7
Sand	9.1	43.2	34.7	10.4	0.8	98.1

Nitrogen Source Materials

TABLE 13. Fertilizer Properties

	N (%)
Urea	45
Ureaformaldehyde (UF)	38
Isobutylidine diurea (IBDU)	31
Sulfur-Coated urea (SCU)	37.1*

*Dissolution rate of 29.6% in 7 days. This term refers to that % of nitrogen which will dissolve in 38°C water during a 7 day period.

TABLE 14. Fertilization Regimes

	Kg N/are	Date
Urea	0.61/mo.	Sept.-Feb.
	0.37/mo.	March-Aug.
UF, IBDU, SCU	2.93	Sept.
	2.93	March

Lysimeter Volume Calculations

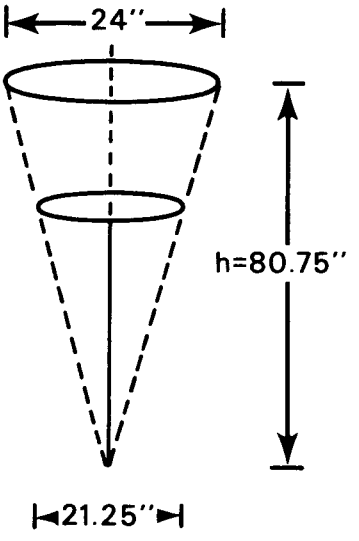


Figure 11. Lysimeter dimensions.

The volume of a cone is calculated according to the equation:

$$V_{cone} = 1/3\ r^2 h \qquad (A.1)$$

$$V_{cone} = V_{total} - V_1 \qquad (A.2)$$

$$t_{an}(8.46°) = 0.1486 = R/h \quad h = R/0.1486 = 12/0.1486 = 80.75 \text{ in}$$

$$V_{total} = 1/3 \quad (12 \text{ in})^2 \ (80.75) = 12176.813$$

$$V_1 = 1/3 \quad (10.625 \text{ in})^2 \ (80.75\text{-}9.25 \text{ in}) = 8453.08$$

$$V_{total} = 12176.813 - 8453.08 = 3723.73 \text{ in}^3$$

LITERATURE CITED

1. Alexander, M. 1965. Most-Probable-Number Method for Microbial Populations. In C.A. Black (ed.) Method of Soil Analysis. Part 2. Agronomy 9:1467-1472. Am. Soc. of Agron., Madison, WI.

2. Alexander, M. and F.E. Clark. 1965. Nitrifying Bacteria. In C.A. Black (ed.) Methods of Soil Analysis. Part 2. Agronomy 9:1477-1483.

3. Allen, S.E. and D.A. Mays. 1974. Coated and Other Slow-Release Fertilizer for Forages. Forage Fertilization. p. 559-582.

4. _____, G.L. Terman and H.G. Kennedy. 1978. Nutrient Uptake by Grass and Leaching Losses from Soluble and Sulfur-Coated Urea and KCL. Agron. J. 70:264-268.

5. Allsion, F.E. 1955. The Engima of Soil Nitrogen Balance Sheet. Adv. Agron. 7:213-250.

6. Anonymous. 1977. Instruction Manual for Nitrate Electrode. ORION Research, Inc. p. 4.

7. Arminger, W.H., I. Forges, Jr., R.E. Wagner and F.O. Lundstrom. 1948. Ureaformaldehyde: A Nitrogen Fertilizer of Continued Availability: Experiments with Turfgrass. Agron. J. 40:342-356.

8. Basaraba, J. 1964. Mineralization of Ureaformaldehyde Compounds at Different pH Levels and Temperatures. Canadian J. Soil Sci. 44:131-136.

9. Beard, J.B. 1973. Turfgrass: Science and Culture. Prentice-Hall, Inc., Englewood Cliffs, N.J.

10. Beaton, J.D., W.A. Hubbard and R.C. Speer. 1967. Coated Urea, Thirourea, Ureaformaldehyde, Hexamine, Oxamide, Glycoluril and Oxidized Nitrogen - Enriched Coal as Slowly Available Sources of Nitrogen for Orchardgrass. Agron. J. 59:127-133.

11. Benson, N. and R.M. Barnette. 1939. Leaching Studies with Various Sources of Nitrogen. Agron. J. 31:44-54.

12. Bredakis, E.J. and J.E. Steckel. 1963. Leachable Nitrogen from Soils Incubated with Turfgrass Fertilizers. Agron. J. 55:145-146.

13. Bremner, J.M. and D.R. Kenney. 1965. Steam Distillation Methods for Determination of Ammonium, Nitrate and Nitrite. Anal. Chim. Acta. 32:485-495.

14. Broadbent, F.E., G.N. Hill and K.B. Tyler. 1958. Transformation and Movement of Urea in Soils. Soil Sci. Am. Proc. 22:303-307.

15. Brown, K.W., R.L. Duble and J.C. Thomas. 1977. Nitrogen Losses from Golf Greens. USGA Greens Section Record. 15(1):5-7.

16. _____, _____ and _____. 1977. Influence of Management and Season on Fate of Nitrogen Applied to Golf Greens. Agron. J. 69:667-671.

17. Brown, M.A. and G.M. Volk. 1966. Evaluation of Ureaformaldehyde Fertilizer Using Nitrogen-Labeled Materials in Sandy Soils. Soil Sci. Soc. Am. Proc. 30:278-281.

18. Byrne, T.G. and O.R. Lunt. 1962. Ureaformaldehyde Controlled Available Fertilizers. Calif. Agric. 16:10-11.

19. Calhoun, C.R. and E.C. Roberts. 1969. Artificial Soil Mixtures for Putting Greens. Agron. Abstr. 1969:52.

20. Daniel, W.D. 1975. Slow-Release Isobutylidene Diurea - Promising New Tests. Weeds, Trees and Turf. January, 14-62.

21. Daniel, W.H. and N.R. Goetze. 1960. Heavy Nitrogen Fertilization of Cool-Season Turf Grasses. Agron. Abstr. 1960:69.

22. Davis, R.R. 1965. Forms of Nitrogen for Fertilizing Kentucky Bluegrass in Ohio. Golf Course Reporter. 33(5):42-50.

23. Duble, R.L. and K.W. Brown. 1973. Environmental Concerns for the Golf Superintendent. USGA Greens Section Record. 11(6):6-10.

24. Duich, J.M. and H.B. Musser. 1958. A Response of Creeping Bentgrass Turf under Putting Green Management to Urea-Form and Other Nitrogenous Fertilizers. Agron. Abstr. 1958:64.

25. Edwards, D.M., P.E. Fischback and L.L. Young. 1972. Movement of Nitrates under Irrigated Agriculture. ASAE Trans. 15(1):73-75.

26. Ellis, B.G. 1969. Factors Affecting the Accumulation of Nitrates in Soil, Water and Plant. Annu. Progr. Rep. Project 1042, Michigan State Univ.

27. English, K.R., R.H. Miller and P.R. Henderlong. 1974. Nitrogen Loss through 'USGA Golf Green' Type Soil Columns Related to Source and Frequency of Application. Agron. Abstr. 1974:98.

28. Focht, D.D. and H. Joseph. 1973. An Improved Method for the Enumeration of Denitrifying Bacteria. Soil Sci. Soc. Am. Proc. 37:698-699.

29. Giordano, P.M. and J.J. Mortvedt. 1970. Release of Nitrogen from Sulfur-Coated Urea in Flooded Soil. Agron. J. 62:612-614.

30. Goetze, N.R. and W.H. Daniel. 1957. Turf Quality as Influenced by Nitrogen Fertilization. Agron. Abstr. 1957:77.

31. _____. 1962. Control of Nitrification by 2-Chloro-6 (Trichloromethyl) Pyridine. Soil Sci. 93(3):211-218.

32. Griffin, Holman M. 1978. Economics of Golf Course Maintenance. National Golf Foundation Information Sheet AG-3.

33. Hamamoto, A.D. 1966. Isobutylidene Diurea as Slow-Acting Fertilizer and the Studies in this Field in Japan. Proc. Fert. Soc. No. 90:1-77.

34. Hanson, A.A. and F.V. Juska. 1967. Effect of Nitrogen Sources, Rates and Time of Application on Performance of Kentucky Bluegrass Turf. Am. Soc. Hort. Sci. 90:413-419.

35. Hawes, D.T. and A.M. Decker. 1971. Response of 'Penncross' Bentgrass as Determined by Reflectance Readings and Rate of Coverage when Grown at Four Soil Temperatures and Fertilized with Two Nitrogen Sources at Three Rates. Agron. Abstr. 1971:47.

36. Hays, J.T. 1963. Fertilizers for Controlled Release of Nitrogen. Proc. 11th Ann. Calif. Fert. Cong. p. 18-28.

37. _____ and W.W. Haden. 1965. Soluble Fractions of Ureaforms-Nitrification, Leaching and Burning Properties. Agron. Abstr. 1965:45.

38. Heilman, M.D., J.R. Thomas and L.N. Namken. 1966. Reduction of Nitrogen Losses under Irrigation by Coating Fertilizer Granules. Agron. J. 58:77-80.

39. Hughes, T.D. 1975. Release of Nitrogen in Soil from Isobutylidene Diurea. Agron. Abstr. 1975:99.

40. _____. 1976. Nitrogen Release from Isobutylidene Diurea: Soil pH and Fertilizer Particle Size Effects. Agron. J. 68:103-106.

41. Ishizuka, Y. and H. Takagishi. 1959. Studies on the Ureaformaldehyde, "Ureaform," as Nitrogenous Fertilizer. 1. Ammonification and Nitrification Processes of Various Ureaforms. J. Sci. Soil Manure, Japan. 29(1):494-500.

42. Jagschitz, J.A. and C.R. Skogley. 1965. Turfgrass Response to Dacthal and Nitrogen. Agron. J. 57:35-38.

43. Jones, M.B., J.E. Street and W.A. Williams. 1974. Leaching and Uptake of Nitrogen Applied to Annual Grass and Clovergrass Mixtures in Lysimeters. Agron. J. 66:256-258.

44. _____, C.C. Delwiche and W. A. Williams. 1977. Uptake Losses of Nitrogen Applied to Annual Grass and Clovergrass Mixtures in Lysimeters. Agron. J. 69:1019-1023.

45. Juska, F.V. and A.A. Hanson. 1967. Effect of Nitrogen Sources, Rates and Time of Application on the Performance of Kentucky Bluegrass Turf. Am. Soc. Hort. Sci. Proc. 90:413-419.

46. _____, _____, and A.W. Hovin. 1970. Growth Response of Merion Kentucky Bluegrass to Fertilizer and Lime Treatments. Agron. J. 62:25-27.

47. Kenney, D.R. and J.M. Bremner. 1967. Determination and Isotope-Ratio Analysis of Different Forms of Nitrogen in Soils:7. Urea. Soil Sci. Soc. Am. Proc. 31:317-321.

48. Kilian, K.C. 1964. Use of Ureaformaldehyde and Other Slowly Available Forms of Nitrogen for Grass. Ph.D. Thesis. Univ. of Wisconsin. Univ. Microfilms. Ann Arbor, MI, Diss. Abstr. 24:3485.

49. _____, O.V. Attoe and L.E. Englebert. 1966. Ureaformaldehyde as Slowly Available Form of Nitrogen for Kentucky Bluegrass. Agron. J. 58:204-206.

50. Kinbacher, E.J. and R.C. Sherman. 1976. Utilization of Nitrogen from Various Nitrogen Carriers by Turfgrass. Agron. Abstr. 1976:91.

51. Ledeboer, F.B. and C.R. Skogley. 1973. Effects of Various Nitrogen Sources, Timing and Rates on Quality and Growth Rate of Cool Season Turfgrass. Agron. J. 65:243-246.

52. Lorenz, O.A., B.L. Weir and J.C. Bishop. 1974. Effect of Controlled-Release Nitrogen Fertilizers on Yield and Nitrogen Absorption by Potatoes, Cantalopes and Tomatoes. J. Am. Soc. Hort. Sci. 97(3):334-337.

53. Lunt, O.R. 1968. Modified Sulfur-Coated Granular Urea for Controlled Nutrient Release. Int. Congr. Soil Sci. Trans. 9th (Adelaide, Australia). 3:377.

54. _____ and S.B. Clark. 1969. Properties and Values of 1, 1-Diureido Isobutane (IBDU) as a Long-Lasting Nitrogen Fertilizer. J. Agric. Food Chem. 17:1269-1271.

55. Markland, F.E. and E.C. Roberts. 1979. Influence of Nitrogen Fertilizer on Washington Creeping Bentgrass, (*Agrostis palustris* Huds.) 1. Growth and Mineral Composition. Agron. J. 61:698-700.

56. Mays, D.A. 1972. Response of Tifway Bermudagrass to Soluble and Slow-Release Nitrogen Sources. Agron. Abstr. 1972:146.

57. _____ and G.L. Terman. 1969. Sulfur-Coated Urea and Uncoated Soluble Nitrogen Fertilizers for Fescue Forage. Agron. J. 61:489-492.

58. Mazur, A.R. and T.D. Hughes. 1975. Nitrogen Transformations in Soil as Affected by the Fungicides Benomyl, Dyrene, and Maneb. Agron. J. 67:755-758.

59. McAlpine, V.M. 1979. Isobutylidene Diurea a Slowly Available Nitrogen for Turfgrass. Agron. Abstr. 1979:144-145.

60. Menn, W.G., K.W. Brown and J.R. Meton. 1972. Nitrate Mercury and Arsenic Leaching through Golf Green Profiles. Agron. Abstr. 1972:64.

61. Mitchell, W.H., A.L. Morehart, L.J. Cotnoir, B.B. Hesseltine and D.N. Langston, III. Methods on Leaching of Nitrogen in Golf Greens. Agron. J. 70:29-35.

62. Moberg, E.L., D.V. Waddington and J.M. Duich. 1970. Evaluation of Slow-Release Nitrogen Source on Merion Kentucky Bluegrass. Soil Sci. Soc. Am. Proc. 34:335-339.

63. Musser, H.B. and J.W. Duich. 1958. Response of Creeping Bentgrass Putting Green Turf to Ureaformaldehyde Compounds and Other Nitrogenous Fertilizers. Agron. J. 381-384.

64. Nash, R.G. and D.D. Johnson. 1962. Soil Texture Influence of Applied Nitrogen Recovery. Agron. J. 59:272-275.

65. Palmertree, H.D., E.L. Kimbrough and C.V. Ward. 1966. The Evaluation of Several Sources and Rates of Nitrogen for Fertilization of Established Roadside Turf. Agron. Abstr. 1966:39.

66. Pearson, R.W., F. Abruna and J. Vicente-Chandler. 1962. Effects of Lime and Nitrogen Applied on Downward Movement of Ca and Mg in Two Humid Tropical Soils of Puerto Rico. Soil Sci. Soc. Am. J. 93:77-82.

67. Peterson, L.A. and O.V. Attoe. 1965. Importance of Soil Nitrates in Determination of Need and Recovery of Fertilizer Nitrogen. Agron. J. 57:572-574.

68. Powell, A.J. and W.H. McKee, Jr. 1965. Effect of Different Nitrogen Sources on Winter and Spring Response of Cool Season Grass. Agron. Abstr. 1965:46.

69. Prasad, M. 1976. The Release of Nitrogen from Sulfur-Coated Urea as Affected by S. Moisture, Coating Weight and Method of Placement. Soil. Sci. Soc. Am. J. 40:134-136.

70. Prasad, R., G.B. Rajale and B.A. Lakhdive. 1971. Nitrification Retarders and Slow-Release Nitrogen Fertilizers. Adv. Agron. 23:337-383.

71. Rajale, G.B. and R. Prasad. 1970. Mineralization of Slow Release Nitrogen Fertilizers at Varying Moisture Levels. Fertilizer News (India). 15(5):38-39.

72. Raney, W.A. 1960. The Dominant Role of Nitrogen in Leaching Losses from Soils in Humid Regions. Agron. J. 52:563-566.

73. Skogley, C.R. and J.W. King. 1968. Controlled Release Nitrogen Fertilization of Turfgrass. Agron. J. 60:61-64.

74. Smalley, R.R., W.L. Pritchett and L.C. Hammond. 1962. Effects on Four Amendments on Soil Physical Properties and on Yield and Quality of Putting Greens. Agron. J. 54:393-395.

75. Smika, D.E., D.F. Heermann, H.R. Duke and A.R. Batchelder. 1977. Nitrate-N Percolation through Irrigated Sandy Soil as Affected by H_2O Management. Agron. J. 69:623-636.

76. Snyder, G.H., B.L. James, E.O. Burt and J.M. Davidson. 1973. Nitrogen Fertilization of Bermudagrass Turf in S. FL with Urea, Ureaformaldehyde and Isobutylidene Diurea. II. Nitrate Leaching. Agron. Abstr. 1973:62.

77. Steel, R.G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York, N.Y.

78. Stout, P.R. and R.B. Burau. 1975. The Extent and Significance of Fertilizer Build-up in Soils as Revealed by Vertical Distribution of Nitrogenous Matter between Soils and Underlying Water Reservoirs. In AAAS Symposium on Agriculture and The Quality of Our Environment. AAAS Publ. 85, Washington, D.C.

79. Tisdale, Samuel L. and Werner L. Nelson. 1975. Soil Fertility and Fertilizers. Macmillan Publishing Co., Inc., New York.

80. Volk, G.M. 1966. Efficiency of Fertilizer Urea as Affected by Method of Application, Soil Moisture and Lime. Agron. J. 58:249-253.

81. _____ and G.C. Horn. 1975. Response Curves of Various Turfgrasses to Application of Several Controlled-Release Nitrogen Sources. Agron. J. 67:201-204.

82. Waddington, D.V. 1975. Use of Sulfur-Coated Urea on Turfgrass. Agron. Abstr. 1975:174.

83. _____ and J.M. Duich. 1976. Evaluation of Slow-Release Nitrogen Fertilizer on Pennpan Creeping Bentgrass. Agron. J. 68:812-815.

84. _____ and E.L. Moberg. 1971. Turfgrass Fertilization with Isobutylidene Diurea. Agron. Abstr. 1971:51.

85. _____, _____, J.M. Duich and T.L. Watschke. 1976. Long-Term Evaluation of Slow-Release Nitrogen Sources on Turfgrass. Soil Sci. Soc. Am. Proc. 40:539-597.

86. Wagnet, R.J. 1977. Tracing Transformation of Urea Fertilizer During Leaching. Soil Sci. Soc. Am. J. 41:896-902.

87. Watschke, T.L. and D.V. Waddington. 1974. Effect of Nitrogen Source, Rate and Timing on Growth and Carbohydrates of Merion Blue. Agron. J. 66:691-696.

88. White, W.C. and J. Pesek. 1959. Nature of Residual Nitrogen in Iowa Soils. Soil Sci. Soc. Am. Proc. 23:39-42.

89. Wilkinson, J.F. 1977. Effect of Isobutylidene Diurea and Urea-formaldehyde Rate and Frequency of Application on Merion Kentucky Bluegrass. Agron. J. 69:657-661.

90. _____, D.P. Martin and R.W. Miller. 1975. Effect of IBDU and UF Rate, Date, and Frequency of Application on Merion Kentucky Bluegrass. Agron. Abstr. 1975:103.

91. Winsor, G.W. and M.I.E. Long. 1958. Development of Ureaformaldehyde Compounds as Nitrogenous Fertilizers. J. Sci. Food Agric. 9:185-194.

92. Wisniewski, A.J. and J.A. DeFrance. 1957. Results of Ureaformaldehyde Fertilization on Lawn and Fairway Turf. Agron. Abstr. 1957:79.

93. _____, _____ and J.R. Kellett. 1959. Results of Ureaformaldehyde Fertilizer on Lawn and Fairway Turf. Agron. J. 50:575-576.

94. Woolhouse, A.R. 1974. An Assessment of the Effect of a Slow-Release Nitrogen Fertilizer on Sports Turf. J. Sports Turf Res. Inst. 50:34-36.

95. Yee, J.Y. and K.S. Lowe. 1946. Nitrification of Ureaformaldehyde Reaction Products. Soil Sci. Soc. Am. Proc. 11:389-392.