AN EVALUATION OF SLOW RELEASE NITROGEN FERTILIZERS ON TURFGRASSES IN HAWAII

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INTRODUCTION

Turfgrasses require available nitrogen (N) throughout the growing season in order to provide maximum beauty and a uniform growth rate. To supply this N, frequent applications of low rates of soluble N or higher rates of less soluble N carriers may be used (Skogley and King 1968).

The value of slow release N fertilizers has long been recognized by homeowners, golf course superintendents and other turfgrass managers. The low solubility of the slow release N sources provides safety from foliar burn, reduces labor costs due to frequent applications, minimizes excessive N uptake and reduces N losses by volatilization and leaching (Lunt 1971).

Slow release N fertilizers may be classified into three categories: 1) natural organic materials, 2) synthetic organic compounds and 3) soluble N sources coated with various hydrophobic compounds.

Much work has been done in comparing various slow release fertilizers in greenhouse studies as well as in field situations where the seasons elicit noted differences. However, very little is known about the behavior of the currently available slow release N fertilizers on turfgrasses in Hawaii. The purpose of this study was to compare the turfgrass response and fertilizer efficiency of some slow release fertilizers on turfgrasses in Hawaii. These include natural organic, synthetic organic and coated materials tested at different rates and schedules.

REVIEW OF LITERATURE

Turfgrasses require N in the largest amount of any of the essential nutrients with the exception of carbon, hydrogen and oxygen. N is also readily leached from soils, therefore it is applied in largest amounts in turfgrass fertilization programs. N is a vital constituent of 1) the chlorophyll molecule, which is involved in photosynthesis; 2) amino acids and proteins, which compose a major portion of the protoplasm; 3) nucleic acids, which function in hereditary transfer of plant characteristics; and 4) enzymes and vitamins, which catalyze metabolic reactions within the plant. All are vitally important in the growth and development of turfgrasses. Bidwell (1974) and Salisbury and Ross (1969) describe biochemical roles of N in plant cells.

If no nutrient deficiency prevails, turfgrasses can contain from 3 to 6 percent total N on a dry matter basis (Beard 1973).

Beard (1973) lists a number of ways in which N nutrition can affect turf. These include effects on 1) shoot growth, 2) root growth, 3) shoot density, 4) color, 5) disease proneness, 6) heat, cold and drought hardiness, 7) recuperative potential and 8) composition of the turfgrass community. N can have substantial influences in the growth of turfgrasses. As the N level is increased from zero, there is an increase in growth rate of roots and shoots. Respiration rate is also increased. However, with increasing levels of N, this overall plant response does not continue. A point is reached in N growth stimulation where the carbohydrates available for protein synthesis becomes limiting. This results in reduced root growth and reduced levels of carbohydrates, while shoot growth continues to respond to higher N levels. Since shoots have priority over the roots for carbohydrates, excessive shoot growth can result in the death of a turfgrass due to a lack of a substantial level of carbohydrates in the roots.

TYPES OF CONTROLLED RELEASE FERTILIZERS

Natural Organic N Sources

N in natural organic nitrogen carriers is not readily water soluble. This quality of such fertilizers aids in the reduction of leaching. The release or availability of N is dependent on microorganism decomposition of the organic compounds or soil weathering through time. Decomposition is most rapid at temperatures favorable for microbial activity and is quite limited at soil temperatures below 12 C (Beard 1973).

Some of the features associated with natural organic carriers include 1) a medium slow release rate, 2) low water solubility, 3) minimum foliar burn potential, 4) higher cost per unit of N, 5) reduced loss of N by leaching, 6) lower N analysis, and 7) longer residual period. The duration and response of these materials was found to be between that of water soluble synthetic organics and the ureaformaldehydes (Musser and Duich 1958).

The natural organic N carriers can be grouped according to their origin into those that are by-products of 1) animals from meat and fish processing industries and 2) plant origin from the vegetable oil industries.

Activated sewage sludge is one of the more common natural organic N carriers used in turfgrass fertilization. Activated sewage products are made from sewage freed of grit and coarse solids by aerating in tanks after being innoculated with microorganisms. The resulting flocculated organic matter is withdrawn from the tanks, filtered and dried, then steam sterilized to kill weed seeds and harmful organisms. Milorganite^{R}[1] is an effective and widely used sewage sludge which also contributes significant amounts of micronutrients such as zinc, copper, manganese, molybdenum and boron to support plant growth (Ward and Thompson Jr. 1965).

Digested sewage sludge is not as desirable for application to turfgrasses due to a much lower nutrient content. Muller (1929) reports that supplemental N, P, and K may be necessary to achieve maximum response when using digested sewage sludge. Another problem associated with this material is that viable weed seeds may be present in it.

Waddington, Troll and Hawes (1964) have suggested the use of animal by-products such as dried blood, animal tankage, bone meal, fish meal and hoof and horn meal as natural organic N fertilizers. However, odor can be a problem with some of these materials such as animal tankages and meals, particularly those from fish.

Beard (1973) mentions seed meals such as cottonseed, castor pomace, and soybean meal as natural organic N carriers, however, these are not widely used. Another natural organic N carrier obtained from plants is corn gluten which is a by-product of carbohydrate extractions from corn and contains 8 percent N. The response of turf to this material is similar to that of Milorganite^{R}.

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[1] Product of the Milwaukee Sewage Commission, Mil., Wis. The use of trade names is for convenience only and does not constitute endorsement by the author, etc.

Synthetic Organic Slow Release Fertilizers

UREAFORMALDEHYDE

Considerable interest has developed in recent years with regard to ureaformaldehyde fertilizer as a slow release source of N for use in turfgrass culture.

Prasad, Rajale and Lakhdive (1971) presented a comprehensive study on ureaformaldehyde products. This product is commercially produced by reacting urea with formaldehyde. A series of compounds, ranging from relatively soluble to completely insoluble are possible, depending on the ratio of urea to formaldehyde in the final product. Yee and Love (1946) and Palmtree, Kimbrough and Ward (1966) have found that ureaformaldehyde usually contains 38 percent N which is largely in an insoluble, slowly available form.

In ureaformaldehyde, the N can be subdivided into three classes based on solubility: 1) cold water (25 C) insoluble (CWIN), 2) cold water soluble (CWSN) and 3) hot water insoluble (HWIN). The quantity of cold water insoluble N is the source of slowly available N. The rate at which the cold water insoluble N becomes available to plants depends on its quality as determined by its activity index:

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

Therefore the quantity and quality of cold water insoluble N determines the suitability of the ureaform products as fertilizers. A satisfactory ureaformaldehyde product should have an activity index of 40 or higher (Beard 1973 and Prasad et al. 1971).

Fuller and Clark (1947) found that the N release from ureaformaldehyde is dependent on the hydrolytic enzyme activity of soil microorganisms. N availability was found to be a function of the soil microorganism population as affected by the soil temperature, pH and nutrient level (Kralovec 1954).

In comparing ureaform compounds supplemented with P_2O_5 and K_2O versus complete ureaform based fertilizers such as 20-6-4 and 10-5-5, Wisniewski, DeFrance and Kollet (1959) found the latter to have the additional quality of providing a quick response to turf besides long seasonal feeding over straight ureaform supplemented with P_2O_5 and K_2O.

Mruck, Wisniewski and DeFrance (1957) conducted experiments with high levels of ureaformaldehyde. The rates that were used were 97.7, 195.4, 390.6, and 488.3 kg/ha of N with the 390.6 and 488.3 kg/ha rates being superior. Kilian, Attoe and Englebert (1966) suggest that topdressing Kentucky bluegrass with adequate amounts of fertilizer mixtures containing 50 percent or more of their N as ureaformaldehyde will give good increases of yield of grass and promote a uniform growth during the season. They also suggest that rather heavy applications of ureaformaldehyde may be made that will supply the N needs of the grass for several years.

Brown and Volk (1966) evaluated ureaform fertilizer using N-15-labeled materials in sandy soils. These included labeled ammonium nitrate and labeled ureaform N on coastal bermudagrass. After 15 weeks a greater proportion of labeled ammonium nitrate was recovered in the plants than in labeled ureaform N. However, more labeled N was found in the soil after one year when ureaform was the source. This experiment illustrates the residual slow release characteristics of ureaform.

Hayes and Hayden (1966) conducted nitrification, leaching and burning properties studies with ureaformaldehyde and found that over 90 percent of the N in ureaform is combined urea N. The chemical combination of urea, even in the lowest condensates with ureaformaldehyde, results in decreased rates of nitrification and of leaching, as well as in greatly reduced burning properties. In a 15 week N mineralization study conducted by Bredakis and Steckel (1963), it was found that leachable N from soils incubated with turfgrass fertilizer was greatest in the first 3 week period and varied as follows in descending order: ammonium sulfate = urea, castor pomace, Milorganite, Uramite = Nitroform. In the 3 to 12 week period, leachable N varied as: Uramite = Nitroform, castor pomace = Milorganite in descending order. Ammonium sulfate and urea did not produce more leachable N after the third week.

In some instances the low recovery of N from ureaformaldehyde may have undesirable effects. In forage trials, Widdowson, Penny and Williams (1962) found nitrochalk superior to ureaformaldehyde in producing higher overall grass yields at the same rates. Kresge and Younts (1962) found that compared to ammonium sulfate and ammonium nitrate, the use of ureaformaldehyde resulted in more uniform seasonal distribution of yield and greater residual effect but caused lower N recovery in bluegrass forage. In an evaluation of tall fescue (*Festuca arundinacea* Schreb.) for lawn turf, Juska, Hanson and Hovin (1969) evaluated the performances of urea, ammonium nitrate and ureaformaldehyde. The plots receiving ammonium nitrate (as determined by visual observation) rated higher in turf quality than those receiving ureaformaldehyde at the same rate applied either in the spring or fall.

An experimental ureaformaldehyde (UFC) having less of its N in the hot water insoluble form and thus a higher availability index than the commercial one (UF) was developed by Chemicals and Phosphates Ltd., Haifa, Israel. The experimental ureaformaldehyde produced a higher N uptake by plants than the commercial one, indicated by a higher N recovery, both under leaching and non-leaching conditions (Hagin and Luiba Cohen 1976).

ISOBUTYLIDENE DIUREA (IBDU)

IBDU is a condensation product between urea and isobutyraldehyde in a 2:1 mole ratio (Prasad et al. 1971). It is being manufactured in large quantities in Japan by Mitsubishi Chemical Industries Ltd. Tokyo.

IBDU is sparingly soluble in water, has less concentration hazard, less hydroscopicity and a low caking tendency. Mitsubishi Chemical Industry has found that IBDU can be mixed with any other fertilizer except strongly acidic superphosphate. The rate of release of N for plant availability is strongly influenced by size and hardness of the granules (Hamamoto 1966). The rate of dissolution increases with reduced granule size, lowering of pH and soil moisture. Its rate of dissolution was not affected by microbial activity. Lunt and Clark (1969) found that plants make effective use of IBDU to pH ranges from below 5 to above 8. However, conversion of IBDU to urea and ammonium or nitrate does not occur under alkaline conditions. Lunt et al. (1969) also found that very high rates can be incorporated into the soil (up to 1562.6 kg/ha of N). This rate is 5 to 10 times higher than the safe rate of conventional fertilizers.

Most recently, Hughes (1976) conducted soil-IBDU incubation studies to determine the effects of soil pH and IBDU particle size on N release patterns. It was determined that the fertilizer particle size had pronounced effects on N release. The N release from IBDU was affected by soil pH shortly after fertilizer application, but this effect disappeared as soon as the NH_4^+ accumulation was exhausted by nitrifying organisms. The smallest diameter particles (0.6 - 0.7 mm) showed higher N recoveries at both pH values of 5.7 and 7.4 while the larger particles resulted in lower N recoveries.

Coated Slow Release Fertilizers

Many attempts have been made to achieve the objectives of the controlled release concept. Fertilizer granules of urea or ammonium nitrate were coated with inert, water resistant coatings or membranes. These include various polymeric substances such as polyethylene, acrylic, acetate and other resins, waxes and paraffins. Also included are gums, tars, pitches, asphaltic substances and others (Prasad et al. 1971).

Perhaps the earliest work done with coated fertilizer materials was by Oertli and Lunt (1962). In their findings, the rate of release from coated granules of ammonium nitrate was influenced by coating thickness and temperature, but was not significantly increased by soil pH and microbial activity. Lunt and Oertli (1962) also demonstrated that the technique of coating soluble granular fertilizers for controlling the rate of mineral transfer to the soil is a promising and interesting tool for dealing with a number of management problems such as excessive leaching losses, placement hazards and labor costs associated with repeated applications of fertilizers.

Ahmed et al. (1963) found that capsulation of fertilizer with polyethylene film gave significant increases in yield of corn. The rate of release was directly related to temperature, number of pinholes per capsule and vapor pressure lowering of water by the fertilizer.

Dahnke et al. (1963) reported that coating ammonium sulfate granules with paraffin wax, followed by pelleting significantly increased the N recovery by corn but did not increase yield. Capsulated fertilizers also gave more uniform growth of Kentucky bluegrass through the season than noncapsulated fertilizers.

In doing research with resinous materials, Brown, Luebs and Pratt (1966) found that resin coatings are very effective in controlling the availability of N from applied urea in moist soil. Release rates are controlled by the thickness of the coating and temperature of the medium. Heilman, Thomas and Namken (1966) reported that resin coated ammonium nitrate was more efficient than uncoated ammonium nitrate at the same rates in increasing forage yields and N content of bluegrass.

SULFUR COATED UREA

The development of sulfur coated urea by the Tennessee Valley Authority is discussed by Rindt, Blouin and Gestinger (1968). At TVA, several studies of controlled release fertilizers have been made. The most extensive study was conducted on the use of sulfur to coat water soluble fertilizers, particularly urea. Sulfur is considered a promising coating agent for several reasons. It is inexpensive as compared with polymeric materials such as polyethylene and polyurethane or natural resins. It is easily handled in the molten state used in coating granules or prills. Also, it may have additional value on sulfur deficient soils.

The TVA process for the manufacture of SCU is simple. The coating is carried out in a rotary pan in which fertilizer granules are sprayed with molten sulfur from an air atomizing nozzle. In a second pan, a wax sealant which contains about 0.5 percent coal-tar oil is applied to the granules to kill microorganisms that might break down the coating and for ease of handling and flowability (Porter 1971).

Allen, Hunt and Terman (1971) reported that dissolution of SCU increased greatly with higher temperatures of cropping or incubation. Also, dissolution rates of SCU granules were decreased with heavier coating with sulfur, by inclusion of 0.5 percent coal-tar oil microbicide in the coating, and by surface application as compared to incorporating it into the soil.

Because of its slow release properties, Allen, Mays and Terman (1968) found that the chief effect of using sulfur coated urea was to delay forage production until later in the season. Better quality forage and more even yields per cutting was also a result of the use of sulfur coated urea as compared to ammonium nitrate. Furthermore, very high rates of sulfur coated urea gave maximum yield response with no foliar burn when applied to a bermudagrass turf while uncoated urea at the same high rates caused serious foliar burn.

Yield trials involving fescue forage exhibited higher first cutting yields with ammonium nitrate and urea as compared to higher later cutting yields with sulfur coated urea (Mays and Terman 1962). Allen and Mays (1971) found that sulfur coated urea gave more uniform uptake of N and a higher yield of bermudagrass forage than uncoated urea over a 16 week period. Finally Davies (1973) found that a single spring application of sulfur coated urea gave similar or superior dry matter yields of grass and N recovered in the grass to those from split applications of ammonium nitrate. Sulfur coated urea also gave higher grass dry matter yields and N recoveries than ureaformaldehyde.

Comparative Studies

Some of the earlier work done in evaluating slow release fertilizers was done by using natural organic N sources and ureaform fertilizers. Markland and Roberts (1969) conducted an evaluation of various N fertilizers on Washington creeping bentgrass. These N sources included: inorganic N sources, activated sewage sludge, processed tankage and ureaformaldehyde. Activated sewage sludge and the inorganic N sources performed better than processed tankage and ureaform.

Skogley and King (1968) compared two experimental products. These were urea-impregnated petroleum wax products and prilled urea with a petroleum based coating. These were compared with prilled urea, processed tankage and ureaform. Based on turf quality, yield of N content of clippings, and efficiency of N usage, the experimental products were superior to the standard materials. Later studies by Moberg, Waddington and Duich (1970) compared the more recent slow release fertilizers such as IBDU, ADM (a coated urea) and Urex (a urea paraffin) in Pennsylvania. They found that IBDU and Urex resulted in the best color and highest N recovery over the other treatments (ureaform and activated sewage sludge were included in the test). Further slow release comparison experiments were conducted in Hawaii by Boonduang, Kanehiro and Murdoch (1972) who reported that osmocote, SCU and IBDU were equal and most effective in producing the highest total N uptake by "Sunturf" bermudagrass. Sewage sludge and Agriform were last in that order. Volk and Horn (1975) have evaluated the responses of turfgrasses to various controlled release N sources. These were SCU, IBDU, Milorganite^{R} and ureaform. SCU gave the most desirable type of response for summer fertilization followed by IBDU, Milorganite^{R} and ureaform. IBDU was superior to all other materials because it did not show the cold weather depression of latent N release exhibited by Milorganite^{R}, SCU and ureaform.

MATERIALS AND METHODS

Four different fertilizer materials were used in this study to determine their efficiency as slow release fertilizers. A soluble fertilizer material was included as a check.

The slow release N materials were: activated sewage sludge, sulfur coated urea, isobutylidene diurea and a ureaformaldehyde based fertilizer. A description of each of the fertilizer materials is given below.

Fertilizers

Activated sewage sludge (hereafter referred to as ASS). Orga-Nitro^R is a source of N from activated sewage sludge with an analysis of 6-2-4. The N in this material is divided into 2.25 percent from sludge and 3.75 percent from urea. P is present in the form of phosphoric acid which is derived from sludge while K is in the form of KCl.

Sulfur coated urea (hereafter referred to as SCU). Gold-N^R is a sulfur coated urea which is manufactured by Imperial Chemical Industries in the United Kingdom. This material contains 32 percent N, all of which is available for uptake by plants. This product also contains 30 percent sulfur.

Isobutylidene diurea (hereafter referred to as IBDU). Parex IBDU^R is a synthetic organic slow release source of N and contains 31 percent N by analysis. This material is strictly a N carrier as other elements are not present. It is slightly soluble in water and release of N is by dissolution. This product is produced by the Mitsubishi Chemical Company, Tokyo, Japan.

Ureaformaldehyde (hereafter referred to as UF). Greens King 50^R is a ureaformaldehyde based product with an analysis of 22-5-10. The N in this material is divided into three parts: 3 percent in the ammonical form, 13.5 percent in the ureaformaldehyde water insoluble form and 5.5 percent in the ureaformaldehyde water soluble form. The material also contains P in the form of ammonium phosphate and 10 percent K as KCl.

Soluble N. Turf $Supreme^R$ is a soluble source of nitrogen with an analysis of 16-6-8. This is a synthetic inorganic fertilizer material which contains N in the ammonical form, P as ammonium phosphate and K as KCl. The characteristics which are associated with this material are 1) high water solubility, 2) rapid initial plant response, 3) high foliar burn potential, 4) limited residual response of 4 to 6 weeks and 5) low cost per unit of N.

Except for Turf $Supreme^R$, which was applied at a rate of 73.2 kg N/ha monthly, all of the fertilizer materials were applied on three different schedules. The schedules include monthly, bimonthly and trimonthly applications as presented in Table 1.

Field Experiments

Two experiments were conducted simultaneously at different locations to evaluate the performances of the different N fertilizer sources and schedules.

One site was on a tee of common bermudagrass (Cynodon dactylon L.) located on the Leilehua Golf Course in Wahiawa, Oahu. The second was on a tee of "Tifgreen" bermudagrass (Cynodon dactylon x Cynodon

Table 1

Treatments

ASS	73.2 kg N/ha/1 month
ASS	146.5 kg N/ha/2 months
ASS	219.7 kg N/ha/3 months
SCU	73.2 kg N/ha/1 month
SCU	146.5 kg N/ha/2 months
SCU	219.7 kg N/ha/3 months
IBDU	73.2 kg N/ha/1 month
IBDU	146.5 kg N/ha/2 months
IBDU	219.7 kg N/ha/3 months
UF	73.2 kg N/ha/1 month
UF	146.5 kg N/ha/2 months
UF	219.7 kg N/ha/3 months

transvaalensis, Burtt-Davey) located on the Hawaii Kai Golf Course in Hawaii Kai, Oahu.

All of the treatments in Table 1 were initially applied on July 1, 1975. The monthly treatments were applied every 4 weeks thereafter on July 29, August 26, September 23, October 21 and November 18. The bimonthly treatments were applied every 2 months thereafter on August 26 and October 21. The trimonthly treatments were applied on July 1 and September 23.

The fertilizer treatments were applied in a randomized complete block design at each location with four replications at Leilehua Golf Course and two replications at Hawaii Kai Golf Course. The plots were 1.52 m. x 3.04 m. (5 ft. x 10 ft.) in size.

Standard maintenance practices of mowing twice a week at approximately 1.3 cm. and irrigating three times per week to provide approximately 4 cm. of water per week were carried out at both locations throughout the duration of the experiments.

Visual color ratings were recorded on all treatments every 2 weeks over a period of 24 weeks. The ratings were based on a scale of one to ten, with half units. Ratings of one and ten represented the lightest and darkest green color respectively. The data were analyzed as a combined experiment with rating dates as main plots and N sources and N schedules as subplots. Duncan's Bayesian LSD test (BLSD) was used to compare differences between main effect means as well as interaction effect means.

Glasshouse Experiments

A glasshouse experiment was conducted for the purposes of obtaining visual color ratings, dried clipping yields and to determine total N recovery.

Common bermudagrass (C. dactylon L.) was seeded in 15.24 cm (6 in) diameter pots on February 19, 1976 at a rate of 1 g of seed per pot. The potting mixture consisted of 50 percent volcanic trachite pumice and 50 percent soil. One gram of a 10-30-10 fertilizer and 2 g of KCl were incorporated into the mixture of each pot to provide good seedling establishment. The pots were irrigated three times per week and clipped weekly to a height of approximately 1.5 cm.

All of the treatments which included the monthly, bimonthly and trimonthly schedules were applied on April 1, 1976. The monthly treatments were applied thereafter on April 29, May 27, June 24, July 22, and on August 19. The bimonthly treatments were applied every 2 months thereafter on May 27 and on July 22. The trimonthly treatments were applied on April 1 and on June 24.

Clippings were forced air dried at 75 C and dry weights were obtained. The samples were then ground and analyzed for total N by the method of Cataldo, Schrader and Youngs (1974).

Visual color ratings were recorded on each clipping date using a scale from one to ten with half units. Ratings of one and ten represented the lightest and darkest green color respectively.

Yield and color data were taken over a period of 24 weeks which began on April 1, 1976 and ended on September 16, 1976.

Treatments were replicated four times in a randomized complete block design. Visual color ratings and dried clipping weights were analyzed as a combined experiment (LeClerg, Leonard and Clark 1962) having weekly dates as main plots and N sources and N schedules as subplots.

Total N content was analyzed separately for each schedule of application in a combined experiment over time. The monthly schedules were analyzed for N every week during the first month, while the bimonthly schedules were analyzed every 2 weeks for the first 2 months and the trimonthly schedules were analyzed every month for the first 3 months. The analysis for total percent N was repeated during the second 3 month period for the monthly and trimonthly schedules. The bimonthly schedules were analyzed every 2 weeks after its final application the start of the fifth month.

RESULTS AND DISCUSSION

Field Experiments

The average turf color ratings for the various N sources at different schedules are presented in Table 2.

At Hawaii Kai Golf Course, there were no significant differences among N sources. Each material performed extremely well with overall average ratings ranging from 8.9 to 9.3. Significant differences occurred among N schedules with trimonthly applications being superior to monthly applications. There were no significant differences in the N source by N schedule interaction, however, SCU and IBDU tended to have higher ratings at the trimonthly schedule than ASS or UF.

The performances of the individual materials varied considerably for the first 10 weeks as illustrated in Figure 1. ASS and SCU produced a very rapid greening response soon after initial applications then dropped in ratings after the fourth or fifth week. IBDU produced a slower but more consistent rise in performance due to its properties of being sparingly soluble in water (Hamamoto 1966). UF produced lower ratings until the eighth week when ratings began to rise and by the tenth week were equal to or superior to those of the other materials. After applying the monthly and bimonthly applications on the eighth week, all of the materials began to show increasing performances. By the tenth week, the ratings were consistently in the range of 9 and 10 and performed with excellence throughout the experiment.

From the color ratings of ASS, SCU and UF shown in Figure 1, it appears that these materials need to build up sufficient N reserves

Table 2

Turf color ratings* at two locations as influenced by four nitrogen sources applied at three application schedules (Avg. of 24 dates and 4 reps.).

		Application Schedule			
Location	N source	Monthly	Bimonthly	Trimonthly	Avg.
Hawaii Kai	ASS	9.1	9.1	9.3	9.2
	SCU	9.2	9.2	9.5	9.3
	IBDU	8.9	9.0	9.5	9.1
	UF	8.7	9.0	8.7	8.9
	Avg.	9.0 B**	9.1 AB	9.3 A	

		Application Schedule			
Location	N source	Monthly	Bimonthly	Trimonthly	Avg.
Leilehua	ASS	8.1	8.0	8.1	8.1
	SCU	8.4	8.1	8.0	8.2
	IBDU	7.8	8.1	8.5	8.1
	UF	7.9	7.8	8.3	8.0
	Avg.	8.0	8.0	8.2	

*Turf color ratings were based on a scale of 1 to 10 representing the lightest and darkest green color respectively.

**Nitrogen schedule means followed by the same upper case letter do not differ (P = .05) as determined by BLSD.

before consistent high performance levels can be obtained. Evidence for this is seen before the eighth week where the performance curves start to decline. The monthly and bimonthly applications made on the eighth week increased the performance of these materials.

The suppressed performance of UF was probably due to having a large portion of its N in the insoluble form and not enough in the soluble form for initial plant growth response. The low percentage of soluble N was readily utilized before the insoluble portion became available for plant uptake. As a result, low performance ratings were obtained for this material in the initial stages of the experiment. It appears however, that as UF was applied over a period of time, the insoluble fraction became available providing sufficient N for optimum turf color ratings. This behavioral pattern of ureaform based fertilizers is consistent with findings of Brown et al. (1966), Kilian et al. (1966) and others who obtained low N recovery from ureaformaldehyde at early dates but high recoveries at later dates.

In a similar fashion, turf color ratings for the different schedules of application varied with dates of rating. Significant differences occurred among N schedules during the first 10 weeks after initial application (Fig. 2). During this ten week period, the trimonthly schedules exhibited the highest ratings. Both the trimonthly and bimonthly schedules began a decline in performance from the fourth week after initial application until the eighth week. Color ratings for all application schedules increased 8 weeks after the initial application. For the monthly and bimonthly schedules, this increase was probably due to reapplication of fertilizers along with release of

Figure 1. Turf color ratings at the Hawaii Kai Golf Course at each date of rating as influenced by nitrogen sources

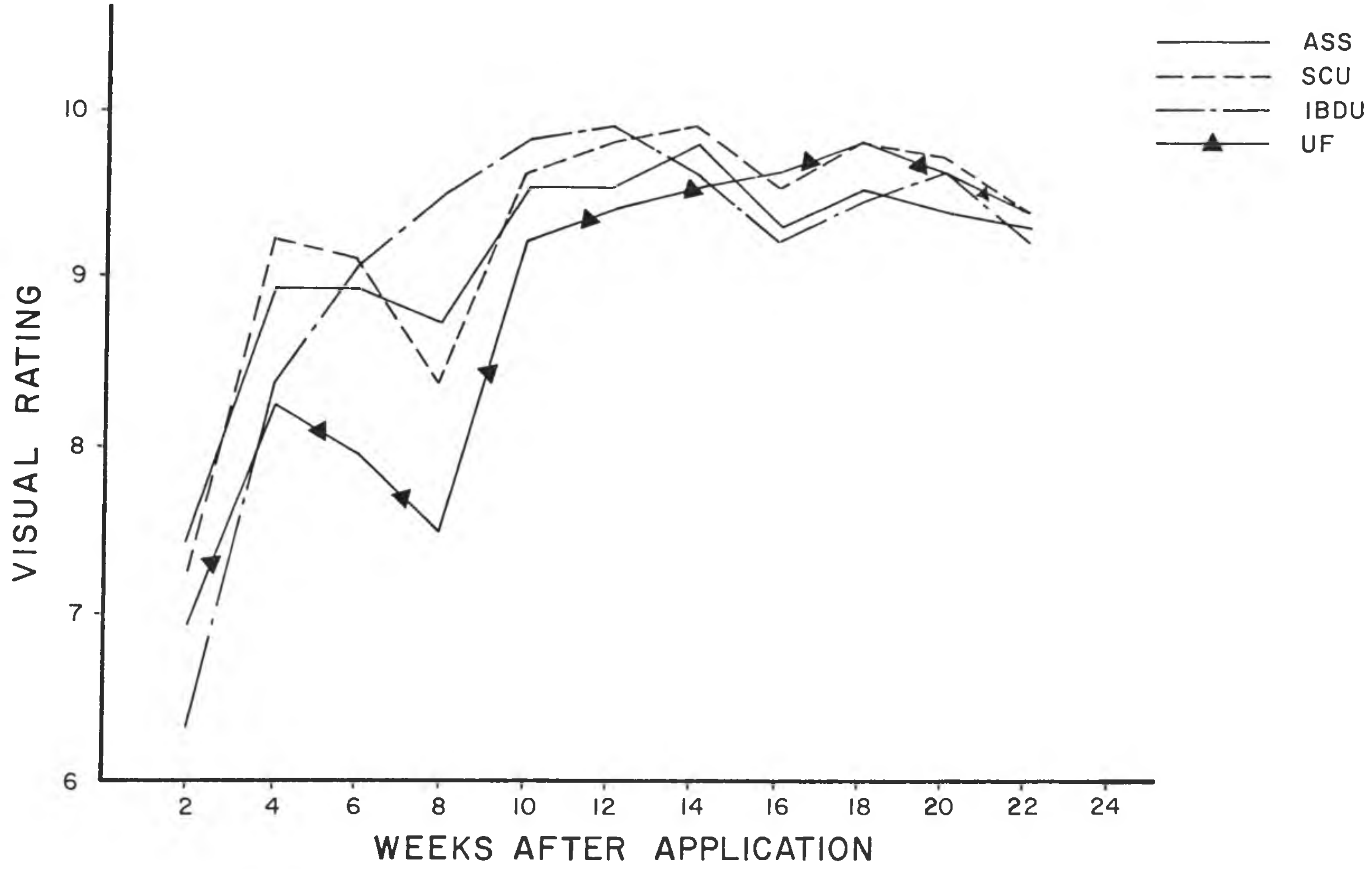
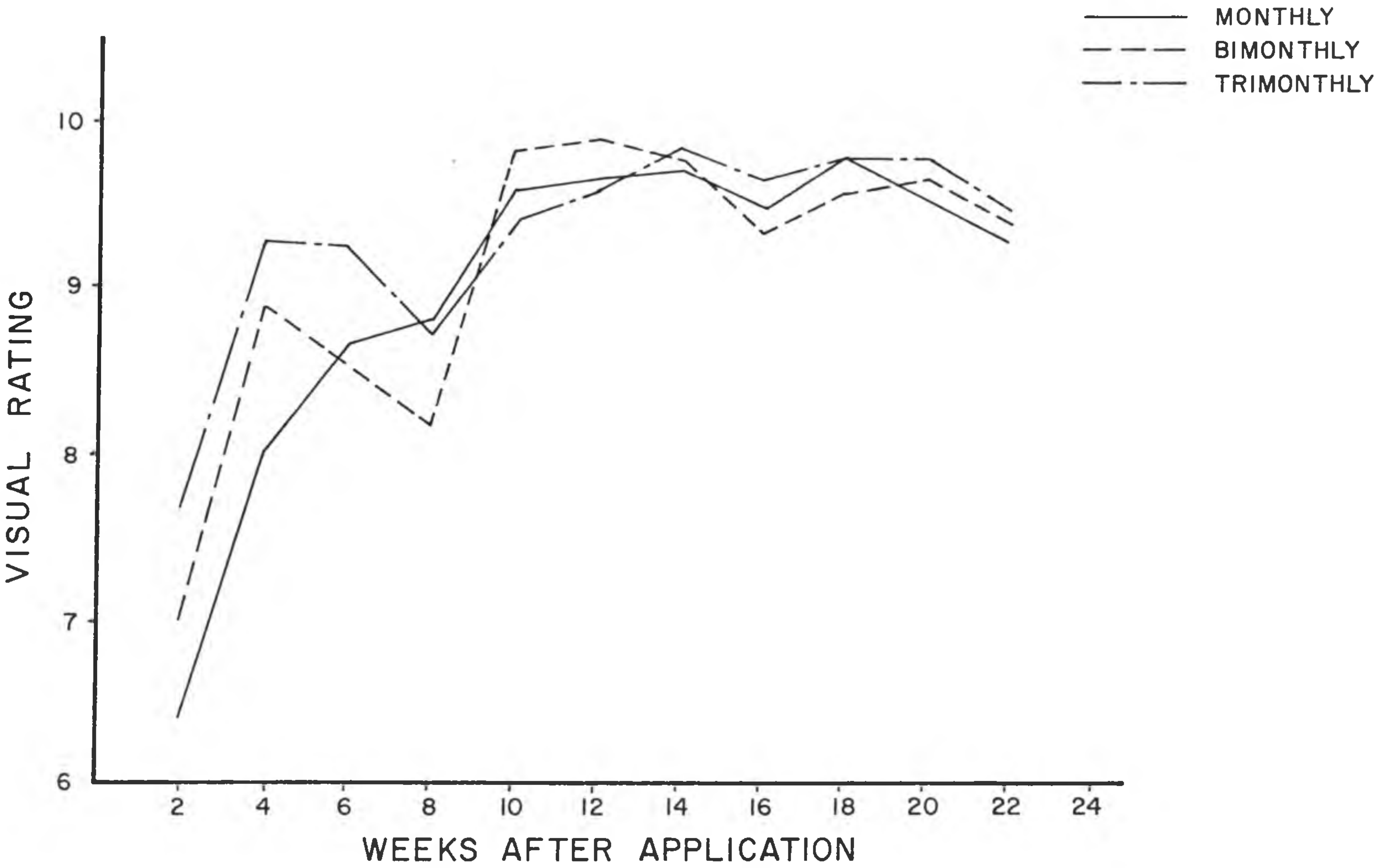

ASS
SCU
IBDU
UF
VISUAL RATING
10
9
8
7
6
2
4
6
8
10
12
14
16
18
20
22
24
WEEKS AFTER APPLICATION

Figure 2. Turf color ratings at the Hawaii Kai Golf Course at each date of rating as influenced by nitrogen schedules.


MONTHLY
BIMONTHLY
TRIMONTHLY
VISUAL RATING
10
9
8
7
6
2
4
6
8
10
12
14
16
18
20
22
24
WEEKS AFTER APPLICATION

insoluble N. The increase in color ratings for the trimonthly schedule at this date was thought to be due to insoluble N becoming available. The monthly schedule gave the lowest results for the first 6 weeks but showed a constant increase from the first week after initial application of treatments.

High average soil temperatures (27 C) in conjunction with an efficient irrigation system were perhaps the main factors which contributed to the excellent performances of these N fertilizers. The tee at this location was set aside strictly for this experiment and was not in use for the 6 month period of the experiment.

There were no significant differences among treatment effects at the Leilehua Golf Course (Table 2). The average color ratings ranged from 7.98 to 8.16 and were considered to be good. The lower averages than those in the Hawaii Kai test and nonsignificance of all of the treatment effects was perhaps attributable to the constant use of the tee at this location. The continual scarring of the turf surface by divets made rating the plots very difficult, and the actual differences may have been confounded by a majority of the scarred plots. Lower average soil temperatures (24 C) may have had a part in preventing these materials from performing at optimum levels. Finally, the tee consisted of common bermudagrass (C. dactylon L.) which was not as dense as the tee of "Tifgreen" (C. dactylon x C. transvaalensis Burt-Davey) bermudagrass at Hawaii Kai.

Greenhouse Experiments

The averages for effect of N treatments on visual ratings of turf quality are presented in Table 3. Significant differences occurred among N sources, N schedules and the interaction between N sources and N schedules. In general, at all rates, the best quality turf resulted from the application of IBDU. SCU was slightly poorer in performance followed by ASS and UF (Fig. 3).

The means of the turf scores for the three N schedules are illustrated in Figure 4. The monthly scheduled treatments resulted in best performances, followed by the bimonthly and trimonthly treatments respectively.

The N sources performed differently at the different schedules of application (Table 3). Lower ratings were obtained from application of ASS with each increasing interval between applications. IBDU produced highest color ratings at the trimonthly schedule than the other materials. Ratings for the trimonthly schedule of IBDU were superior to all other treatments except for SCU and ASS applied monthly. From Figure 5, it is obvious that IBDU performed very well at all scheduled applications. UF produced consistently lower turf color ratings at all application schedules. ASS and SCU produced high color ratings at the monthly schedule with much lower ratings at the bimonthly and trimonthly schedules. The reason for these differences are not readily apparent, however, this may be due to differences in the manner in which N is released from the different materials.

The initial response to IBDU and ASS was slower than for the other materials (Table 4). Three weeks after initial application, IBDU was giving responses equal to or better than all other materials and continued to do so throughout most of the experiment. SCU equalled IBDU in performance on the ninth, seventeenth and eighteenth week.

Table 3

Turf color ratings* in a greenhouse pot study as influenced by four nitrogen sources applied at three application schedules (Avg. of 24 dates and 4 reps.).

	Application Schedule			
N source	Monthly	Bimonthly	Trimonthly	Avg.
ASS	7.9 d**	7.1 f	6.9 g	7.3 C
SCU	8.2 bc	7.6 e	7.5 e	7.8 B
IBDU	8.4 a	8.3 ab	8.1 cd	8.2 A
UF	7.6 e	7.2 f	7.1 fg	7.3 C
Avg.	8.0 A	7.5 B	7.4 C	

*Turf color ratings were based on a scale of 1 to 10 representing the lightest and darkest green color respectively.

**Interaction means followed by the same lower case letter, nitrogen source or nitrogen schedule means followed by the same upper case letter do not differ (P = .05) as determined by BLSD.

Figure 3. Turf color ratings under greenhouse conditions as influenced by N sources (Avg. of 24 dates, 3 application schedules and 4 reps.).

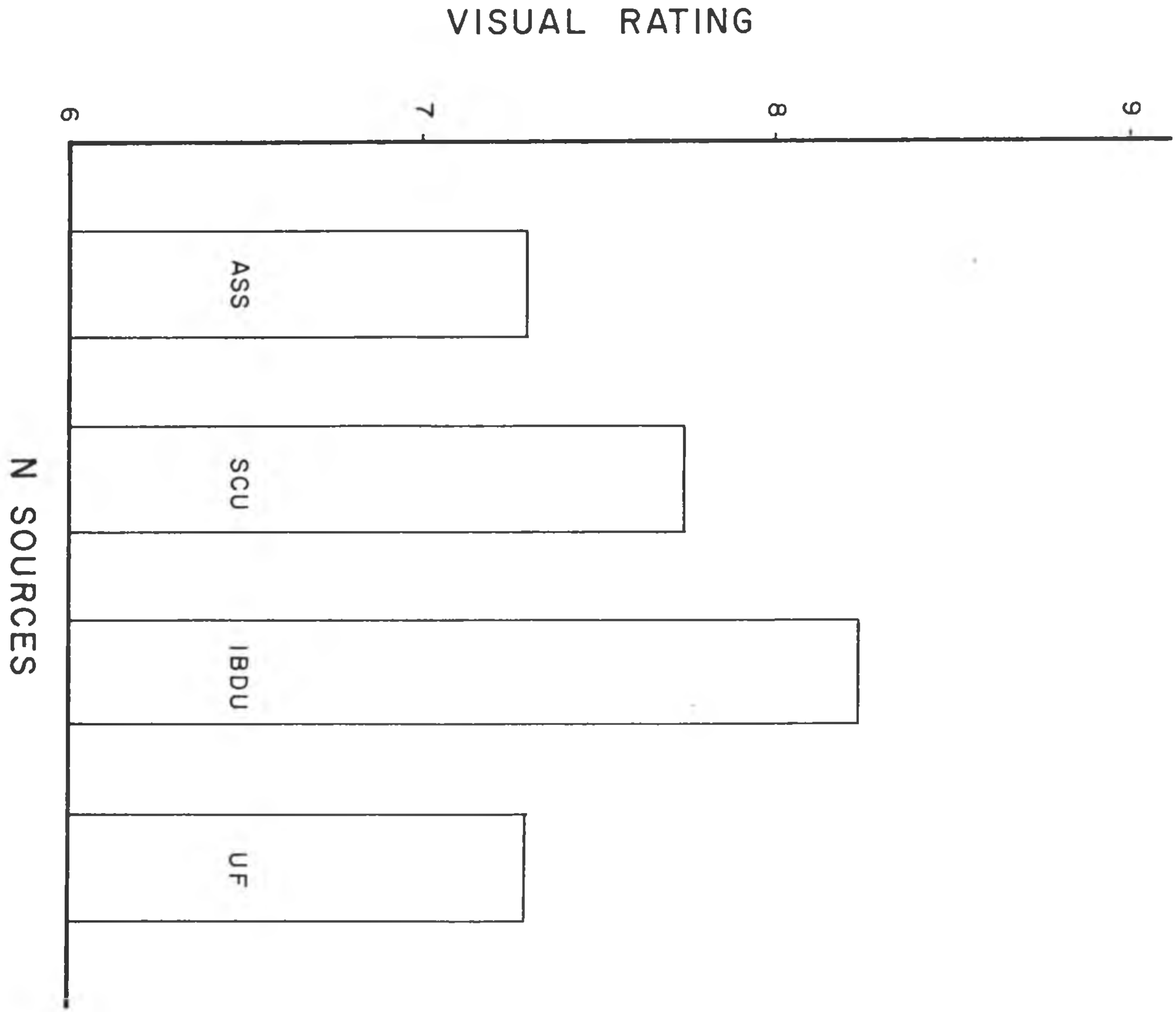
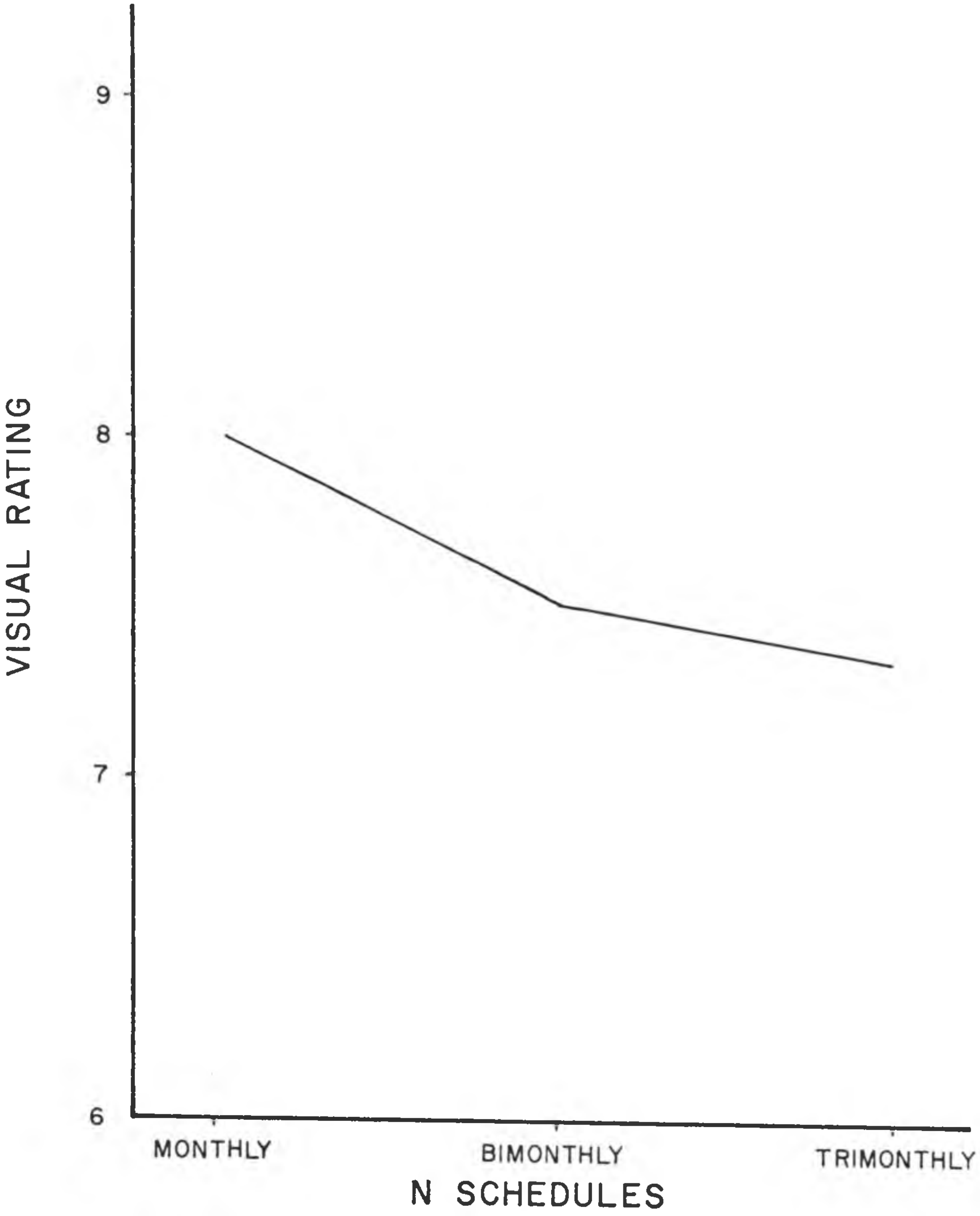

VISUAL RATING
6
7
8
9
N SOURCES
ASS
SCU
IBDU
UF

Figure 4. Turf color ratings under greenhouse conditions as influenced by nitrogen schedules (Avg. of 24 dates, 4 N sources and 4 reps.).


VISUAL RATING
9
8
7
6
MONTHLY
BIMONTHLY
TRIMONTHLY
N SCHEDULES

This result was due to the application of monthly and bimonthly treatments on the eighth and sixteenth week. ASS and UF did not produce very high results and their average scores were significantly lower than IBDU and SCU throughout the experiment.

The monthly scheduled treatments (Table 5) produced the highest ratings overall. The highest scores for these treatments were recorded one week after they were applied. These scores began to decline on the third week after application. The bimonthly schedules ranked second to the monthly schedules. Following initial application, the bimonthly scheduled treatments produced highest ratings on the second week (date 2), then began to decline in performance until the eighth week. The applications of the bimonthly scheduled treatments on the eighth and sixteenth week both resulted in similar score response patterns. The highest scores were obtained one week after applications were made and remained high for the next 4 weeks followed by a decline in performance during the next 4 weeks. The trimonthly scheduled treatments produced the highest average scores during the first five weeks after initial application followed by a decline in performance until the twelfth week. The second application of trimonthly treatments on the twelfth week resulted in a similar response pattern as that of the first 12 week period.

The mean values for each treatment averaged over four replications at each date are presented in Table 6. Significant differences occurred among treatments at each date.

Under greenhouse conditions, the duration of consistently high scores was dependent on the scheduled rate that was applied. Since

Figure 5. Turf color ratings under greenhouse conditions as influenced by nitrogen sources at different schedules (Avg. of 24 dates and 4 reps.).

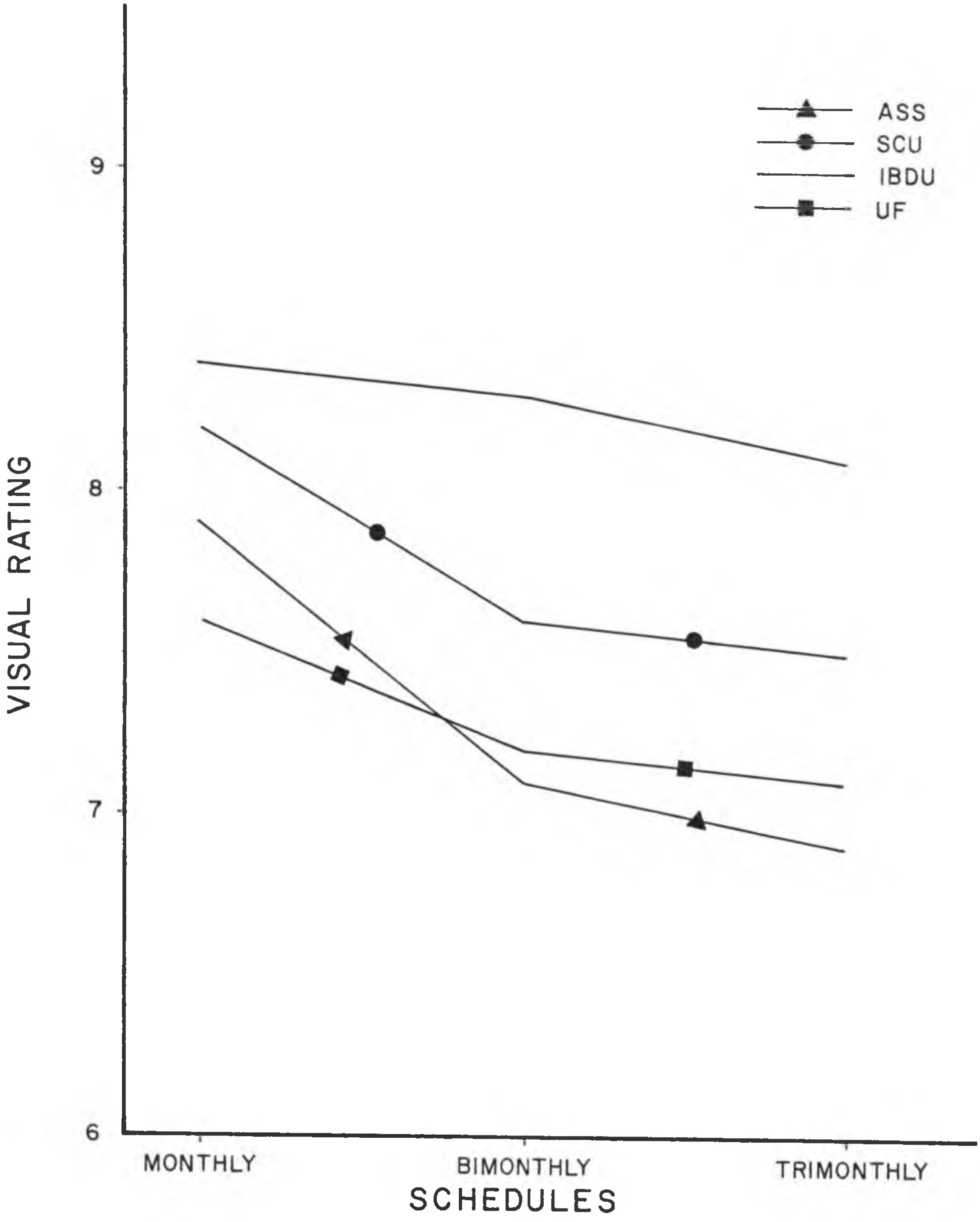

ASS
SCU
IBDU
UF
9
8
7
6
VISUAL RATING
MONTHLY
BIMONTHLY
TRIMONTHLY
SCHEDULES

Table 4

Turf color ratings* under greenhouse conditions as influenced by N sources at each date. (Avg. of 3 application schedules and 4 reps.).

	N Sources			
Weeks	ASS	SCU	IBDU	UF
1	6.5 b**	8.0 a	5.5 c	8.1 a
2	9.0 a	9.0 a	7.8 b	8.8 a
3	8.3 c	8.5 b	8.8 a	7.5 d
4	7.8 c	8.0 b	9.0 a	6.5 d
5	7.9 c	8.2 b	8.5 a	7.6 d
6	6.8 c	7.8 b	8.7 a	6.1 d
7	6.5 c	7.3 b	9.0 a	6.4 d
8	6.7 c	7.1 b	8.3 a	7.1 b
9	8.2 a	8.1 a	8.3 a	8.3 a
10	8.1 b	8.2 b	8.6 a	8.1 b
11	7.0 c	7.5 b	8.0 a	6.7 d
12	6.4 d	6.9 b	7.5 a	6.7 c
13	8.1 c	8.4 b	9.0 a	8.3 bc
14	7.8 c	8.3 b	9.0 a	7.8 c
15	7.4 c	8.1 b	8.4 a	7.2 d
16	7.1 c	7.5 b	8.2 a	6.6 d
17	8.6 bc	8.8 ab	8.8 a	8.5 c
18	8.7 b	9.1 a	9.2 a	8.2 c
19	7.2 c	8.1 b	8.5 a	7.4 c
20	6.2 d	7.3 b	8.2 a	6.8 c
21	6.3 c	7.1 b	7.9 a	7.1 b
22	6.1 c	6.9 b	7.9 a	6.9 b
23	5.9 c	6.4 b	7.6 a	6.4 b
24	5.5 d	5.8 c	7.2 a	6.1 b

*Turf color ratings were based on a scale of 1 to 10 representing the lightest and darkest green color respectively.

**Means in the same row followed by the same letter do not differ (P = .05) as determined by BLSD.

Table 5

Turf color ratings[*] under greenhouse conditions as influenced by N schedules at each date. (Avg. of 4 N sources and 4 reps.).

	N Schedules		
Weeks	Monthly	Bimonthly	Trimonthly
1	7.5 a[**]	7.3 b	7.4 ab
2	8.5 b	8.7 a	8.8 a
3	7.7 c	8.3 b	8.9 a
4	7.3 c	7.8 b	8.4 a
5	8.2 a	7.9 b	8.0 ab
6	8.7 a	6.3 c	7.1 b
7	8.2 a	6.3 c	7.4 b
8	7.5 a	6.9 b	7.4 a
9	8.9 a	8.8 a	6.9 b
10	9.1 b	9.4 a	6.2 c
11	7.7 b	8.4 a	5.8 c
12	6.9 b	7.4 a	6.3 c
13	9.2 a	6.9 b	9.3 a
14	8.7 b	6.1 c	9.8 a
15	7.7 b	6.7 c	9.0 a
16	7.3 b	6.8 c	8.0 a
17	9.0 a	9.0 a	7.9 b
18	8.9 b	9.8 a	7.8 c
19	7.8 b	8.5 a	7.1 c
20	7.1 b	7.5 a	6.7 c
21	8.3 a	6.9 b	6.1 c
22	8.1 a	6.8 b	5.9 c
23	7.7 a	6.4 b	5.6 c
24	7.1 a	6.0 b	5.3 c

[*] Turf color ratings were based on a scale of 1 to 10 representing the lightest and darkest green color respectively.

[**] Means in the same row followed by the same letter do not differ (P = .05) as determined by BLSD.

Table 6

Turf color ratings under greenhouse conditions
as influenced by N sources and N schedules
at each date (Avg. of 4 reps.).

	N Source					
	ASS N Schedule			SCU N Schedule		
Weeks	Monthly	Bimonthly	Trimonthly	Monthly	Bimonthly	Trimonthly
1	8.3 a*	8.1 ab	8.0 ab	8.1 ab	7.8 b	8.0 ab
2	9.0 a	9.0 a	9.0 a	8.9 ab	9.0 a	9.0 a
3	7.6 gh	8.5 cde	8.8 bcd	8.0 fg	8.5 cde	9.1 ab
4	7.0 fg	7.6 de	8.6 b	7.4 ef	8.0 cd	8.8 b
5	8.1 bcd	7.6 ef	7.9 de	8.3 abcd	8.0 cde	8.4 abc
6	8.8 ab	5.0 f	6.6 e	9.1 a	6.8 e	7.4 d
7	7.8 cd	5.4 g	6.5 e	8.1 bc	6.0 f	7.6 d
8	6.9 de	6.4 f	6.8 ef	7.5 bc	6.4 f	7.4 c
9	9.3 a	9.0 ab	6.3 f	9.0 ab	8.6 bc	6.8 e
10	9.4 abc	9.8 a	5.1 h	9.3 bc	9.6 ab	5.6 g
11	7.8 de	8.3 bc	5.0 i	7.9 cd	9.0 a	5.8 h
12	6.4 de	6.9 c	6.0 e	6.8 cd	7.6 b	6.4 de
13	9.3 a	5.9 d	9.3 a	9.1 a	6.9 c	9.1 a
14	8.4 d	5.1 f	10.0 a	8.9 c	5.9 e	10.0 a
15	7.3 c	5.9 e	9.1 a	8.3 b	6.5 d	9.5 a
16	6.8 de	6.8 de	7.8 b	7.6 b	6.5 ef	8.5 a
17	9.3 ab	9.1 abc	7.4 f	9.1 abc	9.0 abcd	8.1 e
18	9.1 bc	10.0 a	6.9 e	9.0 c	10.0 a	8.4 d
19	7.1 f	8.4 bc	6.1 g	8.1 cd	9.0 a	7.1 f
20	6.0 fg	6.6 de	5.9 g	7.1 c	7.8 b	6.9 cd
21	8.4 a	5.5 d	5.0 e	8.4 a	7.0 b	6.0 c
22	8.0 b	5.5 e	4.8 f	8.1 ab	6.9 c	5.6 e
23	7.6 b	5.5 ef	4.5 g	7.6 b	6.3 d	5.4 f
24	7.0 bc	5.1 ef	4.3 g	6.9 bc	5.5 e	5.0 f

Table 6 (continued)

	N Source					
	IBDU N Schedule			UF N Schedule		
Weeks	Monthly	Bimonthly	Trimonthly	Monthly	Bimonthly	Trimonthly
1	5.6 c	5.1 d	5.6 c	8.0 ab	8.1 ab	8.1 ab
2	7.5 e	7.9 de	8.1 cd	8.5 bc	9.0 a	9.0 a
3	8.3 ef	8.9 abc	9.3 a	6.9 i	7.4 h	8.4 def
4	8.4 bc	9.3 a	9.5 a	6.4 i	6.5 h	6.8 gh
5	8.3 abcd	8.6 a	8.5 ab	8.1 bcd	7.3 f	7.4 f
6	8.8 ab	8.4 bc	9.0 a	8.0 c	5.0 f	5.3 f
7	9.3 a	8.4 b	9.4 a	7.5 d	5.5 g	6.1 ef
8	8.5 a	7.9 b	8.4 a	7.3 cd	6.9 de	7.1 cde
9	8.5 c	8.6 bc	7.8 d	8.9 abc	9.1 a	7.0 e
10	9.1 c	9.3 bc	7.4 e	8.5 d	9.0 c	6.8 f
11	8.5 b	9.0 a	6.4 fg	6.6 f	7.4 e	6.1 gh
12	8.0 ab	8.4 a	6.1 e	6.4 de	6.9 c	6.8 cd
13	9.3 a	8.4 b	9.4 a	9.0 a	6.5 c	9.4 a
14	9.3 bc	8.0 d	9.6 ab	8.1 d	5.5 ef	9.8 a
15	8.3 b	7.9 b	9.1 a	6.9 d	6.5 d	8.1 b
16	8.5 a	7.5 bc	8.5 a	6.4 ef	6.3 f	7.1 cd
17	9.0 abcd	8.6 d	8.9 bcd	8.8 cd	9.4 a	7.3 f
18	9.1 bc	9.5 b	9.0 c	8.3 d	9.5 b	6.9 e
19	8.4 bc	8.8 ab	8.3 c	7.6 e	7.8 d	6.8 f
20	8.3 a	8.5 a	7.8 b	6.9 cd	7.3 c	6.3 ef
21	8.4 a	8.3 a	7.1 b	8.3 a	6.9 b	6.3 c
22	8.5 a	8.1 ab	7.0 c	7.9 b	6.6 cd	6.3 d
23	8.3 a	7.8 b	6.8 c	7.1 c	6.3 d	5.8 e
24	7.8 a	7.3 b	6.6 c	6.8 c	6.0 d	5.5 e

*Means in the same row followed by the same letter do not differ (P = .05) as determined by BLSD.

monthly scheduled treatments were most frequently applied, they resulted in the best overall performances. The supply of N for the bimonthly and trimonthly scheduled treatments were greatly reduced within a month, probably as a result of high average greenhouse temperatures (35 C).

The means of the dry clipping yields for the various N sources and N schedules are presented in Table 7.

IBDU gave the highest yields, SCU was next followed by ASS and UF in descending order (Fig. 6).

The monthly scheduled treatments resulted in significantly higher average yields than the bimonthly and trimonthly scheduled treatments, which were ranked equally (Fig. 7).

All scheduled treatments of IBDU and monthly scheduled treatments of ASS and SCU gave the highest clipping weight yields. The bimonthly and trimonthly scheduled treatments of SCU gave slightly lower yields, followed by the bimonthly and trimonthly schedules of ASS. All schedules of UF resulted in lowest clipping weight yields (Fig. 8).

The performance of the various N sources and N schedules at each date are presented in Tables 8, 9, and 10 respectively. From Table 8 it can be seen that IBDU produced highest yields at almost every date after the first 3 weeks. SCU and ASS produced highest yields for the first 3 weeks after initial application. The initial turf responses were immediate for all N sources except IBDU. However, 3 weeks after initial application, IBDU was giving yields that were equal to or higher than all of the other N sources and continued to do so throughout the experimental period of 6 months. SCU produced the highest clipping

Table 7

Turf dry clipping weights* from a greenhouse pot study as influenced by four nitrogen sources applied at three application schedules (Avg. of 24 dates and 4 reps.).

	Application Schedule			
N source	Monthly	Bimonthly	Trimonthly	Avg.
ASS	0.6 ab**	0.5 cde	0.4 de	0.5 C
SCU	0.6 a	0.5 bcd	0.5 bc	0.6 B
IBDU	0.6 a	0.6 ab	0.6 a	0.6 A
UF	0.4 e	0.4 e	0.4 e	0.4 D
Avg.	0.6 A	0.5 B	0.5 B	

*Dry clipping weights measured in grams.

**Interaction means followed by the same lower case letter, nitrogen source or nitrogen schedule means followed by the same upper case letter do not differ (P = .05) as determined by BLSD.

Figure 6. Turf dry clipping yields under greenhouse conditions as affected by N sources (Avg. of 24 dates, 3 application schedules and 4 reps.).

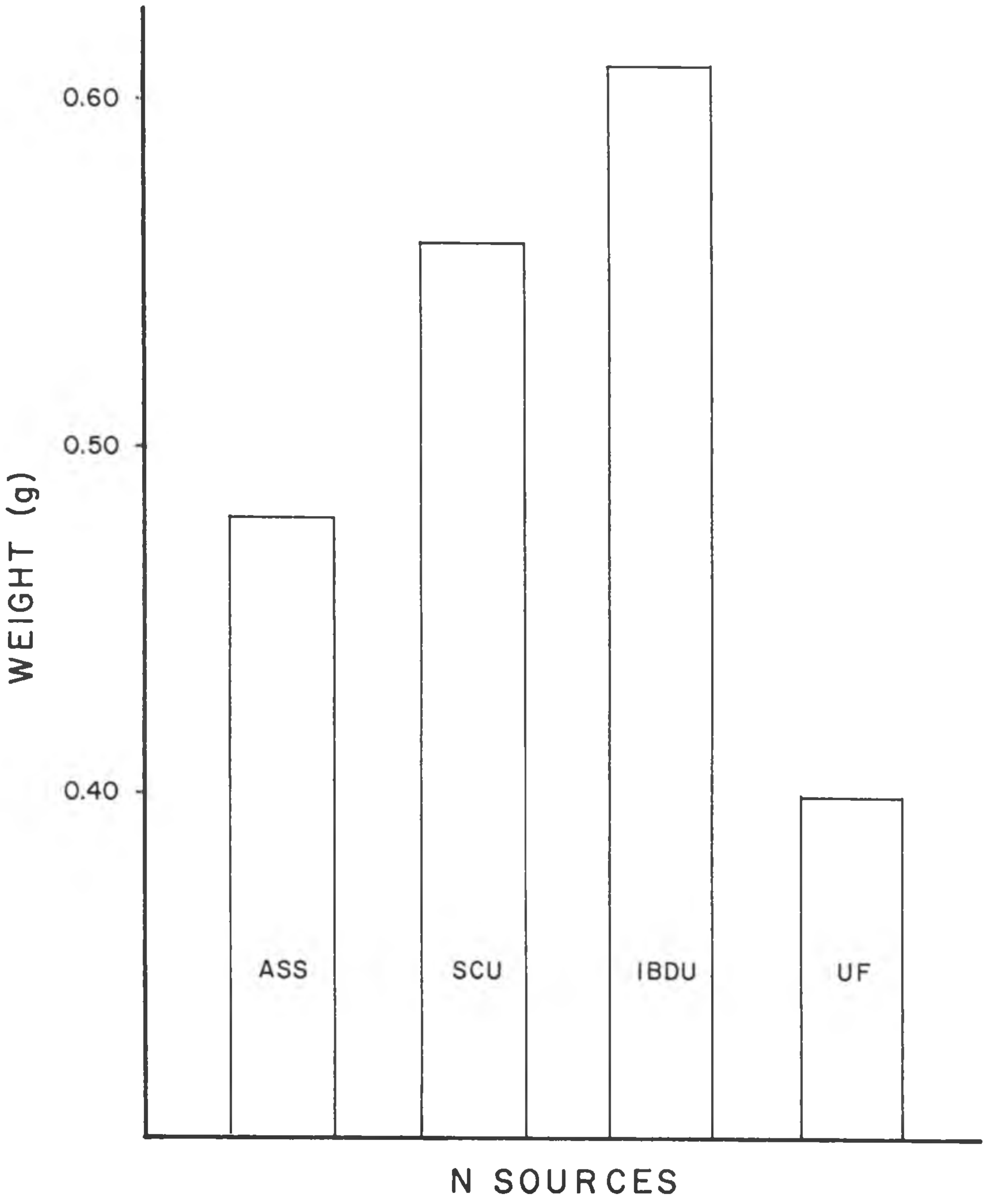

0.60
0.50
0.40
WEIGHT (g)
ASS
SCU
IBDU
UF
N SOURCES

Figure 7. Turf dry clipping yields under greenhouse conditions as affected by nitrogen schedules. (Avg. of 24 dates, 4 N sources and 4 reps.).

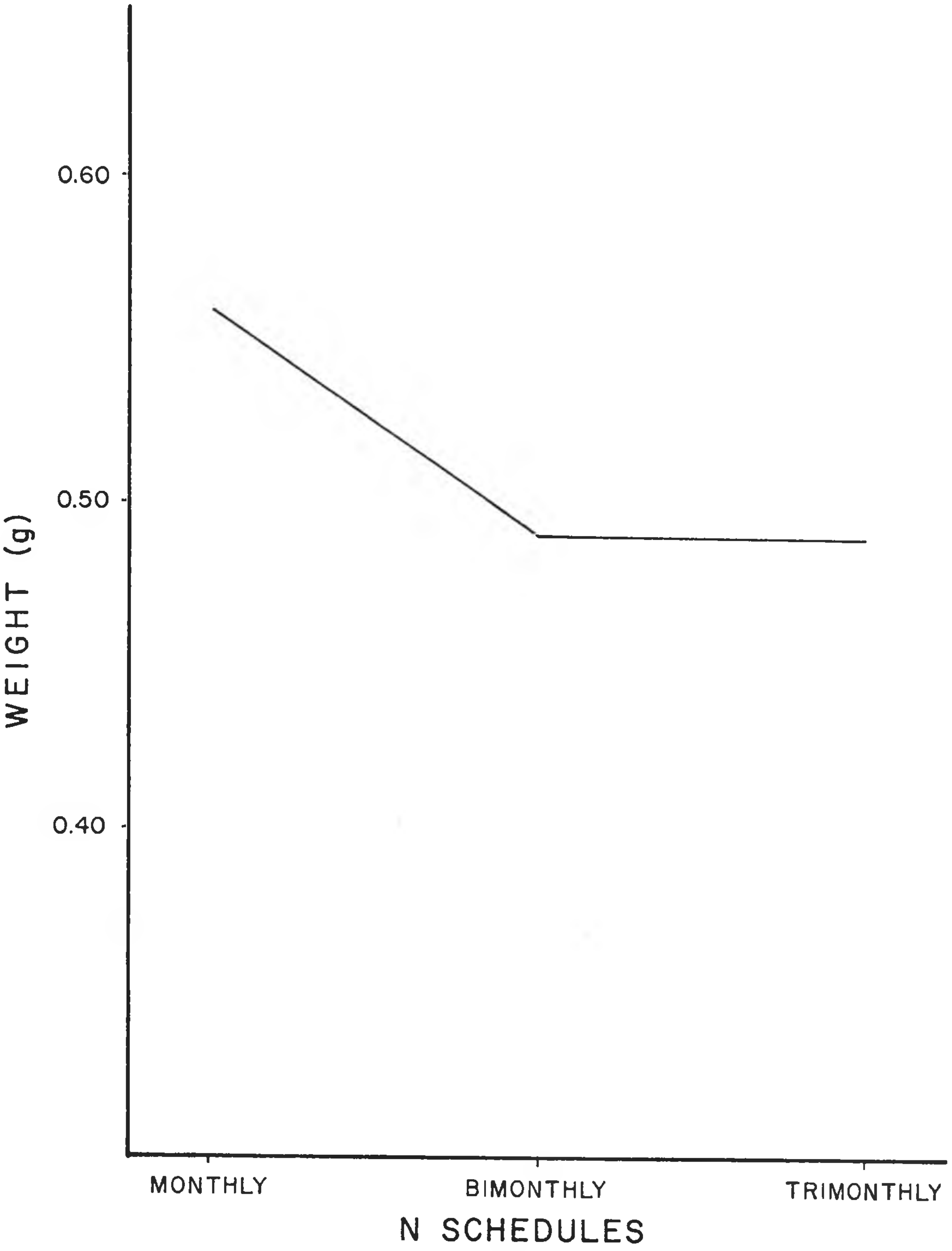

0.60
0.50
0.40
WEIGHT (g)
MONTHLY
BIMONTHLY
TRIMONTHLY
N SCHEDULES

Figure 8. Turf dry clipping yields under greenhouse conditions as affected by nitrogen sources at different schedules (Avg. of 24 dates and 4 reps.).

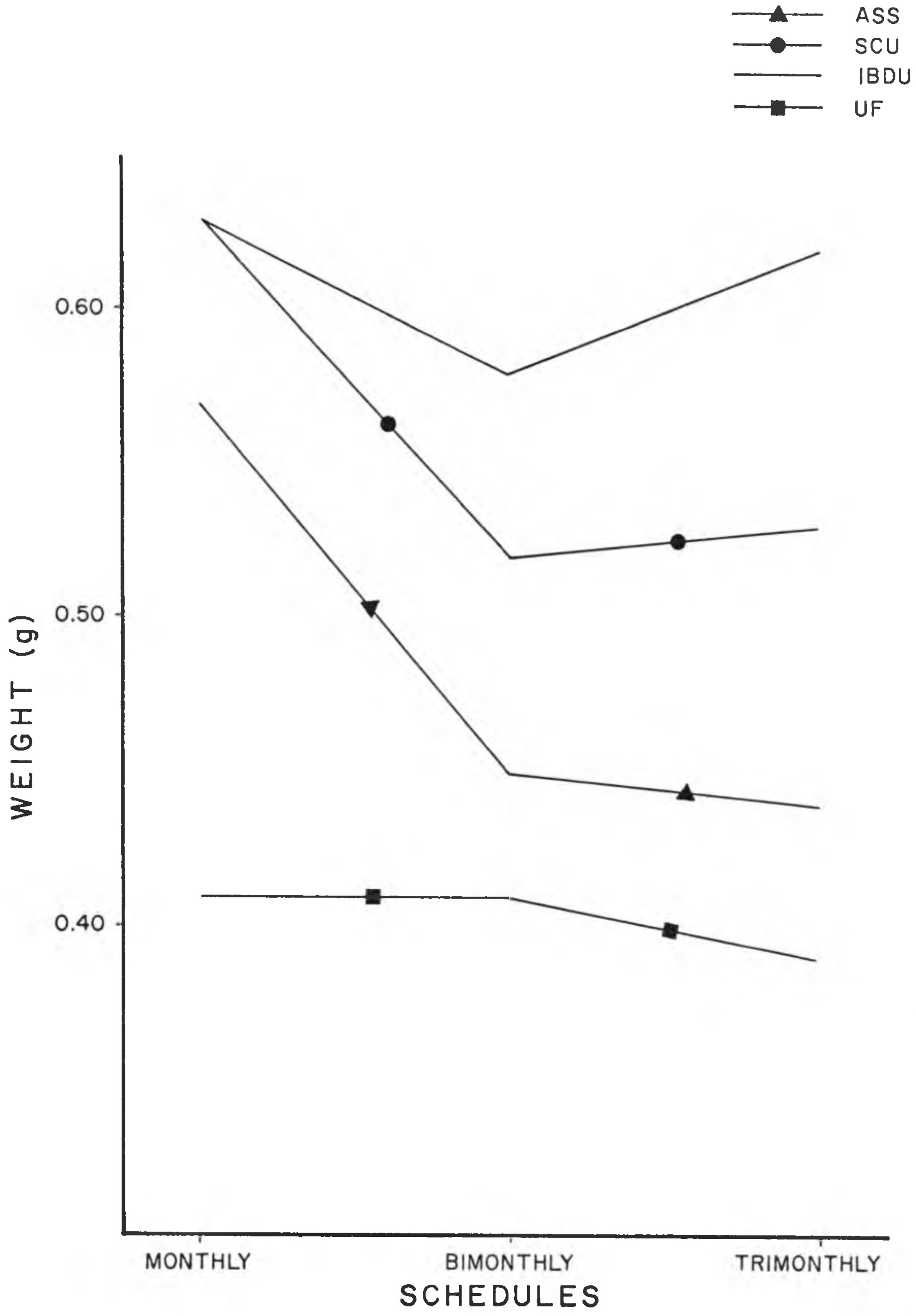

ASS
SCU
IBDU
UF
0.60
0.50
0.40
WEIGHT (g)
MONTHLY
BIMONTHLY
TRIMONTHLY
SCHEDULES

Table 8

Turf dry clipping weights* obtained under greenhouse conditions as influenced by N sources at each date (Avg. of 3 application schedules and 4 reps.).

	N Sources			
Weeks	ASS	SCU	IBDU	UF
1	0.4 a**	0.3 a	0.2 b	0.4 a
2	1.1 a	1.0 a	0.5 c	0.9 b
3	1.2 a	1.2 a	1.0 b	0.8 c
4	0.6 b	0.5 b	0.8 a	0.3 c
5	0.2 b	0.3 b	0.4 a	0.2 c
6	0.4 c	0.5 b	0.7 a	0.2 d
7	0.3 c	0.4 b	0.9 a	0.2 d
8	0.2 b	0.3 b	0.5 a	0.2 b
9	0.6 a	0.5 a	0.6 a	0.6 a
10	0.9 a	0.8 a	0.8 a	0.7 b
11	0.4 c	0.5 b	0.6 a	0.3 d
12	0.3 c	0.4 b	0.6 a	0.3 c
13	0.7 a	0.7 a	0.7 a	0.6 b
14	0.8 b	0.9 a	0.8 b	0.6 c
15	0.4 b	0.6 a	0.6 a	0.4 b
16	0.3 b	0.6 a	0.6 a	0.3 b
17	0.5 b	0.6 ab	0.6 a	0.5 c
18	0.8 b	0.9 a	0.8 b	0.6 c
19	0.4 b	0.7 a	0.7 a	0.4 b
20	0.2 c	0.3 b	0.5 a	0.2 c
21	0.3 b	0.4 b	0.5 a	0.4 bc
22	0.3 b	0.4 a	0.5 a	0.3 b
23	0.3 c	0.4 b	0.5 a	0.3 c
24	0.2 b	0.3 a	0.3 a	0.2 b

*Dry clipping weights measured in grams.

**Means in the same row followed by the same letter do not differ (P = .05) as determined by BLSD.

weight yields during the first 3 weeks as well as after supplemental applications were made on the eighth, twelfth and sixteenth week. ASS also produced high yields for the first 3 weeks following initial application, then began to decline in its production of yield. From the fourth week to the twenty-fourth week, ASS produced equal or less yields than SCU. UF produced its highest yields for the first 2 weeks after initial application then produced lowest yields at every date thereafter throughout the experiment.

The average clipping weight values for the three N schedules at each date are presented in Table 9. The monthly scheduled treatments produced the lowest yields on dates 2, 3 and 4. However, the monthly scheduled treatments produced highest overall yields thereafter throughout the experiment. The bimonthly scheduled treatments produced highest yields for 2 to 3 weeks after application on weeks 8 and 16. The trimonthly treatments followed the same pattern of producing the highest yields for the next 4 weeks after they were applied initially. A second application of these scheduled treatments again resulted in highest yields for the next 4 weeks. There was a constant decline in clipping weight yield after the fourth week for both three month cycles.

The means for each treatment (N source by N schedule by dates) are presented in Table 10. It can be seen that significant differences occurred among treatments at each date. Significant differences were expected since all of the scheduled treatments were applied at different times resulting in different yields.

The data for visual ratings and dried clipping weight yields

Table 9

Turf dry clipping weights* obtained under greenhouse conditions as influenced by N schedules at each date (Avg. of 4 N sources and 4 reps.).

Weeks	N Schedules		
	Monthly	Bimonthly	Trimonthly
1	0.3 a**	0.3 a	0.3 a
2	0.7 c	0.9 b	1.1 a
3	0.8 c	1.1 b	1.2 a
4	0.4 c	0.5 b	0.7 a
5	0.3 a	0.2 b	0.3 ab
6	0.7 a	0.3 c	0.5 b
7	0.6 a	0.3 c	0.5 b
8	0.4 a	0.2 b	0.3 a
9	0.7 a	0.7 b	0.3 c
10	1.0 b	1.1 a	0.4 c
11	0.5 b	0.7 a	0.3 c
12	0.4 a	0.5 a	0.3 b
13	0.9 a	0.3 b	0.9 a
14	0.6 b	0.3 c	1.4 a
15	0.4 b	0.3 c	0.8 a
16	0.4 b	0.3 c	0.6 a
17	0.7 a	0.6 a	0.4 b
18	0.7 b	1.1 a	0.4 c
19	0.5 b	0.7 a	0.4 c
20	0.3 a	0.4 a	0.2 b
21	0.6 a	0.4 b	0.2 c
22	0.7 a	0.3 b	0.2 b
23	0.5 a	0.3 b	0.2 c
24	0.3 a	0.3 a	0.1 b

*Dry clipping weights measured in grams.

**Means in the same row followed by the same letter do not differ (P = .05) as determined by BLSD.

Table 10

Turf dry clipping weights[*] obtained under greenhouse conditions as influenced by N sources and N schedules at each date (Avg. of 4 reps.).

	N Sources					
	ASS N Schedule			SCU N Schedule		
Weeks	Monthly	Bimonthly	Trimonthly	Monthly	Bimonthly	Trimonthly
1	0.4 a[**]	0.4 a	0.3 abc	0.4 a	0.2 bcd	0.3 abc
2	0.9 de	1.1 abc	1.2 ab	0.9 e	1.0 cde	1.2 a
3	0.9 cd	1.2 b	1.4 a	0.9 cd	1.3 ab	1.3 ab
4	0.4 fg	0.6 de	0.7 bc	0.4 fg	0.5 ef	0.7 cd
5	0.3 bcd	0.2 def	0.3 bcde	0.4 ab	0.2 cdef	0.3 bc
6	0.8 b	0.1 e	0.3 cd	1.0 a	0.2 de	0.4 c
7	0.5 cd	0.1 h	0.3 fg	0.7 c	0.2 fgh	0.4 de
8	0.2 bcde	0.1 e	0.2 cde	0.3 bc	0.2 de	0.3 bcd
9	0.9 a	0.7 bcd	0.2 f	0.8 abc	0.6 cde	0.3 f
10	1.1 bc	1.3 a	0.3 f	1.0 bc	1.1 ab	0.4 e
11	0.4 bc	0.6 b	0.2 e	0.5 b	0.8 a	0.3 de
12	0.3 bcd	0.3 cd	0.2 d	0.4 bc	0.5 b	0.2 d
13	1.1 a	0.2 f	0.9 bcd	0.9 bc	0.3 f	0.9 b
14	0.6 d	0.2 e	1.7 a	0.8 c	0.2 e	1.2 b
15	0.4 fg	0.2 h	0.7 bc	0.5 de	0.3 gh	0.9 a
16	0.3 def	0.2 f	0.5 bc	0.5 bc	0.4 cd	0.6 b
17	0.8 a	0.6 abc	0.2 f	0.7 ab	0.6 bcd	0.4 e
18	0.7 d	1.3 a	0.3 f	0.8 cd	1.3 a	0.5 e
19	0.4 de	0.6 cd	0.2 f	0.6 c	1.0 a	0.5 de
20	0.2 def	0.2 def	0.1 f	0.3 cde	0.4 bc	0.2 def
21	0.6 a	0.2 cd	0.1 d	0.6 a	0.4 b	0.2 bcd
22	0.7 b	0.2 f	0.1 f	0.8 a	0.2 ef	0.2 ef
23	0.4 b	0.2 de	0.1 e	0.6 a	0.3 cd	0.2 de
24	0.2 cde	0.2 cde	0.1 e	0.3 bcd	0.4 ab	0.2 e

Table 10 (continued)

	N Sources					
	IBDU N Schedule			UF N Schedule		
Weeks	Monthly	Bimonthly	Trimonthly	Monthly	Bimonthly	Trimonthly
1	0.1 d	0.2 d	0.2 cd	0.3 abc	0.4 ab	0.4 ab
2	0.4 g	0.4 g	0.6 f	0.6 f	1.1 bcd	1.1 ab
3	0.8 d	1.0 c	1.2 b	0.5 e	0.9 cd	1.0 c
4	0.6 de	0.9 ab	1.0 a	0.3 g	0.3 g	0.4 fg
5	0.3 bc	0.5 a	0.5 a	0.2 cdef	0.1 f	0.1 ef
6	0.7 b	0.6 b	0.9 a	0.4 cd	0.1 e	0.1 e
7	1.0 b	0.6 c	1.2 a	0.3 ef	0.1 gh	0.2 fgh
8	0.6 a	0.4 b	0.7 a	0.2 bcde	0.1 de	0.2 bcde
9	0.6 de	0.6 cd	0.5 e	0.7 bcd	0.8 ab	0.2 f
10	1.0 bc	1.0 c	0.5 e	0.7 d	1.0 bc	0.4 ef
11	0.7 b	0.9 a	0.4 cd	0.3 cde	0.4 cd	0.3 de
12	0.7 a	0.8 a	0.3 bcd	0.3 cd	0.4 bcd	0.3 cd
13	0.8 bcd	0.6 e	0.8 cd	0.7 de	0.2 f	0.9 bc
14	0.7 c	0.5 d	1.1 b	0.4 d	0.2 e	1.2 b
15	0.6 cd	0.4 ef	0.8 ab	0.3 fgh	0.3 gh	0.6 cd
16	0.6 b	0.3 cdef	0.9 a	0.3 ef	0.2 ef	0.4 cde
17	0.7 ab	0.5 de	0.7 ab	0.5 cde	0.7 ab	0.2 f
18	0.7 d	0.9 bc	0.7 d	0.5 e	1.0 b	0.3 f
19	0.7 bc	0.8 b	0.6 cd	0.4 ef	0.5 de	0.3 f
20	0.5 ab	0.6 a	0.3 cd	0.2 def	0.3 cde	0.2 ef
21	0.6 a	0.6 a	0.3 bc	0.6 a	0.3 bc	0.2 bcd
22	0.7 ab	0.4 cd	0.3 de	0.5 c	0.2 ef	0.2 ef
23	0.7 a	0.4 b	0.2 cde	0.4 bc	0.3 cde	0.1 de
24	0.5 a	0.3 abc	0.2 de	0.2 cde	0.2 cde	0.1 e

*Dry clipping weights measured in grams.

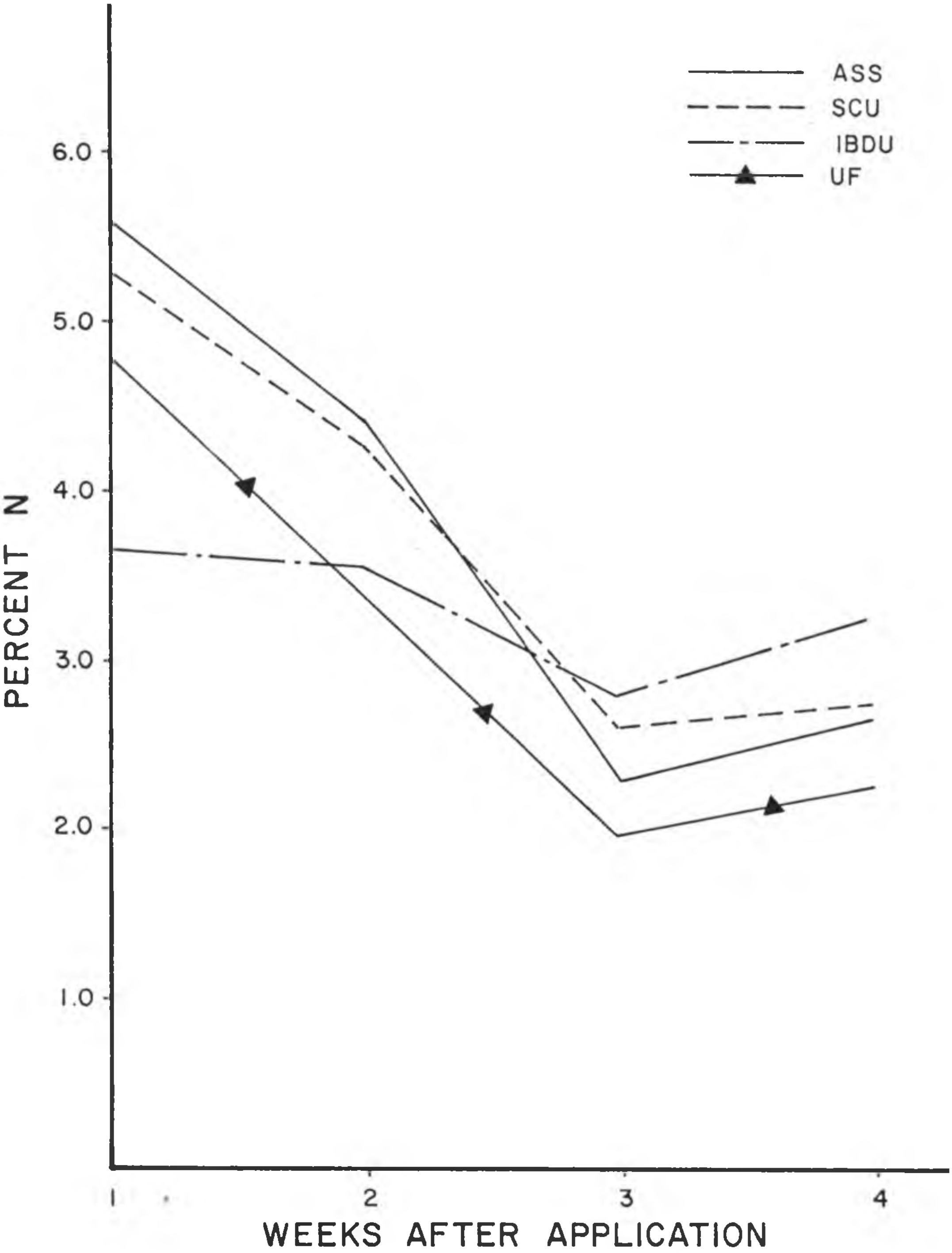
**Means followed by the same letter do not differ (P = .05) as determined by BLSD.

resulted in similar response patterns. IBDU, which gave both highest visual scores and clipping weight yields was the most efficient slow release fertilizer as evidenced by its long lasting qualities under high greenhouse temperatures (35 C).

The release of N from IBDU appeared to be slower but more uniform than that of the other materials as evidenced by both visual color ratings and dry matter yield. N release from SCU and ASS appeared to be more rapid as shown by higher color ratings and dry matter yield from these materials at frequent application schedules and a sharp reduction at less frequent schedules. Color ratings and dry matter yield were consistently low for all schedules of UF. These data are consistent with others (Lunt and Clark, 1969 and Hughes 1976) who show that rate of dissolution of IBDU is more dependent upon moisture and soil pH than microbial activity and therefore would be less influenced by the high greenhouse temperatures. Others have shown (Kresge and Younts, 1962 and Juska, Hanson and Hovin 1969) that the amount of N recovered in UF is low.

The means of the total percent N in the clippings at each schedule for the first 3 months are illustrated in Figures 9, 10 and 11 respectively. As evidenced by these illustrations, significant differences occurred among the various N sources at each date of analysis. During the first 3 month period ASS and SCU had the highest percent N among the monthly scheduled treatments followed by IBDU and UF, which were not significantly different (Fig. 9). In the first week, ASS and SCU produced extremely high N percentages followed by UF and IBDU with the lowest percentage. In the second week the N

Figure 9. Percent total N as affected by the various nitrogen sources at the monthly schedules for the first three month period of the greenhouse experiment (Avg. of 4 reps.).


ASS
SCU
IBDU
UF
PERCENT N
6.0
5.0
4.0
3.0
2.0
1.0
1
2
3
4
WEEKS AFTER APPLICATION

percentages declined, however ASS and SCU still had the highest N percentages followed by IBDU and lastly, UF. By the third week, ASS had dropped in N percentage and was below SCU and IBDU which were not significantly different. UF resulted in the lowest percent N value. By the fourth week, IBDU gave a higher N percentage than all other materials.

With the bimonthly scheduled treatments, IBDU resulted in the highest overall N percentages followed by SCU, ASS and UF in descending order. ASS and SCU gave very high N percentages on week two as compared to IBDU and UF. On week four, IBDU was giving higher N percentages followed by SCU, ASS and UF in that order. During the sixth week all of the materials had decreased greatly in N percentage except IBDU. By the eighth week, IBDU had also decreased in producing a high N percentage but was giving significantly higher percentages than all of the other N sources. The overall averages at each date decreased significantly with time (Fig. 10).

For the trimonthly scheduled treatments, IBDU resulted in the highest overall averages in percent N followed by all of the other N sources which were not significantly different. ASS, SCU and IBDU gave the highest N percentages on week 4, while UF gave the lowest percentage. On week 8, IBDU was giving the highest N percentages, followed by UF. The N percentages had decreased for ASS and SCU. By week 12, UF and IBDU had higher percentages than ASS and SCU. There was a significant decrease in overall N content with time for each N source (Fig. 11).

Figure 10. Percent total N as affected by the various nitrogen sources at the bimonthly schedules for the first three month period of the greenhouse experiments (Avg. of 4 reps.).

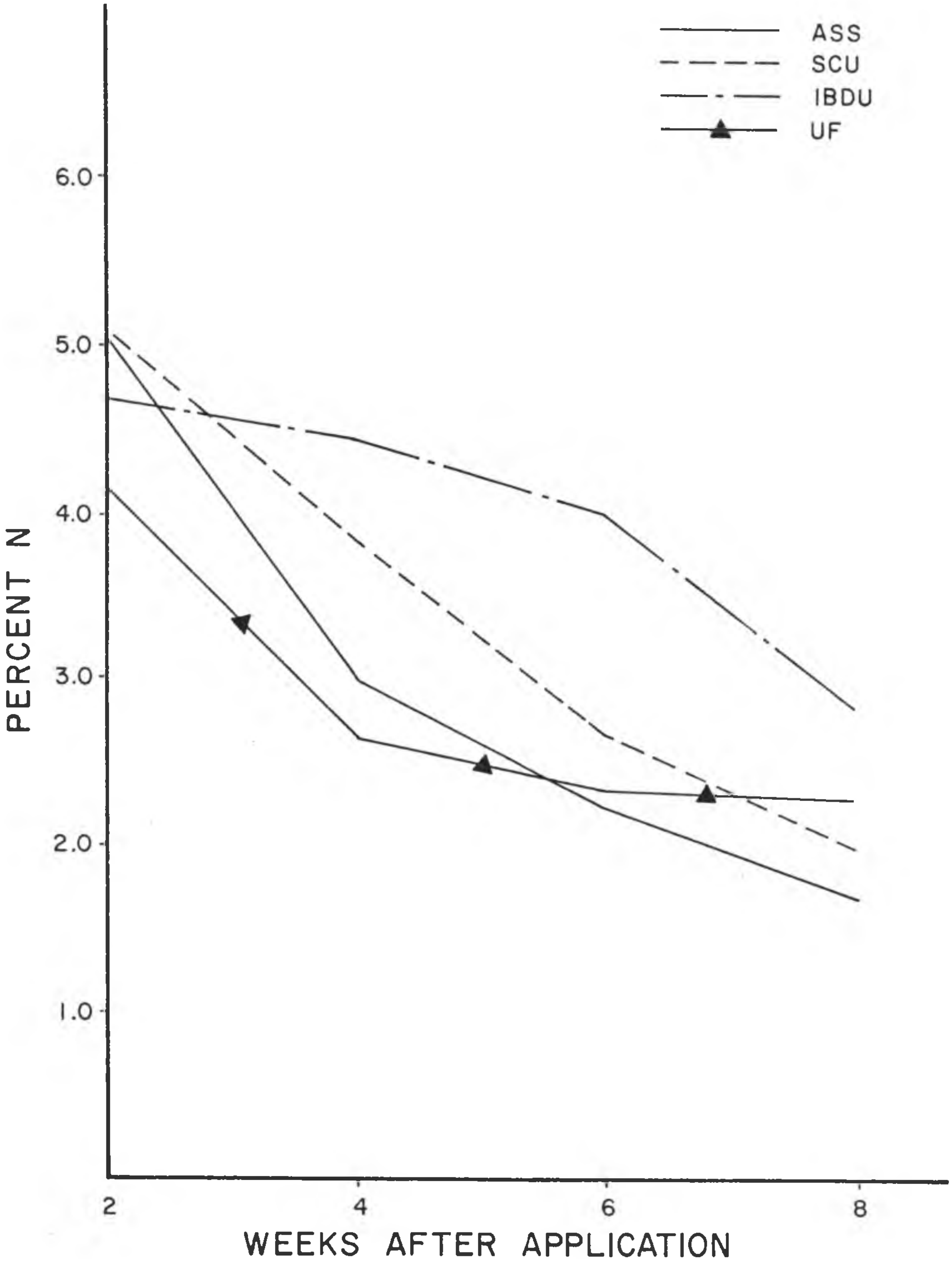
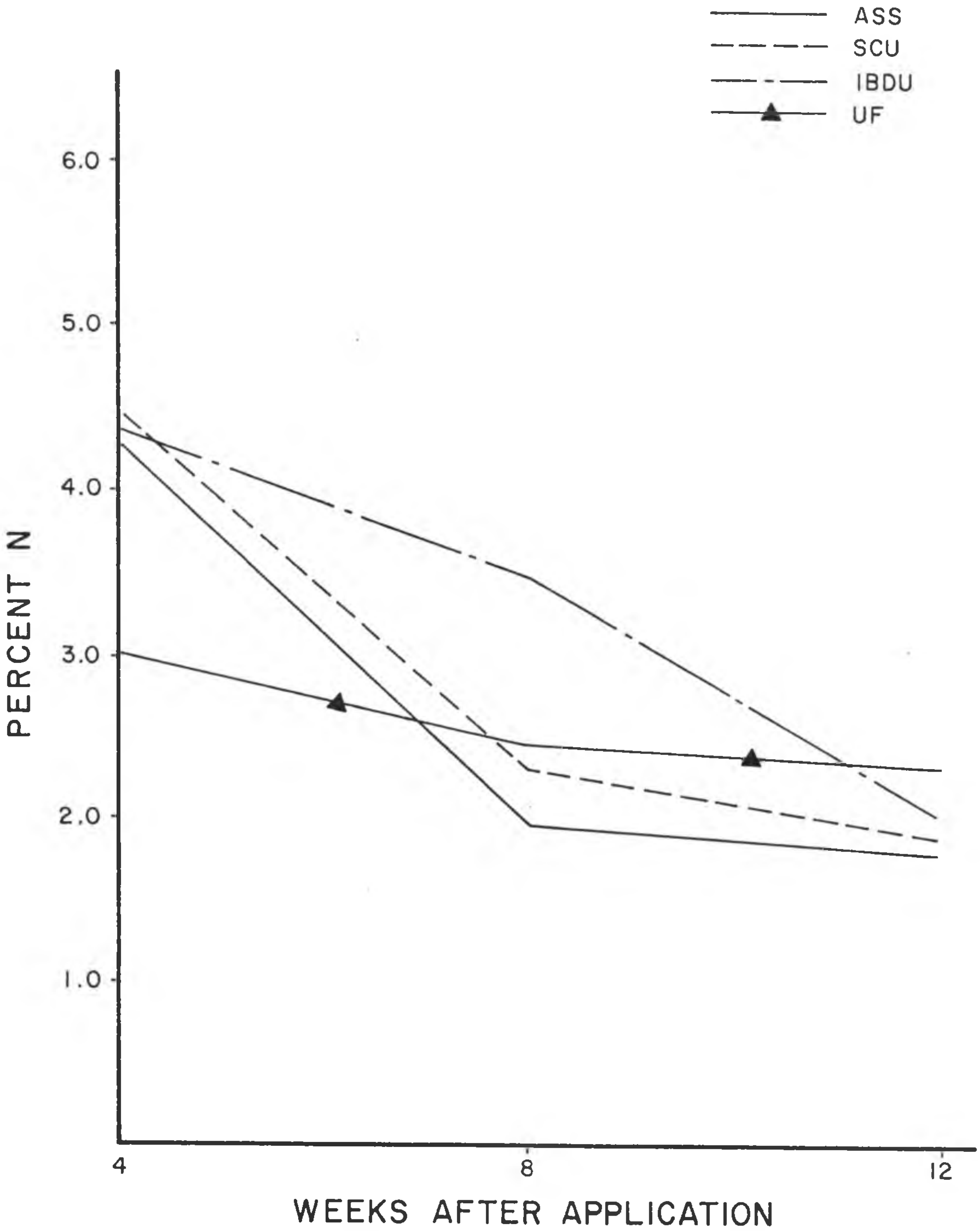

ASS
SCU
IBDU
UF
6.0
5.0
4.0
3.0
2.0
1.0
PERCENT N
2
4
6
8
WEEKS AFTER APPLICATION

Figure 11. Percent total N as affected by the various nitrogen sources at the trimonthly schedules for the first three month period of the greenhouse experiments (Avg. of 4 reps.).


ASS
SCU
IBDU
UF
PERCENT N
6.0
5.0
4.0
3.0
2.0
1.0
4
8
12
WEEKS AFTER APPLICATION

The results for the N percentages of the second three month period are illustrated in Figures 12, 13 and 14 for the monthly, bimonthly and trimonthly scheduled treatments respectively. The response patterns are almost identical with those of the first three month period.

Figure 12. Percent total N as affected by the various N sources at the monthly schedules for the second three month period of the greenhouse experiments (Avg. of 4 reps.).

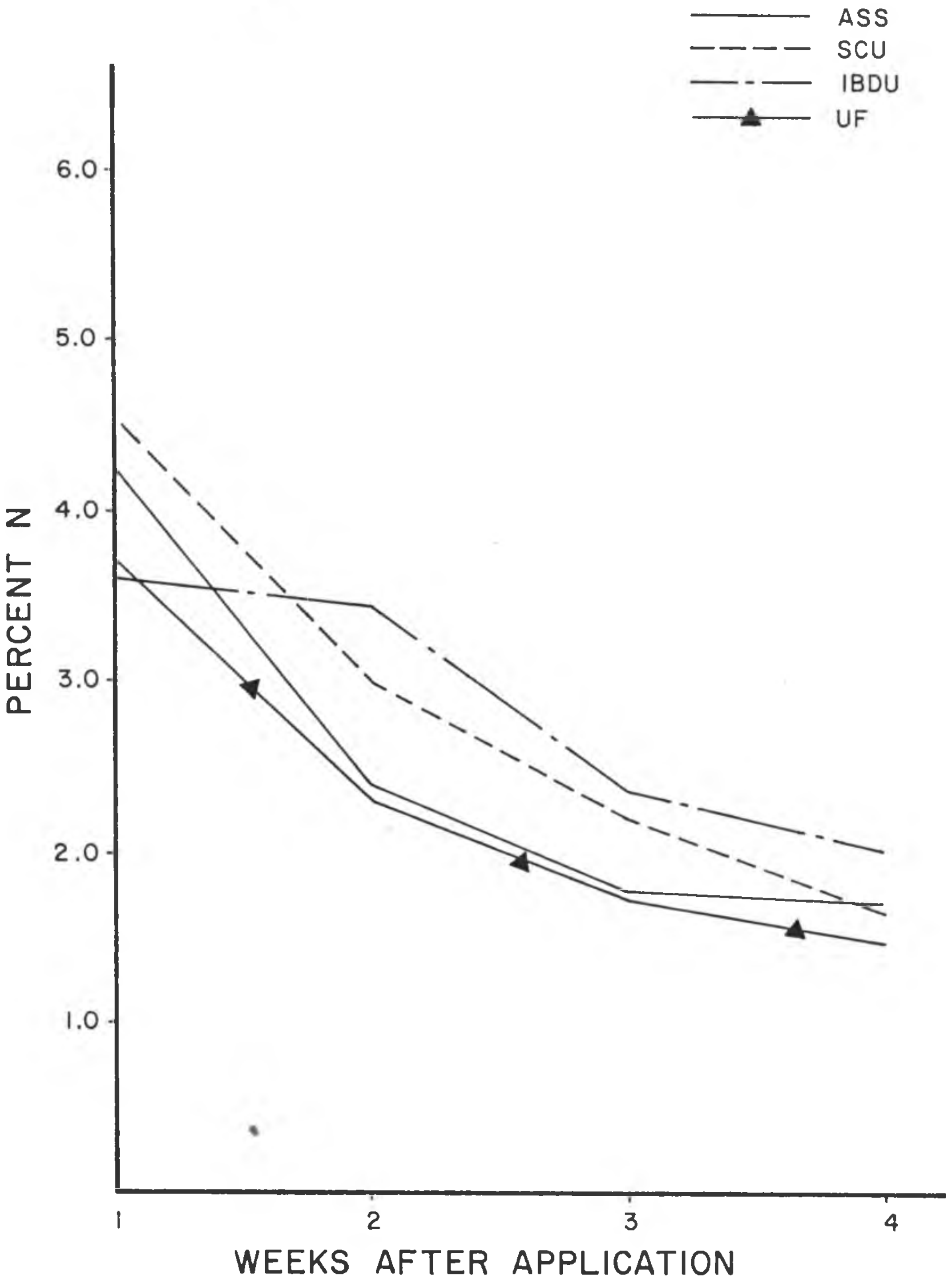

ASS
SCU
IBDU
UF
PERCENT N
6.0
5.0
4.0
3.0
2.0
1.0
1
2
3
4
WEEKS AFTER APPLICATION

Figure 13. Percent total N as affected by the various nitrogen sources at the bimonthly schedules for the second three month period of the greenhouse experiments (Avg. of 4 reps.).

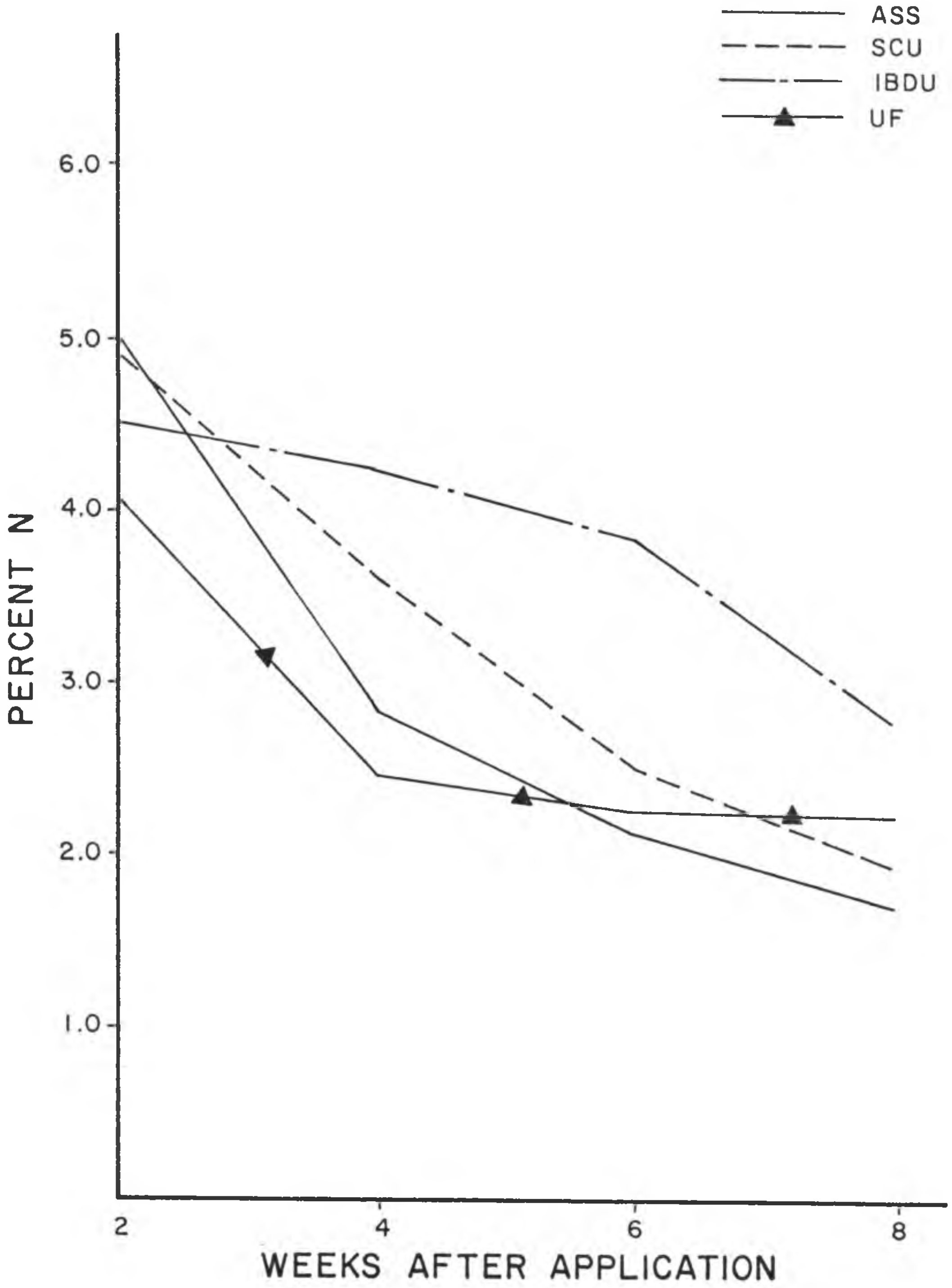
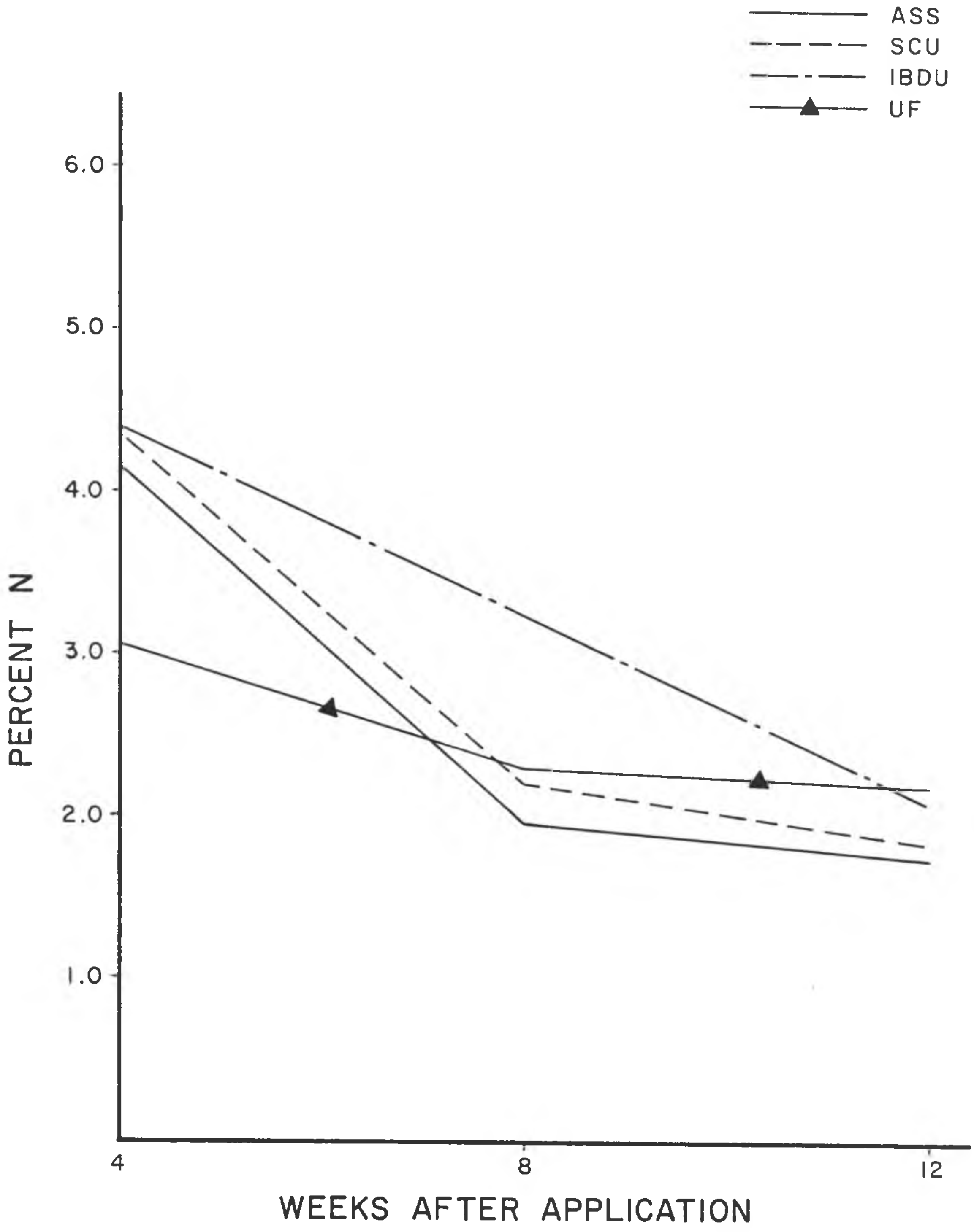

ASS
SCU
IBDU
UF
6.0
5.0
4.0
3.0
2.0
1.0
PERCENT N
2
4
6
8
WEEKS AFTER APPLICATION

Figure 14. Percent total N as affected by the various nitrogen sources at the trimonthly schedules for the second three month period of the greenhouse experiment (Avg. of 4 reps.).


ASS
SCU
IBDU
UF
PERCENT N
6.0
5.0
4.0
3.0
2.0
1.0
4
8
12
WEEKS AFTER APPLICATION

SUMMARY

Turfgrass response to four slow release nitrogen fertilizers was evaluated to determine their efficiency at three different schedules of application.

The fertilizers used in this study were activated sewage sludge, sulfur coated urea, isobutylidene diurea and ureaformaldehyde. Each nitrogen source was applied at rates of 73.2 kg N/ha monthly, 146.5 kg N/ha bimonthly and 219.7 kg N/ha trimonthly. Two field experiments and one greenhouse experiment were conducted. All of the fertilizer materials provided excellent turf quality under field conditions at the Hawaii Kai Golf Course. The responses of the various N sources and N schedules varied considerably during the first 8 weeks of the experiment, then all sources and schedules resulted in excellent turf quality from the tenth week until the end of the experiment. It appears that sufficient N reserves have to be present before consistently high visual scores can be obtained. The trimonthly application schedule resulted in the highest visual ratings. At Leilehua Golf Course, there were no differences among any of the N sources, N schedules and dates of rating. This was perhaps due to the constant use of this tee. The actual differences may have been confounded by the divets which scarred the turf surface and made rating difficult.

Under greenhouse conditions, IBDU gave the highest visual score ratings as well as dry clipping yield and total N percent. IBDU maintained higher N contents in tissue over a longer period than the other N materials under greenhouse conditions. All of the other

materials resulted in a shorter residual response than IBDU. The monthly schedules produced the highest visual scores and dry clipping yields under greenhouse conditions. Perhaps the high greenhouse temperatures (30 to 35 C) caused a more rapid release of N and more rapid turf response.

Results of field and greenhouse experiments indicate that excellent turf appearance and nitrogen uptake can be obtained by application of certain slow release N fertilizers at higher rates and less frequent applications minimizing labor costs. Slow release nitrogen sources also tend to reduce variability in growth response providing uniform, high quality turf throughout the growing season. Based on the data obtained from these experiments, IBDU provided highest, most uniform visual ratings, dry matter yields and total N percent N content over a 6 month period followed by SCU, ASS and UF in that order.

Appendix Table 1

Analysis of Variance for the effects of
the various N treatments at Hawaii Kai.

Source of Variation	d.f.	S.S.	M.S.	F
Total	263	252.9		
Date Plots				
Dates	10	165.4	16.5	75.2
Replications	1	1.2	1.2	5.6
Error A	10	2.2	0.2	
N Plots				
N Sources	3	6.1	2.0	3.5
N Schedules	2	4.6	2.3	4.1*
N Sour. x N Sched.	6	2.8	0.5	
Error B	11	6.2	0.6	
Date x N Plots				
D x N Sources	30	24.3	0.8	5.8**
D x N Schedules	20	14.5	0.7	5.1**
D x N Sour. x N Sched.	60	10.0	0.2	1.2
Error C	110	15.7	0.1	

Appendix Table 2

Analysis of Variance for the visual effects of the various N treatments at Leilehua Golf Course.

Source of Variation	d.f.	S.S.	M.S.	F
Total	527	1032.3		
Date Plots				
Dates	10	517.8	51.8	49.3**
Replications	3	4.8	1.6	1.5
Error A	30	31.6	1.1	
N Plots				
N Sources	3	2.2	0.8	0.6
N Schedules	2	5.8	2.9	2.1
N Sour. x N Sched.	6	14.7	2.5	1.8
Error B	33	45.2	1.4	
Date x N Plots				
D x N Sources	30	14.7	0.5	0.5
D x N Schedules	20	17.2	0.9	0.8
D x N Sour. x N Sched.	60	23.8	0.4	0.4
Error C	330	354.4	1.1	

Appendix Table 3

Analysis of Variance for the visual effects of the various N treatments under greenhouse conditions.

Source of Variation	d.f.	S.S.	M.S.	F
Total	1151	2023.1		
Date Plots				
Dates	23	584.4	23.9	59.6**
Replications	3	7.5	2.5	6.3**
Error A	69	27.8	0.4	
N Plots				
N Sources	3	171.4	57.1	96.9**
N Schedules	2	88.9	44.4	75.3**
N Sour. x N Sched.	6	16.3	2.7	4.6**
Error B	33	19.4	0.6	
Date x N Plots				
D x N Sources	69	257.2	3.7	41.4**
D x N Schedules	46	652.2	14.2	157.6**
D x N Sour. x N Sched.	138	131.8	1.0	10.7**
Error C	759	66.3	0.1	

Appendix Table 4

Analysis of Variance for the turf dry clipping weight yields of the various N treatments under greenhouse conditions.

Source of Variation	d.f.	S.S.	M.S.	F
Total	1151	128.9		
Date Plots				
Dates	23	48.2	2.1	52.3**
Replications	3	0.7	0.2	5.8
Error A	69	2.5	0.1	
N Plots				
N Sources	3	7.0	2.3	58.3**
N Schedules	2	1.2	0.6	14.5**
N Sour. x N Sched.	6	0.6	0.1	2.5*
Error B	33	1.4	0.1	
Date x N Plots				
D x N Sources	69	12.8	0.2	19.0**
D x N Schedules	46	39.8	0.9	86.0**
D x N Sour. x N Sched.	138	7.3	0.1	5.0**
Error C	759	7.5	0.0	

Appendix Table 5

Analysis of Variance for total N
percent of the monthly schedules
during the first three month period.

Source of Variation	d.f.	S.S.	M.S.	F
Total	63	79.3		
Date Plots				
Dates	3	58.4	19.5	72.0**
Replications	3	1.0	0.3	1.2
Error A	9	2.5	0.3	
N Plots				
N Sources	3	4.6	1.5	9.0**
Error B	9	1.6	0.2	
Date x N Plots				
D x N Sources	9	10.1	1.1	22.4**
Error C	27	1.3	0.1	

Appendix Table 6

Analysis of Variance for total N percent of the bimonthly schedules during the first three month period.

Source of Variation	d.f.	S.S.	M.S.	F
Total	63	82.4		
Date Plots				
Dates	3	57.4	19.1	95.7**
Replications	3	0.3	0.1	--
Error A	9	1.8	0.2	
N Plots				
N Sources	3	11.6	3.9	55.3**
Error B	9	0.6	0.1	
Date x N Plots				
D x N Sources	9	8.9	1.0	16.5**
Error C	27	1.7	0.1	

Appendix Table 7

Analysis of Variance for total N
percent of the trimonthly schedules
during the first three month period.

Source of Variation	d.f.	S.S.	M.S.	F
Total	47	50.6		
Date Plots				
Dates	2	34.8	17.4	124.2**
Replications	3	1.0	0.3	2.3
Error A	6	0.8	0.1	
N Plots				
N Sources	3	3.8	1.3	5.7*
Error B	9	2.0	0.2	
Date x N Plots				
D x N Sources	6	7.6	1.3	31.8**
Error C	18	0.7	0.1	

Appendix Table 8

Analysis of Variance for total N percent of the monthly schedules during the second three month period.

Source of Variation	d.f.	S.S.	M.S.	F
Total	63	59.8		
Date Plots				
Dates	3	48.1	16.1	802.5**
Replications	3	1.1	0.4	18.0**
Error A	9	0.1	0.0	
N Plots				
N Sources	3	4.1	1.4	9.2
Error B	9	1.4	0.2	
Date x N Plots				
D x N Sources	9	3.6	0.4	8.0**
Error C	27	1.3	0.1	

Appendix Table 9

Analysis of Variance for total N
percent of the bimonthly schedules
during the second three month period.

Source of Variation	d.f.	S.S.	M.S.	F
Total	63	78.0		
Date Plots				
Dates	3	53.9	18.0	85.5**
Replications	3	0.3	0.1	--
Error A	9	1.9	0.2	
N Plots				
N Sources	3	11.3	3.8	62.5**
Error B	9	0.5	0.1	
Date x N Plots				
D x N Sources	9	8.8	1.0	19.4**
Error C	27	1.4	0.1	

Appendix Table 10

Analysis of Variance for total N percent of the trimonthly schedules during the second three month period.

Source of Variation	d.f.	S.S.	M.S.	F
Total	47	48.7		
Date Plots				
Dates	2	35.8	17.9	149.3**
Replications	3	0.8	0.3	2.1
Error A	6	0.7	0.1	
N Plots				
N Sources	3	3.8	1.3	7.4**
Error B	9	1.5	0.2	
Date x N Plots				
D x N Sources	6	5.4	0.9	22.8**
Error C	18	0.7	0.1	

LITERATURE CITED

1. Ahmed, I.U., O.J. Attoe, L.E. Englebert and R.B. Corey. 1963. Factors affecting the rate of release of fertilizer from capsules. Agron. J. 55:495-499.
2. Allen, S.E. and D.A. Mays. 1971. Sulfur coated fertilizers for controlled release: Agronomic evaluation. J. Agric. Food Chem. 19:809-812.
3. Allen, S.E., C.M. Hunt and G.L. Terman. 1971. Nitrogen release from sulfur coated urea, as affected by coating weight, placement and temperature. Agron. J. 63:529-533.
4. Allen, S.E., D.A. Mays and G.L. Terman. 1968. Low cost slow release fertilizer developed. Crops and Soils 21(3):13-15.
5. Allen, S.E., G.L. Terman and C.M. Hunt. 1971. Soluble and slow release nitrogen fertilizer effects on grass forage, as influenced by rate and placement. J. Agric. Sci., Camb. 77:397-404.
6. Beard, J.B. 1973. Turfgrass: Science and Culture. Prentice-Hall, Inc., Englewood Cliffs, N.J. pp. 408-465.
7. Bidwell, R.G.S. 1974. Plant Physiology. Macmillan Publishing Co., Inc. New York. pp. 173-206.
8. Boonduan, A., Y. Kanehiro and C.L. Murdoch. 1976. Response of Sunturf bermudagrass to slow release nitrogen sources under greenhouse conditions. Hort Science 11(4):379-381.
9. Bredakis, E.J. and J.E. Steckel. 1963. Leachable nitrogen from soils incubated with turfgrass fertilizers. Agron. J. 55:145-147.

10. Brown, M.J., R.E. Luebs, and P.F. Pratt. 1966. Effect of temperature and coating thickness on the release of urea from resin coated granules. Agron. J. 58:175-178.

11. Brown, M.A. and G.M. Volk. 1966. Evaluation of ureaform fertilizer using nitrogen-15-labeled materials in sandy soils. Soil Sci. Soc. Amer. Proc. 30:278-281.

12. Cataldo, D.A., L.E. Schrader and V.L. Youngs. 1974. Analysis by digestion and Colorimetric Assay of Total Nitrogen in Plant Tissues High in Nitrate. Crop Science 14(6):854-856.

13. Dahnke, W.C., O.J. Attoe, L.E. Englebert and M.D. Groskop. 1963. Controlling release of fertilizer constituents by means of coatings and capsules. Agron. J. 55:242-244.

14. Davies, L.H. 1973. Two grass field trials with a sulfur coated urea to examine its potential as a slow release nitrogen fertilizer in the U.K. J. Sci. Food Agric. 24:63-67.

15. Duncan, D.B. 1965. A Bayesian approach to multiple comparisons. Technometrics. 7:171-222.

16. Fuller, W.H. and K.G. Clark. 1947. Microbiological studies on urea-formaldehyde preparation. Soil Sci. Soc. Amer. Proc. 12:198-202.

17. Hagin, J. and Luiba Cohen. 1976. Nitrogen fertilizer potential of an experimental urea formaldehyde. Agron. J. 68:518-520.

18. Hamamoto, A.D. 1966. Isobutylidene diurea as a slow-acting nitrogen fertilizer and the studies in this field in Japan. Proc. 90. The Fertilizer Society, London.

19. Hayes, J.T. and W.W. Haden. 1966. Soluble fractions of ureaforms: Nitrification, Leaching and Burning properties. J. Agric. Food Chem. 14(4):339-341.

20. 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.

21. Hughes, T.D. 1976. Nitrogen release from isobutylidene diurea: Soil pH and fertilizer particle size effects. Agron. J. 68:103-106.

22. Juska, F.V., A.A. Hanson and A.W. Hovin. 1969. Evaluation of tall fescue, <u>Festuca arundinacea</u> Schreb., for turf in the transition zone in the United States. Agron. J. 61:625-628.

23. Kilian, K.C., O.J. Attoe and L.E. Englebert. 1966. Urea formaldehyde as a slowly available form of nitrogen for Kentucky bluegrass. Agron. J. 58:204-206.

24. Kralovec, R.O. 1954. Condensation products of urea and formaldehyde as a fertilizer with controlled nitrogen availability. J. Agric. Food Chem. 2:92-95.

25. Kresge, C.B. and S.E. Younts. 1962. Effect of nitrogen source on yield and nitrogen content of bluegrass forage. Agron. J. 54:149-152.

26. LeClerg, E.L., W.H. Leonard and A.G. Clark. 1962. <u>Field Plot Technique</u>. Burgess Publishing Co., Minneapolis, Minn.

27. Lunt, O.R. 1971. Controlled release fertilizers: Achievements and Potentials. J. Agric. Food Chem. 19:797-800.

28. Lunt, O.R. and S.B. Clark. 1969. Properties and value of 1,1-Diureido Isobutane (IBDU) as a long lasting nitrogen fertilizer. J. Agric. Food Chem. 17(6):1269-1271.

29. Lunt, O.R. and J.J. Oertli. 1962. Controlled release of fertilizer minerals by incapsulating membranes: (I), Efficiency of recovery, influence of soil moisture, mode of application, and other considerations related to use. Soil Sci. Amer. Proc. 26:584-587.

30. Markland, F.E. and E.C. Roberts. 1969. Influence of nitrogen fertilizers on Washington creeping bentgrass, Agrostis palustris Huds. (I), Growth and mineral composition. Agron. J. 61:698-700.

31. Mays, D.A. and G.L. Terman. 1969. Sulfur coated urea and uncoated soluble nitrogen fertilizers for fescue forage. Agron. J. 61: 489-492.

32. Moberg, E.L., D.V. Waddington and J.M. Duich. 1970. Evaluation of slow release nitrogen sources on Merion Kentucky bluegrass. Soil Sci. Soc. Amer. Proc. 34:335-339.

33. Mruck, C.K., A.J. Wisniewski and J.A. DeFrance. 1957. A comparison of ureaformaldehyde materials for turfgrass fertilization. Golf Course Reporter 25(3):5-8.

34. Muller, J.F. 1929. The value of raw sewage sludge as fertilizer. Soil Science 23:423-432.

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

36. Oertli, J.J. and O.R. Lunt. 1962. Controlled release of fertilizer minerals by incapsulating membranes: (II), Factors affecting the rate of release. Soil Sci. Soc. Amer. Proc. 26: 579-583.

37. Palmtree, H.D., E.L. Kimbrough and C.Y. Ward. 1966. The evaluation of several sources and rates of N for fertilization of established roadside turf. 1966 Agronomy Abstracts p. 39.

38. Porter, J.B. 1971. Slow release nitrogen fertilizers. Crops and Soils 24(2):12-13.

39. Prasad, R., G.B. Rajale and B.A. Lahkdive. 1971. Nitrification retarders and slow release nitrogen fertilizers. Adv. in Agron. 23:337-383.

40. Rindt, D.W., G.M. Blouin and J.G. Gestinger. 1968. Sulfur coating on nitrogen fertilizer to reduce dissolution rate. J. Agric. Food Chem. 16(5):773-778.

41. Salisbury, F.B. and C. Ross. 1969. Plant Physiology. Wadsworth Publishing Company, Inc., Belmont, California.

42. Skogley, C.R. and J.W. King. 1968. Controlled release nitrogen fertilization of turfgrass. Agron. J. 60:61-64.

43. Volk, G.M. and G.C. Horn. 1975. Response curves of various turfgrasses to application of several controlled release nitrogen sources. Agron. J. 67:201-204.

44. Ward, C.Y. and W.R. Thompson, Jr. 1965. Influence of nitrogen source and frequency of application on bermudagrass (Cynodon spp.) Golf Green Turf. 1965 Agronomy Abstracts p. 47.

45. Waddington, D.V., J. Troll and B. Hawes. 1964. The effect of various fertilizers on turfgrass yield, color and composition. Agron. J. 56:221-222.

46. Widdowson, F.V., A. Penny and R.J.B. Williams. 1962. An experiment comparing ureaformaldehyde fertilizer with "Nitrochalk"

for Italian ryegrass. J. Agric. Sci. 59:263-266.

47. Wisniewski, A.J., J.A. DeFrance and J.R. Kollet. 1959. Results of ureaform fertilization on lawn and fairway turf. Agron. J. 50:575-576.

48. Yee, J.Y. and K.S. Love. 1946. Nitrification of ureaformaldehyde reaction products. Soil Sci. Soc. Amer. Proc. 11:389-392.