EFFECTS OF NITROGEN FERTILIZATION ON THE SOD DEVELOPMENT OF KENTUCKY BLUEGRASS (Poa pratensis L. Merion) ON HOUGHTON MUCK AS MEASURED BY SEVERAL NITROGEN RESPONSES

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ABSTRACT

EFFECTS OF NITROGEN FERTILIZATION ON THE SOD DEVELOPMENT OF KENTUCKY BLUEGRASS (Poa pratensis L. Merion) ON HOUGHTON MUCK AS MEASURED BY SEVERAL NITROGEN RESPONSES

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Kendall R. English

It is known that excessive application of nitrogen reduces root and rhizome growth. Roots and rhizomes are necessary for a well-knit sod and rapid root and rhizome knitting is an essential goal of sod production. The problem is in finding a guide to nitrogen fertilization of sod. Using color as a guide for fertilization may cause over-fertilization, resulting in reduced root and rhizome growth. Limiting nitrogen levels will produce a weak, thin and poorly-developed sod. Excessive nitrogen, on the other hand, tends to slow sod development, thereby prolonging maintenance and increasing costs.

The purpose of this study was to determine the value of soil nitrate tests and clipping analyses for predicting the nitrogen needs for rapid sod development. To do this, a series of 16 nitrogen treatments were used. Merion Kentucky bluegrass (Poa pratensis L.) was seeded in the fall of 1969 at 40 pounds per acre. Factors studied were soil nitrate tests, clipping weights, nitrogen content of the clippings, total soil nitrogen, sod strength, rhizome length and weight, and re-rooting ability of the sod in the greenhouse.

The soil nitrate tests were not sensitive enough to discern among the lower nitrogen rates (0 to 30 pounds nitrogen per acre per month) which would be practical for sod. With high nitrogen rates (120 pounds nitrogen) the variation in values was extreme.

As nitrogen was increased clipping weights and nitrogen content in the clippings increased accordingly. The nitrogen content of the clippings was especially affected by fertilization and seasonal influences.

Sod strength and rhizome growth measurements obtained on July 22 were generally consistent. Higher nitrogen decreased sod strength and rhizomes. Timing of nitrogen application had a significant effect on both variables. The treatment which received 15 pounds nitrogen per month throughout the season gave consistently strong sod as well as those treatments which did not receive nitrogen after late spring.

Rerooting ability of the sod was affected by nitrogen application prior to harvest. The higher nitrogen rates reduced rerooting which prolonged establishment.

This study did not result in any test that would determine nitrogen needs but valuable insight was gained into seasonal variations of nitrate levels in the soil, shoot growth and percent nitrogen in the clippings. Other important considerations are rate and time of fertilization effects on stress conditions.

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TO ROBERT J. KRAUS

I dedicate this thesis to Robert J. Kraus,

a brother and a friend,

for his encouragement.

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INTRODUCTION

Commercial sod production has grown rapidly in recent years in Michigan. This growth has been primarily due to the demand for sod by our affluent society. Sodding has become an accepted means of establishing a turf. The advantages of sodding over seeding are: an immediate turf is established minimizing dust and mud problems; a quality turf can be established anytime during the growing season; and areas not easily established, such as slopes, are more readily established.

Michigan is well suited for sod production with reasonably moderate temperatures and extensive organic soil deposits located near metropolitan areas. Initially the bulk of the sod was produced on mineral soil, but most of the recent increase in production has occurred on organic soils. Production on organic soil has increased about ten fold between 1955 and 1965. Organic soils are ideally suited for production being relatively level. Sod produced on organic soil is lighter in weight allowing lower transportation costs.

The objective of sod production is to obtain a uniform stand of high quality turfgrass free of weeds, with acceptable color, sufficient maturity, and a root and rhizome system developed to a point where sod can be harvested and handled. The availability of improved Kentucky bluegrass varieties, development of the sod harvester, and utilization of effective pesticides, particularly herbicides, have eliminated many obstacles in producing sod.

Although all essential elements must be available to the turfgrass plant in adequate quantities, nitrogen is the most important nutrient which the sod producer controls. Nitrogen has a major influence on turfgrass color and growth. Excessive nitrogen promotes shoot growth at the expense of root and rhizome growth, thus weakening sod. Using color as a guide to nitrogen fertilization may result in excess nitrogen application. On the other hand, the sod may be weak and will not have an acceptable color if little or no nitrogen is used. There is a need for an effective means of determining the amount of nitrogen needed for growth and development of a mature sod.

It is the purpose of this investigation to study the effect of nitrogen fertilization on soil nitrate tests, clippings produced, nitrogen content of the clippings, and sod strengths. The ultimate objective is to determine the value of soil nitrate tests and nitrogen content of the clippings in predicting nitrogen needs for sod production on organic soil.

LITERATURE REVIEW

Organic Soil: origin, properties, and management.

Basins, lakes, and river beds provide conditions suitable for the development of organic deposits. Glaciation has left the topography in many areas conducive to the formation of swamps and marshes by impeding drainage (8). This has resulted in leaving the region liberally dotted with organic deposits ranging from a few inches to several feet in depth.

Organic soil formation occurs under water or where high ground water levels keep the accumulating organic matter partially saturated. The high water table and ideal climatic conditions produced a highly favorable environment which encouraged the growth of many plants. The plants in endless generations accumulated in the water in which they grew. The water acted as a preservative, by keeping microbial activity to a minimum, thereby delaying decomposition. The result was an accumulation of organic material from preceding generations of vegetation.

Michigan had the conditions for organic soil development to occur and its landscape is dotted with such soils. There are 4-1/2 million acres of organic soil in Michigan (11). Some deposits are so small that it is uneconomical to bring them under cultivation, but others are large and many of these are in crop production.

An organic soil is one that contains at least 30% organic material to a depth of one foot. Most organic soils in Michigan could be described as containing 80% organic material. The materials composing organic soils have been extensively described as accumulations of the plant remains. Plant remains are those parts of a plant which are relatively resistant to rapid decomposition. Two textures, peat and muck, are arbitrarily recognized by those who manage organic soils (8). A well decomposed organic soil is referred to as a muck while a slightly decomposed soil is a peat. An organic soil may be well decomposed on the surface but underlying layers may be only slightly decomposed peat. Thus, in many instances peat has a layer of muck above it. With the advent of drainage, a peat may be oxidized to muck.

Organic soils are classified on vegetative material composition, chemical reaction, depth of the deposit, and the nature of underlying material if the depth of the deposit is less than 42 inches (11).

The management of organic soils is quite different than for mineral soils. Artificial drainage is usually needed for crop production because organic soils were formed under poorly-drained conditions (3). Irrigation is a common practice on organic soils to supplement natural precipitation because of the high productivity of organic soils. The plowing of organic soils is largely for the purpose of covering trash and crop residues rather than for aeration. Organic soils generally need packing rather than loosening (12).

It has long been recognized that organic soils are rich in nitrogen (12). Under certain conditions, however, it may be quite unavailable to growing plants. High acidity, high water table and cool soil temperatures result in slow release of nitrogen. The nitrogen is released from organic material decomposition by soil microbes. The microbes convert very complex organic molecules to an inorganic state. This conversion is called mineralization (1). During this process organic nitrogen is changed to ammonia which is in turn rapidly oxidized to nitrite and than nitrate (29).

Nitrates tend to accumulate in organic soils during the growing season. The amount of accumulation is dependent on both temperature and moisture conditions of the soil (2, 45). Wyler and Delurche (48) showed that water content of soils indirectly influences nitrogen losses from denitrification by inhibiting oxygen diffusion. As the moisture content increases in the soil the amount of oxygen decreases limiting oxidation of the ammonia. Therefore, the nitrogen-fertilizer need for crops grown on organic soils is very dependent on weather conditions that influence soil temperature and moisture. Nitrates are also subject to leaching, denitrification, and volatilization. Even under ideal conditions for mineralization, nitrates may be removed from the soil. Broadbent and Stojanovic (7) found a 16% loss of tagged nitrogen, applied as nitrate nitrogen, under fully aerobic conditions. The losses increased as oxygen tension decreased in the soil.

The activity of the microbes is very low when soil temperatures drop below 5 C and very little organic nitrogen is released (1, 11). Throughout the growing season an increase in soluble nitrogen can be expected from the decomposition of organic material because of the greater activity of microbes in response to an increase in soil temperature.

The nitrogen content of organic soils ranges from 0.3 to 4.0% with reed-sedge peats being at the higher end (11). The plant composition of the organic deposit affects the nitrogen level in the soil. The carbon-to-nitrogen ratio is significant as well. For microbes to thrive the ratio must be close to 10 to 1 (24).

Soil tests for nitrogen have not proved valuable for evaluating soil nitrogen supplying capacity of soils. Results from nitrogen tests are complicated by the fact that nitrogen availability depends on decomposition of organic matter (42).

Sod Industry: history, development, and management.

Sod production is the fifth largest agricultural industry in Michigan (23). Only limited research has been conducted on sod production because of its small acreage until recent years and because it has not been considered an important agricultural commodity. Sod production is not a new industry to Michigan, however.

Commercial sod was first available in 1919, limited primarily to sod of high quality (33). During the developing years, a common practice employed for low quality sod was to mow a Kentucky bluegrass pasture closely for two or three months and then harvest the sod. Sod production has now evolved to a point where the sole objective on many farms is to grow and sell quality sod.

The period of rapid growth began in the middle 1950's. The primary cause of growth was the affluence of our society which was ready to accept sod as a source of an immediate lawn eliminating the time necessary to establish a lawn from seed. Key factors in the development of the expanding industry were the advent of improved Kentucky bluegrass varieties, development of herbicides and pesticides, and technological advances.

Prior to the period of rapid growth, almost all the sod acreage occurred on mineral soils. To meet the need of the expanding industry many farms on organic soils were taken out of vegetable production and placed in sod. Thus, most of the growth of the industry occurred on organic soils, according to Beard et al. (4). In just ten years the acreage on organic soils increased from about 2,000 acres in 1955 to over 20,000 acres in 1965 (33). This rapid increase has slowed only recently.

Organic soils are better suited to sod production than mineral soils. Rieke and Lucas (34) stated that there are several advantages of organic soils over mineral soils in sod production. It generally takes 12 to 18 months to produce a high quality sod on organic soil; mineral soils often take six months longer (3). Organic soils are free of stones and provide relatively flat areas which facilitate establishment.

In a comparison of sod grown on organic and mineral soils, Dunn and Engel (14) found no differences in their rerooting ability, although the thin cut sod of either soil rooted much faster. King and Beard (18) ranked organic soil higher in root production, but not significantly.

A species or variety of turfgrass utilized for sod must be rapid and vigorous in establishment and have a rapid root and rhizome development (3). Merion Kentucky bluegrass (*Poa pratensis* L.) dominates the sod industry in Michigan. Rieke and Beard (32) believe that Merion comprises most of the sod acreage because of its vigorous rhizome growth and sod-forming characteristics and its resistance to *Helminthosporum* leafspot.

The objective of sod production is to obtain a uniform stand of turf possessing a root and rhizome system developed to the point where a piece of sod may be harvested and handled without tearing. High quality sod characteristics are: uniformity, good shoot density, acceptable color, freedom from serious weeds or diseases, adequate sod strength for handling, sufficient carbohydrate reserves for rapid re-rooting, and a minimum thatch layer as clarified by Beard et al. (4).

Sod production has recently become very competitive because of expanded production and because the economy has restricted the market for commercially-grown sod. Thus, to be competitive, the grower must be extremely aware of his costs. Reducing the time between planting and harvest is one important means of reducing cost; still, he must have a saleable product that is acceptable to the consumer.

Schmidt (38) suggested that the more rapidly the root system develops the sooner the crop can be harvested. The root system must be sufficient to hold the sod together during harvest, handling, and laying. The time needed for a sod to develop sufficiently has varied from less than six months to two years or more.

Turf maintenance practices for sod production should consider root and rhizome growth primarily with less emphasis placed on the above-ground portion of the plant (3). Following establishment fertilization may be restricted to nitrogen if the phosphorus and potassium needs have been satisfied by seedbed fertilization (32). Daniel (10) felt that once a turf is established for sod it should be maintained with a moderate nitrogen fertility until the time of sale approaches.

Research: effects of nitrogen fertilization on turf.

The importance of nitrogen for turfgrass is well documented. Roberts (35) felt the nitrogen influence on turfgrass growth and quality was greater than any other mineral nutrient used in turf fertilization. Its most direct effect is on the growth of the plant. According to

Schmidt (38), nitrogen fertilization enhances photosynthesis and normally stimulates respiration and top growth causing a net reduction of plant carbohydrate reserves. Nitrogen stimulates growth of the upper portion of the plant and it improves the appearance of the turf. Nitrogen deficiency is easily recognized by the chlorotic appearance of the turfgrass plant.

Nitrogen requirements depend on many variables including clippings (removed or not removed), soil reaction, soil fertility level, physical condition of the soil, fertilizer characteristics, water program, weather, and the use that will be made of the turf according to Juska and Hanson (17). One of the most important factors in determining the nitrogen fertilizer need is the fertility level of the soil. Grable and Johnson (15) found that soils with a high organic matter content were yielding significantly more perennial ryegrass than soils with low organic matter content. This was probably due to a higher nitrogen fertility level associated with more organic matter. In dealing with an organic soil, the nitrogen fertility requirements may be different than with a mineral soil.

Under normal soil conditions, nitrate is the principal source of nitrogen utilized by most higher plants; it is absorbed into the plant, reduced to ammonia and then incorporated into amino acids and proteins for plant growth (39). Ward (46) reported that most grasses preferentially absorb nitrogen in the nitrate form but may also absorb ammonium nitrogen.

It is well documented that there is an increase in top growth with increased nitrogen. Dotzenko (13) found marked increases in the forage of six forage grasses from nitrogen fertilization. McLean (22) reported that plants grown under variable nitrogen levels produced increased top growth with higher nitrogen rates for 20 agronomic crops including some grasses. Ramage et al. (30) also had the highest dry matter yield of orchardgrass and reed canarygrass with the highest rate of nitrogen fertilizer.

Another important effect of nitrogen fertilization on the turfgrass plant is on root growth. The root system is of primary importance in sod production. Earlier reports (18, 26) show that nitrogen fertilizer, particularly at higher rates, stimulates top growth at the expense of root growth. Oswalt et al. (27) found that roots of orchardgrass and bromegrass reached a greater depth when no nitrogen was applied. Long, slender roots result where nitrogen levels were low, whereas nitrogen increased the root diameter and decreased the rate of elongation causing shorter roots (5, 43). Schmidt (38) felt that root growth could be improved with low additions of nitrogen but higher amounts would inhibit root development. Therefore, nitrogen fertilizer has the greatest influence on the development of sod. Too little or no nitrogen leaves a weak, poorly developed turf which is subject to weed invasion reducing sod quality. On the other hand, excessive nitrogen tends to delay development of sod (36).

The growth of roots on a Kentucky bluegrass plant is perennial. Stuckey (41) found differences in the type of root regrowth for various grasses. Some species initiate new roots and the old roots die while other species maintained growth of the old roots and initiated few new roots. There are also peak periods of root growth. Stuckey (41) reported that root growth occurred mainly in the spring and fall on most species of grass and that during the summer months no elongation occurred and no new roots appeared.

Increases in shoot growth and decreases in root growth occur simultaneously. Oswalt et al. (27) found the addition of nitrogen increased the weight of shoots while decreasing the weight of roots, the number of roots, and the rate of root elongation. Harrison (16) reported that high nitrogen caused the plants to stop producing rhizomes during the fall with short, cloudy days and many roots and rhizomes died due to a lack of carbohydrate reserves. Madison et al. (21) found that increasing nitrogen not only increases yield but also verdure (quantity of green turf) and chlorophyll, while decreased rooting resulted.

Upon casual observation, the effect of nitrogen fertilizer is to improve color and stimulate growth but many physiological changes occur as well. Carroll (9) found that high nitrogen fertilization of turfgrasses caused them to be less able to withstand adverse conditions. Dotzenko (13) observed a loss of stand at high rates of nitrogen on six grasses. Pellet et al. (28) found that high nitrogen reduced resistance to high temperature stress more than low nitrogen, while phosphorus and potassium had no effect on the Kentucky bluegrass.

Turfgrasses fertilized with high rates of nitrogen have comparatively low carbohydrate reserves and consequently are subject to rapid deterioration during periods of stress. Schmidt (38) found that respiration and top growth have priority over root development in utilizing carbohydrates. Stimulated growth, encouraged by heavy nitrogen, is produced by depleting the carbohydrates and other food reserves. Pellet et al. (28) felt that the use of carbohydrates and food reserves for growth makes them unavailable for differentiation processes necessary for increased resistance of plant tissues to unfavorable conditions.

It is of interest to consider the nitrogen content of the clippings as affected by various amounts of nitrogen fertilizer. Dotzenko (13) reported a higher percentage total nitrogen in the forage of six grasses with an increase in nitrogen fertilizer applied but a reduced percentage of nitrogen recovered. Volk and Horn (44) found the percentage of nitrogen in bermudagrass was always highest with the higher nitrogen applications, which in general agreed with the visual turf ratings for color. Walker et al. (45) found that Italian ryegrass uptake of both fertilizer nitrogen and soil nitrogen increased with the amount of nitrogen applied.

Grable and Johnson (15) reported the nitrogen content of ryegrass was increased in every instance by additions of nitrate nitrogen but nitrogen content decreased from the first clipping date to the last because only one application was made at the beginning. Nitrogen fertilization seems to bring on a new flush of growth but as time passes the nitrogen disappears. Mortimer and Ahgren (25) observed that the percentage of nitrogen in herbage of Kentucky bluegrass varied directly with the amount of nitrogen fertilizer applied and that grass with a high nitrogen content is produced only where frequent applications of nitrogen are made throughout the growing season.

Nitrogen recovery decreases with amount of nitrogen applied. Grable and Johnson (15) reported that, in field experiments using ryegrass, efficiency decreased with increasing increments of nitrogen in nearly every instance. They also found greater efficiency in the greenhouse, possibly due to the fact that leaching did not occur in the greenhouse. Ramage et al. (30) reported percentage nitrogen recovery decreased with increasing rates of nitrogen applied except for the lowest rate. Scarsbrook (37) studied the efficiency of nitrogen fertilizers and found that ammonium nitrate resulted in the highest nitrogen recovery on bermudagrass.

The type of fertilizer is of importance as to its rate of nitrogen release, but Juska and Hanson (17) reported the rates and time of application appeared to be of greater importance in maintaining turf quality than did sources of nitrogen. Overstimulation, following one heavy application of nitrogen, can be more serious than the same amount applied in several applications (17).

For the production of a high-quality sod, proper manipulation of nitrogen is needed. Kurtz (19) concluded that 4 pounds of nitrogen per 1000 sq. ft. over a period of three months produced higher-quality sod on a mineral soil than did lower nitrogen rates. This treatment produced the most top growth, initiated the most rhizomes, and had the greatest turf density.

Satari (36) in sod production studies on Houghton muck found that nitrogen reduces the production of rhizomes only during the later stages of development. Potassium also played an important role. He showed that root production was highly correlated with rhizome production and nitrogen reduces the yield of both with increased amounts applied.

It can now be understood why nitrogen is the key nutrient in turfgrass growth and development. The manipulation of nitrogen for rapid sod development is an important management variable. Presently, color is the most important guide to nitrogen fertilization. It is rather abstract and may lead to errors. It is purposed that this study will aid the development of a more meaningful technique for nitrogen fertilization of sod.

MATERIALS AND METHODS

I. Plot location and design.

Field plots were established at the Michigan State University Muck Experimental Research Farm. The soil samples taken from the area were analyzed by the Michigan State University Soil Testing Laboratory. The results of this analysis were pH 6.9; phosphorus and potassium were adequate for sod. Individual plot size was 9 feet by 15 feet. Sixteen treatments were applied with three replications for each treatment in a randomized block design.

II. Establishment.

The plot area was plowed to a depth of 12 inches, followed by discing and leveling operations for a firm, smooth seedbed. A Brillion cultipacker-seeder was used to seed Merion Kentucky bluegrass (*Poa pratensis* L.) at 40 pounds per acre on August 29, 1969.

III. Nitrogen treatment and application.

Ammonium nitrate (33.5% N) was used as the nitrogen source. All fertilizer applications were weighed in the laboratory and applied by hand to control application rates carefully. A long plywood board was used as a guide for the boundaries to prevent any overlapping. The nitrogen treatments utilized are given in Table 1. Seedbed nitrogen treatments were applied to the soil surface immediately after seeding and were raked in with a light hand raking. Treatments 9 through 12 did not receive nitrogen until after the seedlings were established on October 6, 1969.

The first nitrogen treatments in the spring were applied May 1, 1970 when drainage and weather conditions allowed. Subsequent applications were approximately a month apart except for September when frequent rains prevented application before September 30.

Table 1. Pounds of actual nitrogen applied per acre and application dates.

Treatment	1969	May 1	June 5	June 30	Aug 4	Sept 30	Total for 1970
1	0*	0	0	0	0	0	0
2	30*	30	30	30	30	30	150
3	60*	60	60	60	60	60	300
4	120*	120	120	120	120	120	600
5	0*	15	15	15	15	15	75
6	30*	15	15	15	15	15	75
7	60*	15	15	15	15	15	75
8	120*	15	15	15	15	15	75
9	0**	30	30	30	0	0	90
10	30**	30	30	30	30	30	150
11	60**	30	30	30	60	60	210
12	120**	30	30	30	120	120	330
13	30*	30	30	0	0	0	60
14	30*	30	30	30	30	30	150
15	30*	30	30	60	60	60	240
16	30*	30	30	120	120	120	420

*Ammonium nitrate in seedbed August 29, 1969.

**Topdress application of ammonium nitrate October 6, 1969.

IV. Soil sampling.

Soil samples were taken during the 1970 growing season on a bi-weekly interval from all plots. A stainless steel soil probe was used to take eight cores at random from each plot. Since most of the turfgrass roots are located within four inches of the soil surface, it was decided to sample to that depth. All surface vegetation was removed from the cores to facilitate handling in the laboratory. The samples were collected in one-pint plastic freezer bags to prevent loss of moisture or nitrates. The samples were stored in a cold room at 3 C until extraction could be performed.

V. Clippings.

Mowing commenced May 18, 1970 continuing at twice-a-week intervals except when weather conditions prevented mowing and during August when growth was especially slow. Mowing was done after the dew had evaporated and the turf was essentially dry. An 18-inch, reel-type mower with a catcher attachment was used to collect the clippings from an area 18 inches wide and 13.5 feet long in the middle of each plot. The entire plot area was mowed with a 5-gang, reel-type mower after completion of the sampling. Mowing height was 1 1/2 inches.

The harvested clippings were placed in a paper sack. The sacks were taken immediately to the laboratory for weighing for fresh weight determinations. They were placed in a forced air drying oven at 65 C for one week. The clipping samples were again weighed for dry weight and were stored for analyses.

VI. Sod strength.

Sod strength is a physical measurement which relates well to the development of roots and rhizomes. The more roots and rhizomes present, the greater the sod strength. An apparatus was developed at Michigan State University to measure sod strength (31). The preparation of a sample involves cutting a strip of sod (16 inches wide) with a sod cutter. The sod strip is then cut into three-foot lengths.

The apparatus is composed of a stationary and a movable platform, each 18 inches in length. There are hinged tops for each platform which can be clamped to the bottom part. The sod piece is laid across the platforms and clamped down with the hinged tops to prevent slippage.

Once the sod piece is secured in place, the movable platform is pulled with a uniformly increasing force until the sod tears apart. The force required to tear the sod is measured by inserting a spring scale (capacity 0 to 200 pounds) between the movable platform and a wench. The sod strength is measured by recording the highest value reached on the scale before tearing occurs. The sod is all cut to the same depth, approximately three-fourths inch.

Three sod pieces were tested for each plot. The sod strength measurements were performed on July 22, 1970 and October 15, 1970. The sod strip was cut along the south end of the plots for the first measurement and along the north end for the second measurement.

VII. Rhizome weight and length.

Samples were taken for rhizome measurements immediately following sod strength determinations on July 22. Samples were obtained with a 4 1/4-inch diameter golf course cupcutter. The depth of the plug was sufficient to remove all rhizomes. Three plugs were taken from each plot a short distance from the sod pieces used for sod strength measurements.

To facilitate separation of the rhizomes, a water hose was used to remove most of the soil from each plug. The rhizomes, which are larger and whiter than the roots, were removed, dried in an oven at 40 C and weighed. The dry rhizomes were measured by stretching each rhizome along a ruler and recording its length.

Laboratory Analyses

I. Nitrate analyses of soil samples.

The stored soil samples were removed within 48 hours after field sampling for extraction. The soil sample was mixed as thoroughly as possible in the plastic bag. A subsample of 25 to 35 gm was taken for moisture determination. The subsample was placed in a moisture can and weighed. The can and subsample were placed in a drying oven at 60 C for two days. The subsample was again weighed and all the weights recorded.

Two subsamples of between 5 and 10 gm were taken for nitrate analyses. Each subsample was placed in a 125 ml Erlenmeyer flask and 50 ml of saturated calcium sulfate solution was added. These were shaken on a rotary shaker at 200 rpm for 30 minutes. The mixture was filtered through No. 3 Qualitative Whatman filter paper. The extract was collected in 2 oz round glass bottles. These bottles of extractant were returned to the cold room for storage until nitrate analysis could be made. An attempt was made to keep the storage period at a minimum.

Two nitrate analyses were made on each subsample. Nitrate determinations were made using the procedure by Lowe and Hamilton (20) as automated by B. G. Ellis. The nitrate analyses required that the enzyme, nitrate reductase, reduce nitrate to nitrite which can be determined colorimetically.

Nitrate reductase is found in the bacteroids of soybean nodules. Soybean nodules were harvested from soybeans grown in the greenhouse and later from soybeans in the field. The nodules are removed from the soybeans and washed. Washing to clean and remove all soil particles was done using cold distilled water. The nodules were blotted dry with cheesecloth and ground with a cold mortar and pestle in K-succinate (0.1 M) buffer (5 mls per gram of nodules). For more complete grinding a Waring blender was later used to grind the nodules.

The slurry was squeezed through four layers of cheesecloth. The liquid was centrifuged at 5,000 G for five minutes or more. The red-colored supernatant was discarded. The solid portion was resuspended in the same amount of K-succinate buffer and recentrifuged. This was repeated until all the red color disappeared. The last resuspended solution was frozen. The greatest difficulty was to ascertain the activity for nitrate reductase. Use of standard solutions on each series of analyses not only provided the standard curve but insured nitrate reductase activity. It was found that repeated refreezing of bacteroid suspension was limited to one or two times before activity was lost. The frozen life of nitrate reductase was limited to one or two months without loss of activity.

As the summer proceeded, soil nitrates increased so smaller soil subsamples were used to reduce the need for dilution of the extractant. Potassium nitrate was used as the source of nitrate for the standard solutions. The standard curve ranged from 0 to 4.0 ppm nitrate nitrogen. After color was developed, percent transmission was measured on a colorimeter. The following formula was used in calculating ppm nitrate nitrogen in the extract:

$$\text{ppm } NO_3\text{-N} = \frac{(1-)\log \%A + \log \%X)\ (\text{Conc B} - \text{Conc A})}{(\log \%B - \log \%A)}$$

where A and B are results for 0 and 4 ppm standard solutions. Correction was made for percent moisture and the number of grams used in the subsamples using the formula:

$$\text{ppm } NO_3\text{-N/gm soil} = \frac{(50)\ (\text{gms dry soil}+1)\ (\text{ppm } NO_3\text{-N})}{(\text{gms wet soil} - \text{gms dry soil}+1)\ (\text{Wt subsample})}$$

The value 50 represents the 50 ml of saturated calcium sulfate used in extraction.

II. Total nitrogen analyses of the clippings.

Because of the large number of clipping samples only the first five treatments for all clipping dates were analyzed. A modified semi-micro Kjeldahl method (6) was used. Those samples larger than 20 gm were mixed and subdivided until the subsamples were between 10 and 20 gm. All samples and subsamples were ground in a Wiley Mill to pass a 40-mesh screen.

Approximately two hundredths of a gm of plant material was weighed for each sample and placed in a micro-Kjeldahl flask. Two ml of distilled water were added and the mixture was allowed to stand for 30 minutes. For digestion of the sample, two tenths of a gm of potassium sulfate-catalyst mixture and two ml of concentrated sulfuric acid were added. This was heated cautiously on a digestion stand until frothing stopped and water was removed. It was sometimes necessary to use hydrogen peroxide to wash particles down the sides of the Kjeldahl flask during digestion.

The samples were then steam distilled on a distillation apparatus. The distillant was caught in a 50 ml Erlenmeyer flask containing 5 ml of boric acid-indicator solution. Approximately 15 ml of distillant was caught in 3 to 5 minutes. This was titrated against a standardized solution of sulfuric acid until the first gray color appeared. The following equation was used to calculate the percent nitrogen:

$$\% \, N = (T-B)\ (N)\ (1400)/S$$

Where T is ml of acid used for titrating the sample, B is ml of acid used in titrating the blank, N is the normality of the sulfuric acid, and S is the sample weight in mg.

III. Total nitrogen analysis of the soil.

Total nitrogen is usually of little value in determining nitrogen availability to plants. Therefore, soil samples from the first five treatments were run for four selected dates. It was decided that if there was any useful information in the total nitrogen analysis of the soil it would appear in these samples. The procedure of analysis was similar to that used for the clippings except approximately one-tenth of a gm of soil was used.

Greenhouse Rerooting Experiment

In an effort to determine the effect of nitrogen treatment on re-rooting of sod, a rooting study was done in the greenhouse. When the October 15 sod strength measurements were made, a 4 1/4-inch plug was taken from each piece of sod (3/4 inch depth). These were transplanted in one-quart cottage cheese containers located in the greenhouse.

A loamy sand soil was screened and fertilized to add one pound nitrogen and four pounds each of K_2O and P_2O_5 per 1000 square feet with 6-24-24. Eleven hundred gm of the fertilized soil was placed in each container. Two hundred ml of distilled water was added to each pot. The plugs were placed in firm contact with the moistened soil and another 100 ml of distilled water was added immediately afterwards. At each watering all pots were brought up to a standard weight to reduce variability in watering.

Each pot was clipped on November 3 and November 20. Clippings were dried in a forced air oven (65 C) and weighed. The experiment was treated for powdery mildew November 3 with sulfur. The experiment was terminated November 23, 1970. The sod plugs were removed and all the original sod was separated from the underlying soil with scissors. The roots were removed from the soil by washing over a 4-mesh screen. The roots were removed from the screen with tweezers and placed in coin envelopes. They were dried in a drying oven (40 C) and weighed.

Statistical Methods

An analysis of variance was compiled on each date for all data and each treatment for all dates. If the F test for treatment means was significant, then the least significant difference was examined at the 5% level (40).

Units of Measure

The units of measure are expressed in the English system except for very small values which are stated in the metric system. The English system is used for easy interpretation by those involved in sod production. The following can be used for converting metric units to the English system:

$$\text{pounds} = \text{grams} \times (1/453.59)$$

$$\text{inches} = \text{centimeters} \times (1/2.54)$$

RESULTS AND DISCUSSION

I. Nitrate soil test.

The results of the nitrate soil tests are presented in Table 2 and summarized in Figures 1, 2, and 3.

The data for Treatments 1 through 4 are represented graphically in Figure 1. Treatment 1 did not receive any nitrogen fertilizer for the entire experiment and is referred to as the check. The nitrate level of the check, in general, increased during the season. The lowest was on May 14, being 4.4 ppm nitrate nitrogen in the soil, and the highest on October 27 with 36.6 ppm. The increase in nitrates during the season for the check is probably due to nitrogen release from the soil by microbial activity, nitrogen additions by rainfall, and the decomposition of clippings returned by mowing.

Treatment 2 (30 pounds nitrogen per acre per month) varied little from the check being significantly higher on only two dates. Treatment 3 (60 pounds nitrogen per month) did vary from the check with the largest increases occurring one week after fertilizer application. The nitrate levels for Treatment 3 approached those of the check at three weeks after fertilization. The increase of nitrates following fertilizer application in Treatment 3 was greater after each subsequent fertilizer application. Treatment 4 (120 pounds nitrogen per month) was highly erratic with sharp increases in nitrates following fertilizer application and steep declines before the next fertilization, but values were

Table 2. Nitrate nitrogen in soil, ppm, average of 3 replications by date and treatment.

	Date of Sampling										
Treatment No.	4-24	5-14	6-1	6-17	7-6	7-24	8-11	8-24	10-7	10-27	Average
1	14.5	4.4	14.0	14.6	16.9	34.3	26.2	21.8	34.8	36.6	22.4
2	10.4	14.2	17.1	14.6	22.0	33.3	32.5	25.9	36.1	43.2	24.9
3	16.9	13.7	17.3	29.8	33.3	35.4	53.4	30.4	84.2	51.0	36.5
4	16.9	107.6	19.5	151.0	199.1	61.8	228.6	95.3	310.1	91.1	128.1
5	9.7	9.4	13.8	17.4	23.1	36.2	33.9	25.0	41.3	66.8	27.7
6	11.9	6.9	17.6	14.3	25.7	27.8	33.2	27.8	35.4	62.8	26.3
7	12.4	6.4	10.7	14.9	24.1	31.4	28.9	28.6	39.4	42.8	23.9
8	10.5	6.1	14.2	18.7	22.4	30.1	26.0	27.5	40.1	49.4	24.5
9	10.2	5.7	13.8	16.4	23.4	26.9	29.8	29.8	33.9	46.5	23.6
10	8.4	6.9	11.6	22.6	26.6	27.6	26.8	30.6	41.4	53.7	25.6
11	20.2	6.8	13.6	19.3	26.9	32.9	26.9	30.3	54.6	66.2	29.8
12	16.2	6.7	13.9	17.7	23.7	32.2	71.0	39.5	262.1	86.8	57.0
13	10.5	9.6	13.6	20.8	25.5	34.9	29.0	30.0	40.1	41.8	25.6
14	10.3	10.8	12.4	12.6	24.8	30.1	25.3	21.9	47.6	50.7	24.6
15	9.5	4.6	8.6	15.9	27.2	38.3	30.8	26.2	65.2	115.7	34.2
16	12.2	4.9	12.6	16.8	29.2	35.0	63.2	34.2	199.9	74.1	48.2
lsd, .05	1.7	2.1	2.9	4.3	8.4	3.4	9.1	6.0	11.0	11.1	2.7

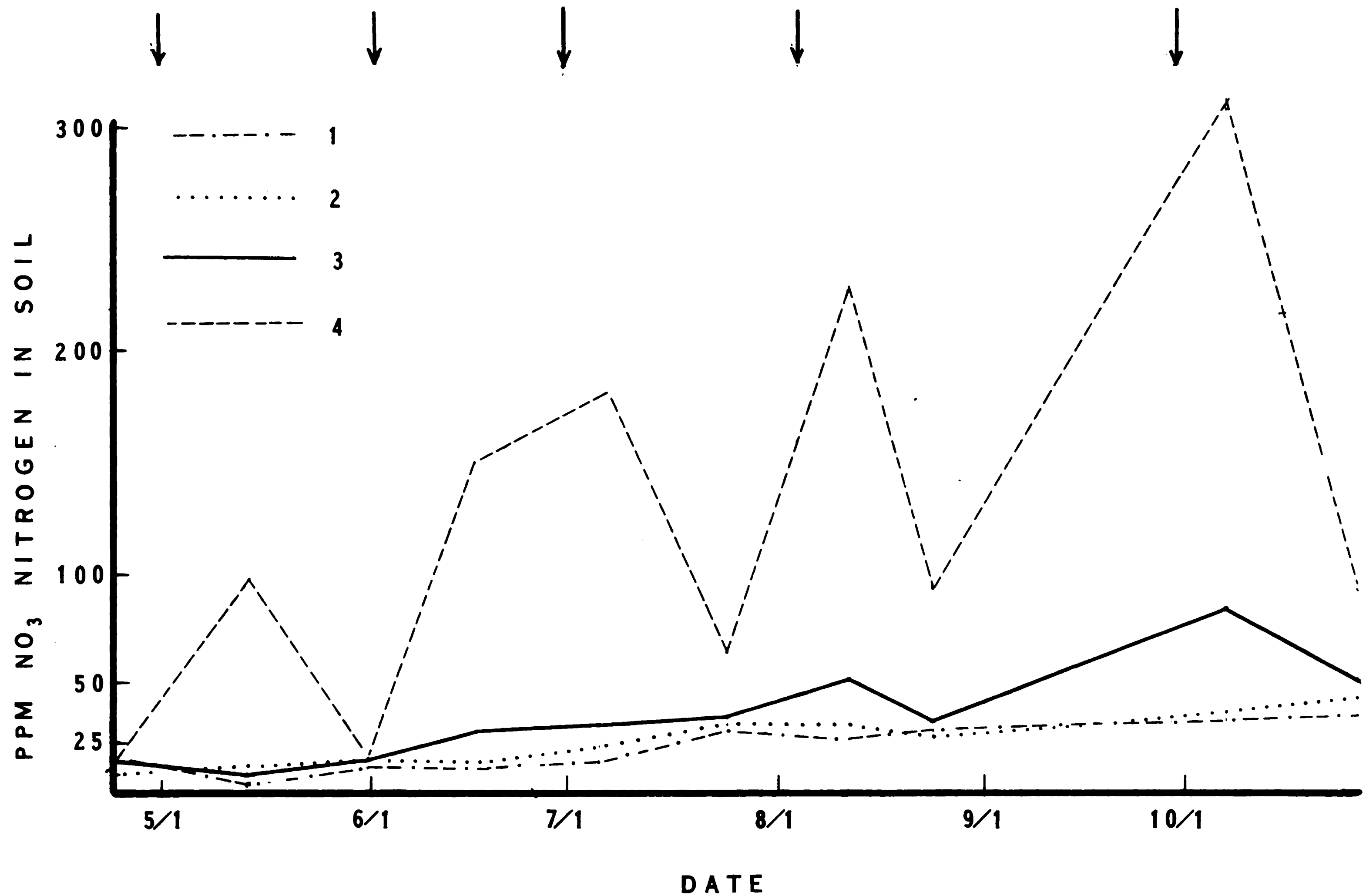


Figure 1. Average ppm nitrate nitrogen in soil for Treatments 1 through 4 of 0, 30, 60, and 120 pounds nitrogen per acre, respectively. Arrows indicate date of fertilizer application.

always significantly higher than the check. The nitrate nitrogen levels for Treatment 4 generally increased during the season as with other treatments.

It is apparent that there are large losses of nitrates in the heavily-fertilized plots. These losses cannot be specifically determined by this study but may be due to leaching, immobilization, or gaseous loss of nitrogen.

Treatments 5 through 8 received 15 pounds of nitrogen per month after the initial seedbed application. There were only small differences between these treatments and the check.

Treatments 9 through 12 received 30 pounds nitrogen per month for the first three fertilizer applications, then on August 4 the treatments were changed to 0, 30, 60, and 120 pounds of nitrogen, respectively. Figure 2 presents the data in graphic form for these treatments. The differences between these treatments were small and similar to nitrate levels for Treatment 2 until the change in fertilization rates. Immediately following the August 4 applications there was a significant increase in the nitrate level of Treatment 12, while Treatments 9, 10, and 11 varied little. Treatment 12 remained significantly higher for the rest of the season. The September 30 application of nitrogen produced another sharp increase in nitrate levels in Treatment 12 as was observed with Treatment 4, but not of the same magnitude. Nitrate levels for Treatment 11 also increased significantly following the September 30 fertilizer application, while differences between Treatments 9 and 10 remained nonsignificant.

Treatments 13 through 16 are summarized in Figure 3. They received 30 pounds of nitrogen fertilizer per month for the first two applications in 1970, then on June 30 they were changed to 0, 30, 60, and 120 pounds

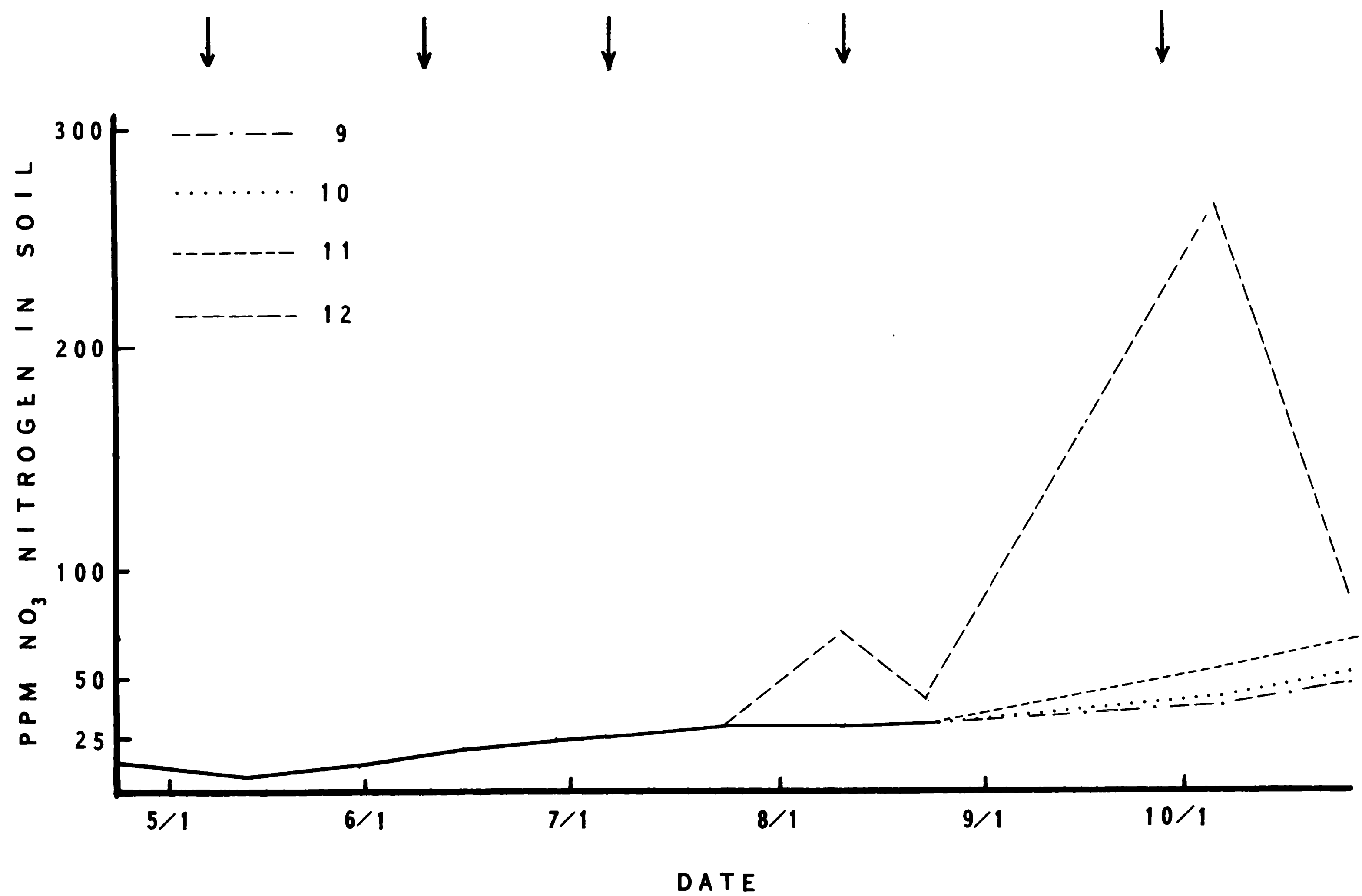


Figure 2. Average ppm nitrate nitrogen in soil for Treatments 9 through 12. Arrows indicate date of fertilizer application. The first three applications were 30 pounds nitrogen per acre for all treatments and the last two were 0, 30, 60, and 120 pounds nitrogen per acre, respectively.

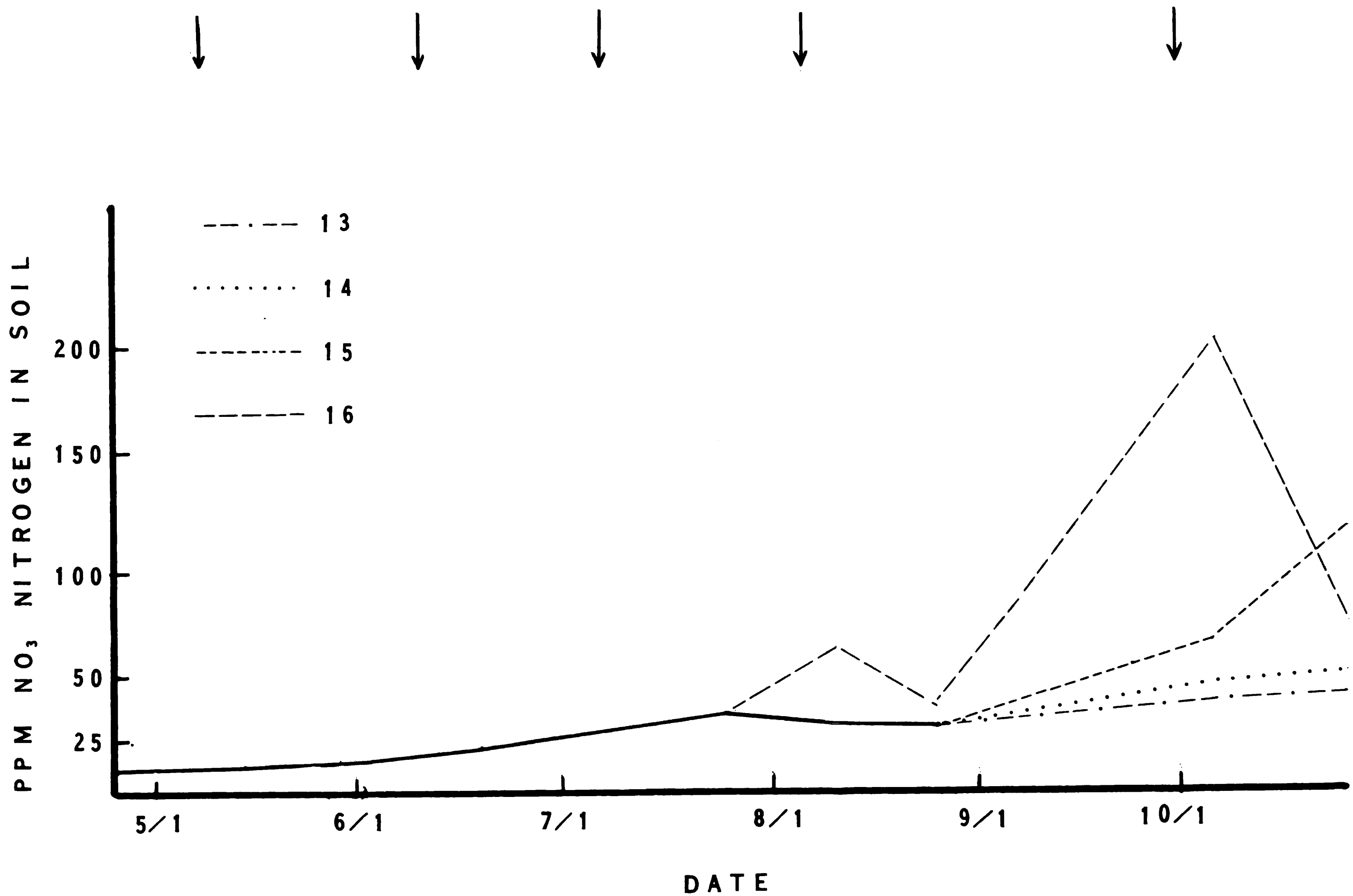


Figure 3. Average ppm nitrate nitrogen in soil for Treatments 13 through 16. Arrows indicate time of fertilizer application. The first two applications were 30 pounds nitrogen per acre for all treatments and the last three were 0, 30, 60, and 120 pounds nitrogen per acre, respectively.

nitrogen per acre per month, respectively. It is interesting to note that there was no change among the treatments until after the August 4 fertilizer application. Following this fertilizer application, the effect was similar to that observed in Treatments 9 through 12. The nitrate level of Treatment 16 increased significantly, while the others remained similar. Then, following the September 30 application of fertilizer, there was a sharp increase in nitrates for Treatment 16, but they did not increase as much as Treatment 12 which received less total nitrogen. Treatments 13 and 14 remained similar, while Treatment 15 increased significantly only after the September 30 application.

It may be noted that Treatment 15 exhibited a significant increase in nitrate level at the last sampling date compared to all other treatments. This was also a marked increase over the previous sampling date and was not characteristic for Treatments 13, 14, and 16. The nitrate values for the third replication on October 27 were unusually high causing this unreasonable difference in the data. There is no ready explanation for this difference with the possible exception of contamination of the sample.

It is important to realize that Treatments 1 through 12 all received varying amounts of nitrogen fertilizer the previous fall, but the April 24 nitrate soil tests did not show any trends for increased nitrates in the soil which were related to rate of nitrogen applied. This points out that fall-applied nitrogen may not be available to the plant the following spring.

All treatments showed a trend for an increase in nitrate nitrogen in the soil during the season. It is obvious that the excessive rate of 120 pounds nitrogen per acre can be detected soon after it is applied. The soil nitrate test is somewhat less sensitive for the lower nitrogen treatments especially at the 15 or 30 pound-per-month level which are more practical rates of application. Thus the value of nitrate soil tests in determining the amount of nitrogen needed for sod development is of questionable value. Although one could determine that an excessive amount of nitrogen has been applied recently this has little practical significance to the grower.

The statistical analyses showed that there were some significant differences between replications which reduced the significance of the differences between treatments. There was no date of sampling without some replications within a treatment being significantly different at the 5% level.

II. Clipping weights.

The fresh clipping weights by date are given in Tables 3 through 6. The accumulative fresh clipping weights are summarized in graphic form in Figures 4, 5, and 6. The accumulative dry clipping weights are given in Tables 12 and 13 of the Appendix. The moisture content of the clippings increased with increasing amounts of nitrogen fertilizer applied. The results of the treatments receiving 0, 15, 30, 60, and 120 pounds nitrogen per month had average moisture contents of 67.0, 71.6, 72.8, 74.8, and 76.1 percent, respectively, of the amount of top growth that has occurred.

Figure 4 shows results for Treatments 1 through 5. The check had a small increase in clipping weights during the early part of the season with little further increase during the rest of the season. Total fresh weight production was 1400 pounds per acre. Treatment 5 received only 15 pounds nitrogen per month but showed a significant increase in growth over the check. Even these small increments of nitrogen greatly

Table 3. Fresh clipping weights for Treatments 1 through 4, pounds per acre.

Date	Treatment No. 1	2	3	4	*lsd .05
5-18	359	1580	3398	4970	1125
5-23	182	690	1721	2401	396
5-26	153	394	688	1173	143
5-28	44	118	255	360	53
6-4	121	351	764	1415	140
6-9	50	271	574	971	123
6-11	27	162	375	483	62
6-16	34	489	939	1095	177
6-19	19	207	464	771	109
6-22	18	232	458	661	107
6-25	14	144	364	464	68
6-29	17	146	339	641	66
7-2	10	135	370	596	53
7-6	9	180	595	817	119
7-9	9	149	421	705	75
7-13	12	249	594	1081	121
7-16	10	137	392	709	82
7-21	7	187	379	799	135
7-29	9	106	298	699	79
7-30	3	9	67	268	34
8-6	1	16	114	338	69
8-13	3	43	448	739	95
8-20	3	89	698	1330	244
8-26	7	127	684	1398	182
9-1	5	120	506	921	115
9-4	11	135	376	645	105
9-8	19	191	491	784	88
9-11	37	372	592	776	113
9-16	35	284	601	953	135
9-21	36	344	710	980	156
10-1	53	502	1078	1552	253
10-6	18	251	482	678	125
10-15	26	421	728	801	189
10-27	34	428	998	1435	192
11-12	6	138	517	866	143
Total	1400	9395	22480	35276	1890

*Least significant differences at 5% level are based on analyses of variance of all 16 treatments.

Table 4. Fresh clipping weights for Treatments 5 through 8, pounds per acre.

Date	Treatment No. 5	6	7	8	*lsd .05
5-18	1313	1506	1592	1780	1125
5-23	696	824	847	780	396
5-26	454	529	410	439	143
5-28	126	167	144	144	53
6-4	302	345	351	375	140
6-9	260	292	275	251	123
6-11	116	154	141	128	62
6-16	239	327	290	229	177
6-19	113	191	128	97	109
6-22	98	176	101	84	107
6-25	63	112	87	74	68
6-29	80	119	81	64	66
7-2	64	102	68	76	53
7-6	81	139	95	90	119
7-9	62	84	74	62	75
7-13	116	159	129	107	121
7-16	101	119	88	74	82
7-21	72	74	70	69	135
7-29	49	60	53	56	79
7-30	3	2	2	2	34
8-6	3	3	3	4	69
8-13	7	6	6	8	95
8-20	16	14	16	19	244
8-26	34	19	24	29	182
9-1	28	26	34	30	115
9-4	80	62	61	64	105
9-8	106	103	115	79	88
9-11	228	219	222	231	113
9-16	184	207	196	191	135
9-21	218	220	219	238	156
10-1	369	368	366	360	253
10-6	175	171	181	166	125
10-15	251	269	284	259	189
10-27	198	185	235	224	192
11-12	69	76	57	78	143
Total	6373	7429	7046	6963	1890

*Least significant differences at 5% level are based on analyses of variance of all 16 treatments.

Table 5. Fresh clipping weights for Treatments 9 through 12, pounds per acre.

	Treatment No.				
Date	9	10	11	12	*lsd .05
5-18	870	2211	2056	2362	1125
5-23	688	958	918	1539	396
5-26	441	518	542	806	143
5-28	142	136	183	218	53
6-4	327	482	436	453	140
6-9	366	374	326	398	123
6-11	250	213	183	241	62
6-16	647	611	500	626	177
6-19	311	288	286	333	109
6-22	269	276	243	264	107
6-25	171	215	139	158	68
6-29	189	217	173	197	66
7-2	197	185	150	169	53
7-6	315	324	229	277	119
7-9	237	235	202	179	75
7-13	386	448	303	284	121
7-16	271	228	210	240	82
7-21	230	160	184	197	135
7-29	170	128	135	135	79
7-30	13	8	11	10	34
8-6	17	13	16	20	69
8-13	16	50	150	359	95
8-20	23	82	375	1163	244
8-26	120	105	434	1371	182
9-1	29	98	331	843	115
9-4	76	134	284	553	105
9-8	108	207	376	622	88
9-11	218	339	506	705	113
9-16	202	322	470	683	135
9-21	228	358	534	834	156
10-1	349	544	810	1192	253
10-6	105	281	515	593	125
10-15	161	445	748	808	189
10-27	144	451	803	1008	192
11-12	41	188	443	544	143
Total	8329	11834	14204	20473	1890

*Least significant differences at 5% level are based on analyses of variance of all 16 treatments.

Table 6. Fresh clipping weights for Treatments 13 through 16, pounds per acre.

Date	13	14	15	16	*lsd .05
	Treatment No.				
5-18	1521	2063	2374	1802	1125
5-23	752	928	1312	1014	396
5-26	356	552	543	605	143
5-28	123	178	206	173	53
6-4	428	477	541	451	140
6-9	336	439	486	395	123
6-11	203	271	278	265	62
6-16	497	664	655	593	177
6-19	225	367	305	284	109
6-22	192	339	330	316	107
6-25	195	200	177	168	68
6-29	184	213	197	193	66
7-2	154	189	173	182	53
7-6	163	299	292	141	119
7-9	137	213	251	314	75
7-13	169	324	340	541	121
7-16	106	239	236	395	82
7-21	87	212	207	317	135
7-29	81	150	153	244	79
7-30	5	9	14	28	34
8-6	6	16	21	83	69
8-13	6	66	187	346	95
8-20	13	152	449	1195	244
8-26	24	71	614	1241	182
9-1	42	137	402	732	115
9-4	70	140	278	537	105
9-8	100	237	412	605	88
9-11	199	343	552	638	113
9-16	193	347	520	703	135
9-21	210	414	599	758	156
10-1	310	614	913	1155	253
10-6	100	325	509	536	125
10-15	143	493	796	752	189
10-27	176	394	911	1104	192
11-12	48	183	472	638	143
Total	7554	12258	16706	19746	1890

*Least significant differences at 5% level are based on analyses of variance of all 16 treatments.

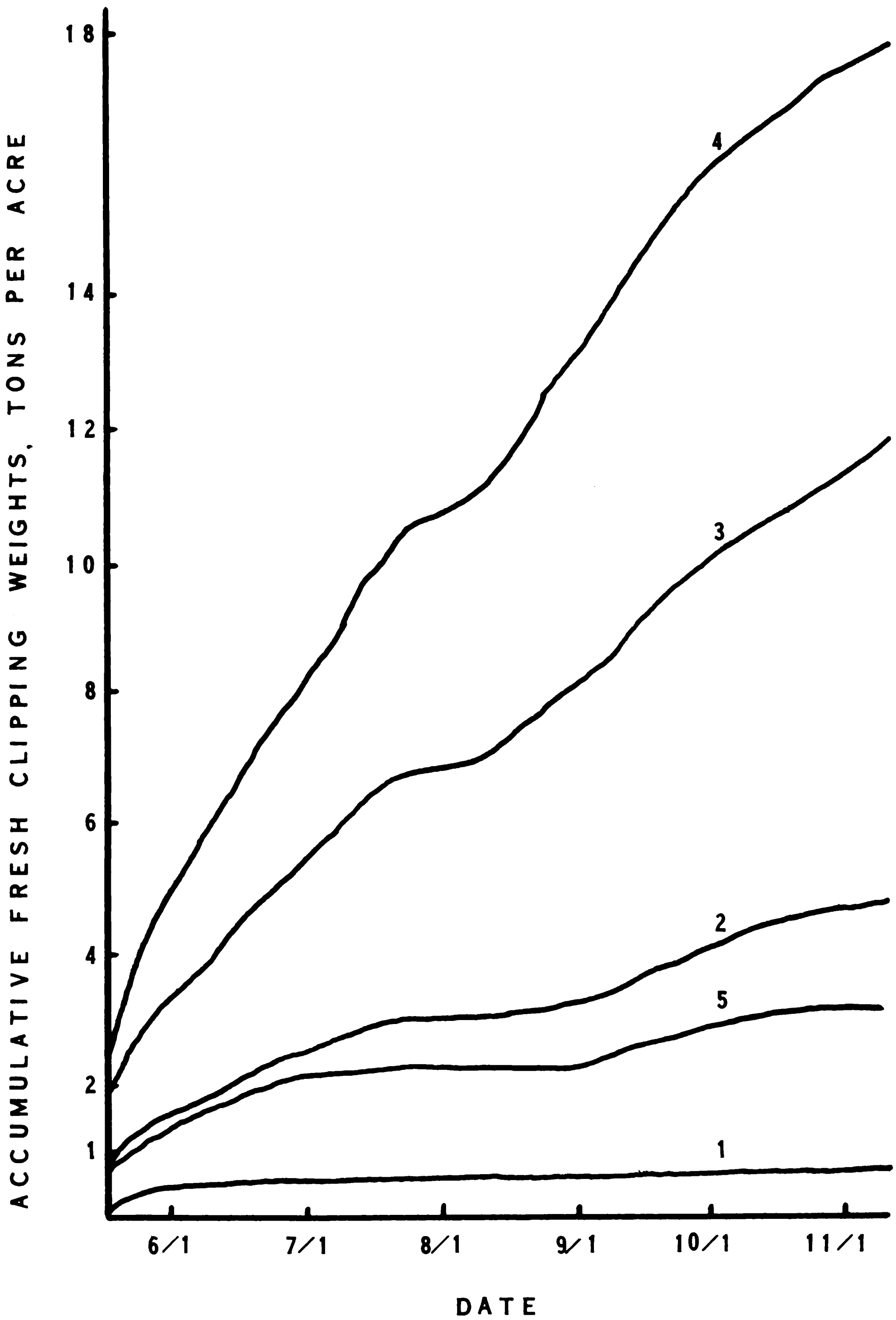


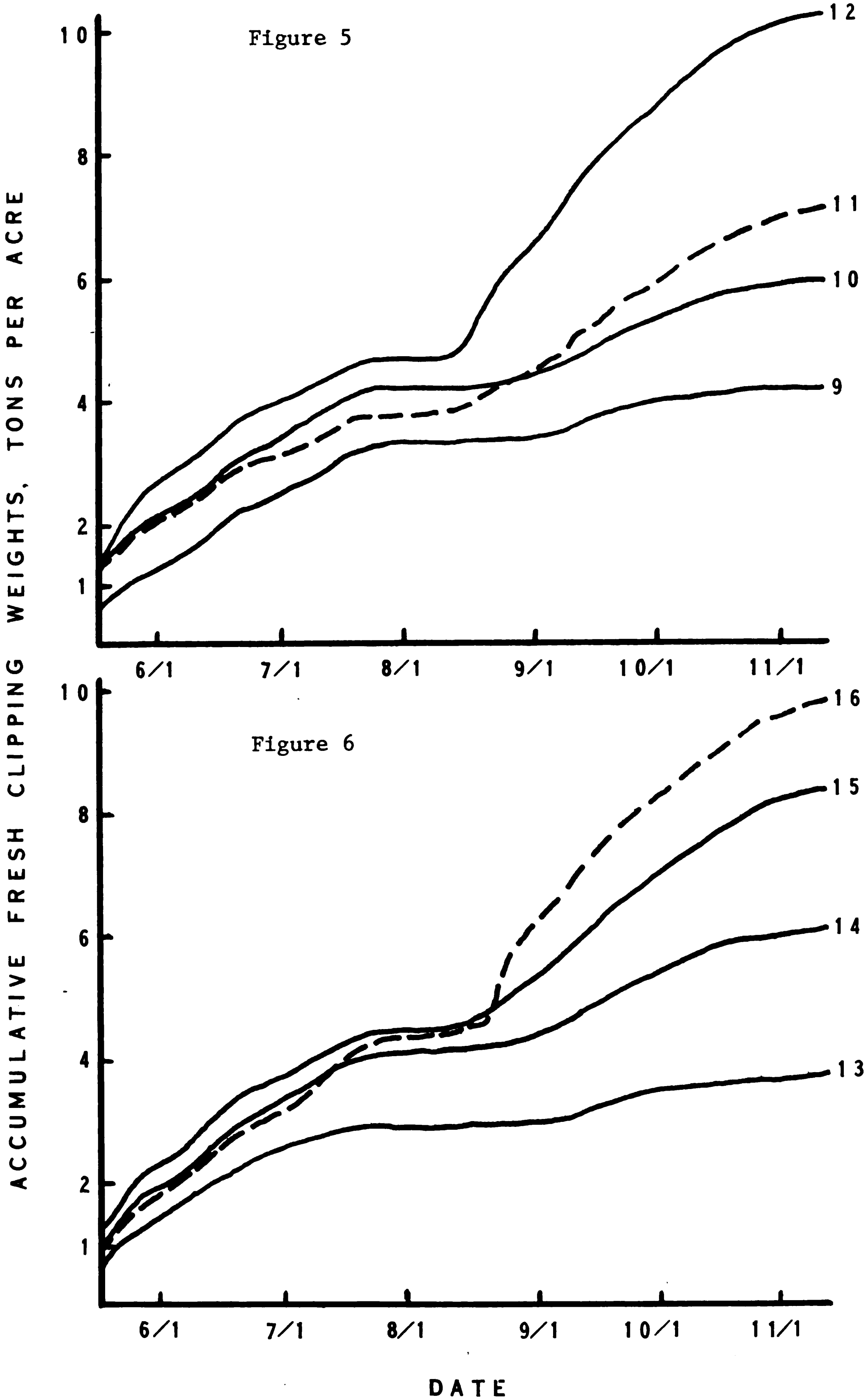
Figure 4. Accumulative fresh clipping weights for Treatments 1 through 5 (0, 30, 60, 120, and 15 pounds nitrogen per acre applied monthly, respectively).

benefitted growth by producing 6373 pounds of fresh clippings per acre. Treatment 2 produced a significant increase over the check and Treatment 5 with more than four tons per acre of fresh clippings. The yields for Treatments 3 and 4 increased significantly as well with production of about 11 and 18 tons per acre, respectively.

Treatments 2, 3, 4, and 5 exhibited very apparent plateaus beginning late July. The check also had this plateau but it is not as obvious because of the very small increases that it had both before and after the plateau. This leveling off of growth occurred during the hottest and driest part of the season which resulted in environmental stress upon the turfgrass plants. Although the plots were irrigated as deemed necessary to prevent wilt, the stress condition cannot be attributed to either moisture or high temperature stress alone. It is interesting to note that the length of time of the depressed growth was shorter for the higher nitrogen rates. Apparently nitrogen increased the rate of recovery of the turf from the stress condition.

There were no significant differences between clipping weights for Treatments 5 through 8 (Table 4) indicating there was no residual influence of the fall nitrogen applications on growth the following season. This supports the soil nitrate observations. This small amount of nitrogen fertilizer (15 pounds per month) did stimulate substantial growth over the check. There is an obvious plateau in growth during the environmental stress period of late July and August as occurred with other treatments. Growth resumed shortly after the stress period, although the rate of recovery was slow. Total production of fresh material was more than 3 tons per acre for each treatment.

Clipping weights for Treatments 9 through 12 are presented in Table 5 and Figure 5. Early in the season there were significant



Figures 5 and 6. Accumulative fresh clipping weights for Treatments 9 through 12 and Treatments 13 through 16, respectively.

differences in clipping weights due to the fall topdressing treatments but these differences disappeared after May. In June the increases in growth were about the same for all treatments until mid-August. Clipping weights for Treatment 9 diminished during the stress period and top growth did not resume except for a small increase in mid-September. Clipping weights for Treatment 10 which were slightly above Treatment 11 prior to the stress period dropped below the growth rate of the latter following the resumption of growth. Treatment 11 resumed growth shortly before Treatment 10 and sustained growth at a more rapid rate to the end of the season. The resumption of growth occurred most rapidly with Treatment 12. Its rate of growth was greater than the others with a total production of more than 10 tons of fresh material per acre.

Data for Treatments 13 through 16 are presented in Table 6 and Figure 6. These treatments were changed June 30. Growth for Treatment 13 leveled off prior to the stress period in late July and had only a slight increase in growth in mid-September. Total production of fresh material was less than Treatment 9 because it did not receive the June 30 application of nitrogen. The growth rates for these four treatments are similar until July 1 except for Treatment 13 which was lower. There is no difference in growth observed between Treatments 14 and 15 before the stress period, then was slowed by the environmental stress.

Following the stress period there was an unequal resumption of growth. Unlike the previous treatments the highest rate of nitrogen did not cause growth recovery first. Treatment 15 was the first to resume growth while Treatment 16, which had assumed rapid growth prior to the stress period was slow to regain this growth rate. This delay may be due to physiological changes that occurred during rapid growth prior to the environmental stress period. The growth was less than for Treatment 12 which received less nitrogen. Although Treatments 13 through 16 received changed nitrogen applications one month before Treatments 9 through 12, soil nitrate tests and clipping results do not reflect these changes as rapidly as would be expected (See Figures 3 and 6).

The amount of clipping weights is a direct result of the amount of nitrogen applied. The check plot which did not receive nitrogen had the lowest production of clippings. But Treatments 5 through 8 which had a total of 75 pounds nitrogen fertilizer per acre in five applications did not produce more clippings than Treatment 13 which had a total of 60 pounds nitrogen per acre in two applications early in the season. Those treatments receiving more than one half of their total nitrogen fertilizer after late July did not produce as many clippings as those plots receiving a more equal distribution of their nitrogen fertilizer. This occurred, most likely, as a result of the reduced growth rate for all treatments during the stress period. Treatment 4 which received a total of 600 pounds of nitrogen, the highest rate, produced the most clippings.

III. Sod strengths.

The results of the sod strength measurements on July 22 and October 15 are given in Table 7 and summarized in Figures 7 and 8. The sod strengths on July 22 for the first four treatments show a significant increase in sod strength by increasing nitrogen from none to 30 pounds per acre per month. The check had a sod strength of 109 pounds, while Treatment 2 was 123 pounds. Treatment 3 decreased sod strength significantly compared to Treatment 2 and was about equal to the check. Treatment 4, the high nitrogen treatment, significantly decreased the sod

Table 7. Field observations on sod strengths and root and rhizome weights of Merion Kentucky bluegrass grown for sod on Houghton muck.

Treatment No.	Sod strength 7-22 (lb)	Sod strength 10-15 (lb)	Rhizome* length (cm)	Rhizome* weight (mg)	Rhizome weight / Rhizome length
1	109	146	52.8	99.0	1.875
2	123	130	82.2	119.8	1.457
3	105	97	30.7	42.7	1.39
4	68	67	12.7	13.6	1.07
5	148	188	53.1	89.4	1.68
6	155	182	68.5	112.9	1.65
7	135	180	80.9	160.0	1.98
8	130	171	96.0	189.9	1.98
9	157	143	70.4	126.4	1.80
10	128	173	83.1	142.9	1.72
11	137	105	53.2	82.2	1.55
12	119	130	27.2	39.3	1.44
13	137	192	148.8	271.7	1.83
14	128	113	48.0	93.9	1.96
15	136	93	81.4	144.2	1.77
16	128	114	58.9	96.6	1.64
lsd (.05)	8.5	11.6	32.3	66.6	

*July 22 observations

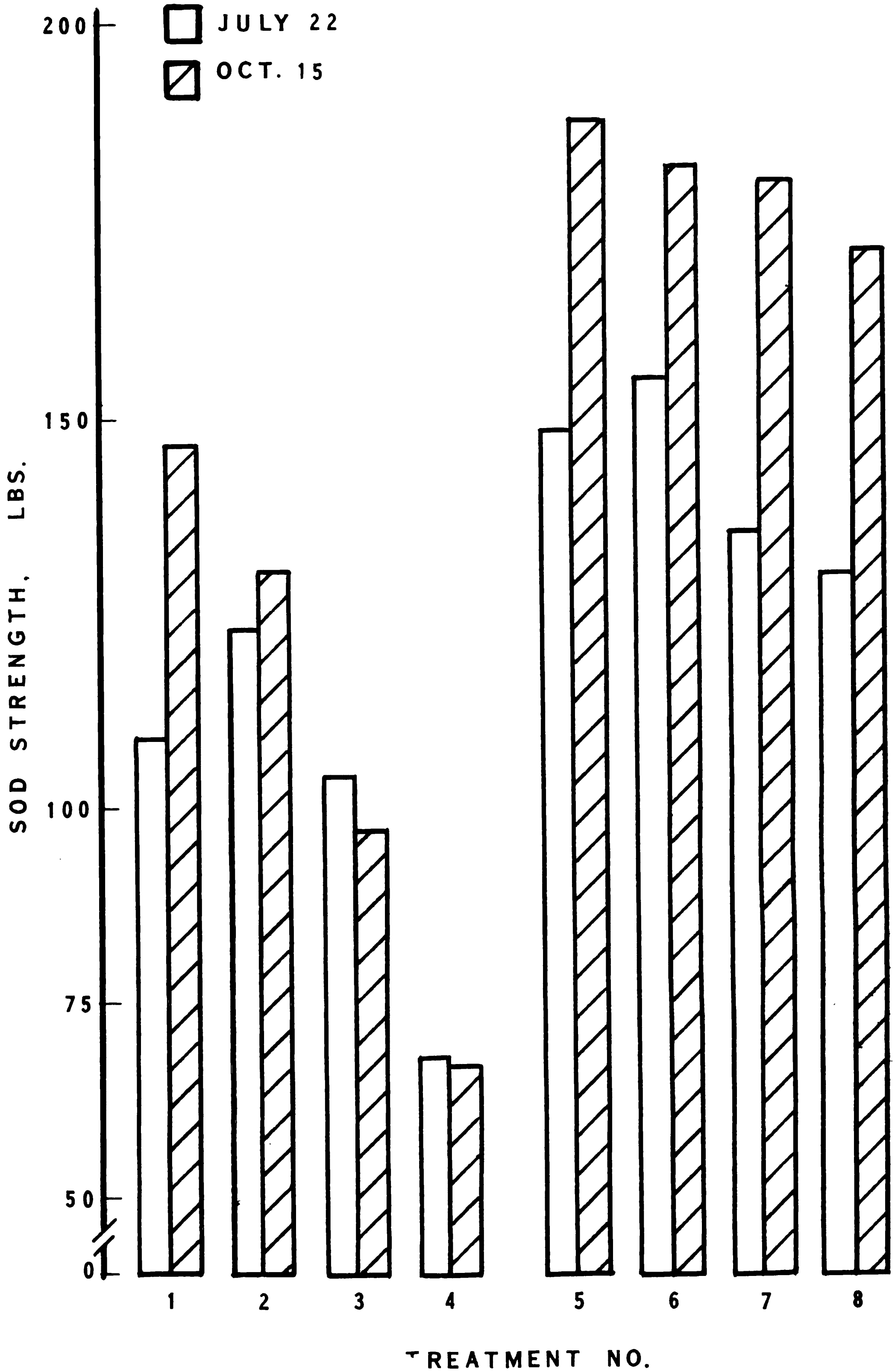


Figure 7. Sod strengths for Treatments 1 through 8 on July 22 and October 15, 1970.

strength even further. Although there is no significant difference between Treatments 1 and 3 the check had an unacceptable appearance with a very light color and occasional weed infestations. In contrast, Treatment 3 showed a much more desirable color and quality of top growth throughout the year.

The sod strengths taken on October 15 for the first four treatments had a change in the order of results from those observed on July 22. Sod strength was highest for the check and decreased significantly between each treatment. The largest change between dates was the significant increase in sod strength of the check. Treatment 5, corresponding to a 15-pound nitrogen treatment per month, gave consistently stronger sod strengths than Treatments 1 through 4.

Treatments 5 through 8 all received the same rate of nitrogen during 1970, but there were 0, 30, 60 and 120 pounds nitrogen per acre, respectively, applied in the seedbed in August 1969. This may account for the significant differences in Treatments 5 and 6 compared to Treatments 7 and 8 on July 22, with the lower rates of application in the seedbed giving significantly higher sod strengths. The increases in sod strengths for Treatments 5 through 8 between July 22 and October 15 were significant. On October 15, Treatment 5 had a significantly stronger sod than Treatment 8. The sod strengths of Treatments 5 through 8 are significantly higher than all other treatments except Treatment 13 which was unusually high on October 15.

The sod strengths for Treatments 9 through 12 (Figure 8) were all significantly different for each date. The behavior is somewhat erratic but partial explanation may be the topdressing nitrogen applied after seedling emergence the previous fall. In general, the higher

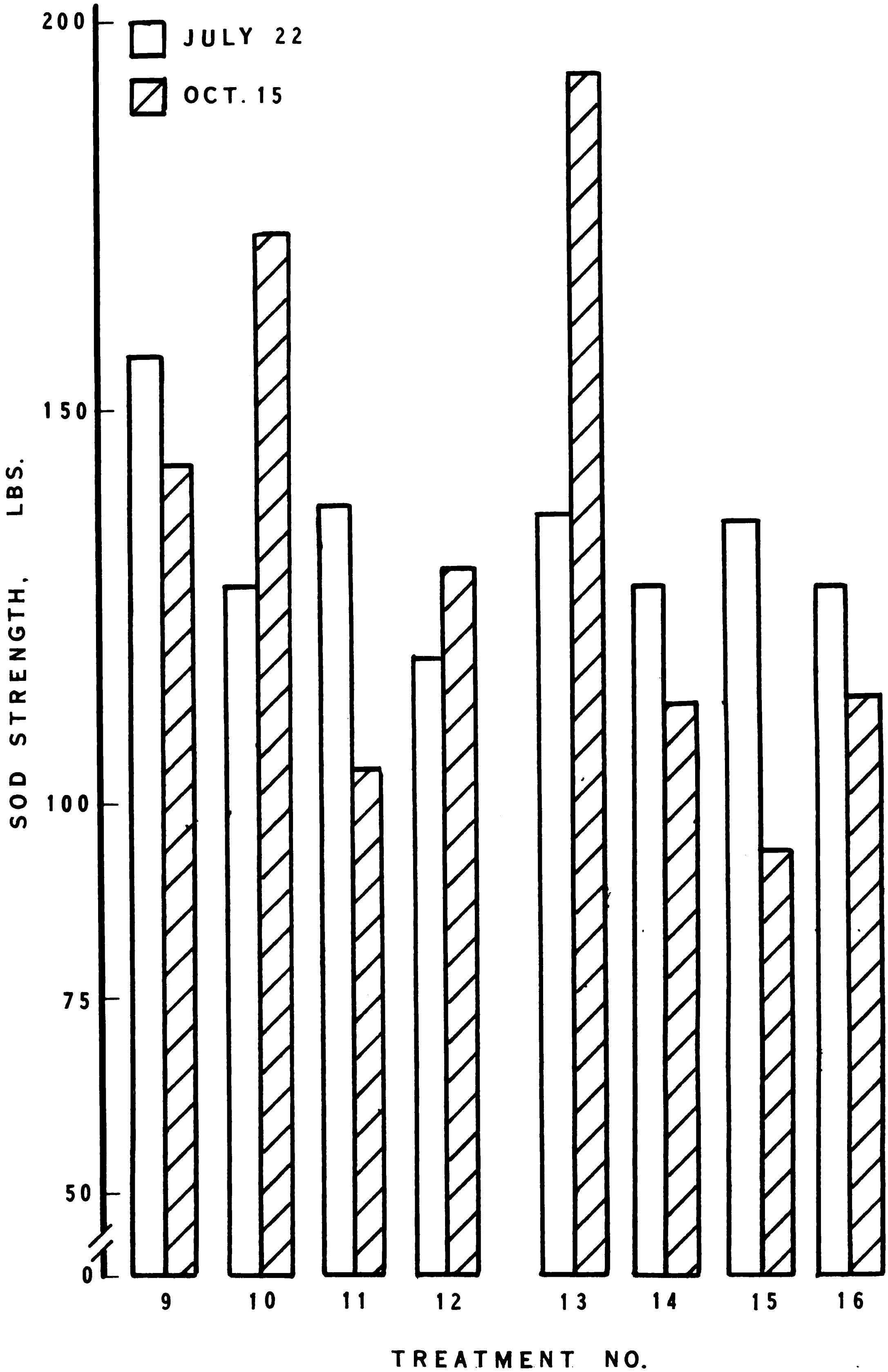


Figure 8. Sod strengths for Treatments 9 through 16 on July 22 and October 15, 1970.

nitrogen topdressing rate in the fall caused a decrease in sod strength on July 22. This was not as apparent on October 15, however. The late fall topdressing application tended to reduce sod strength more than the seedbed treatment.

Sod strengths on July 22 for Treatments 13 through 16 showed small variations. The consistency of sod strengths on July 22 for Treatments 2, 10, and 13 through 16 which were quite similar in nitrogen fertilization to that time indicate that the sod strength data are quite consistent.

The change in sod strengths on October 15 showed a very marked increase for Treatment 13 while decreases occurred for Treatments 14 through 16. There was an unexpected decrease in sod strength for Treatment 14 which does not compare well with results from Treatments 2 and 10 receiving the same fertilization. There was a significant decrease in sod strength of Treatment 15, which is expected and a slight decrease in sod strength of Treatment 16.

The overall results show that the 15-pound nitrogen per month application had the strongest sod while decreasing sod strength occurred with higher nitrogen rates. The higher nitrogen fertilization in the seedbed did benefit the turf in sod strength somewhat but topdressing seemed to be less advantageous. The change in the fertilization program during mid-season can significantly change the sod strength. Increasing nitrogen rates decreased sod strength and the discontinuation of fertilization increased sod strength. Therefore, in a few months the sod strength of turf can be rapidly changed. The general appearance of the turfgrass improved with increased rates of nitrogen fertilizer and the lower rates (0 and 15 pounds nitrogen per month) were chlorotic.

IV. Length and weight of rhizomes.

The length and weight of rhizomes obtained July 22 are presented in Table 7 and summarized in Figures 9 and 10. These can be compared to the results of the sod strength determinations taken on the same date. Large differences in rhizome lengths were necessary for significance because of wide variability between plugs.

Total rhizome length increased from the check (52.8 cm) to the 30-pounds nitrogen per month application, Treatment 2 (82.2 cm), a difference of 29.4 cm. There is a significant decrease of 51.5 cm in rhizome length between Treatments 2 and 3 with a further decrease of 18.0 cm between Treatments 3 and 4. The results compared well with those obtained with the sod strength data on July 22. Treatments which increased the sod strength also increased the rhizome length.

There was a consistent increase in rhizome length from Treatments 5 through 8, though the only significant difference was between the two extreme treatments. This suggests the higher seedbed nitrogen rates encouraged rhizome growth. In contrast, the higher nitrogen rates caused a significant decrease in rhizome length when the nitrogen was topdressed in the fall as suggested by data for Treatments 9 through 12 (Figure 10). These results do compare well with the sod strength data except that Treatment 10 has a sod strength lower than for Treatments 9 on July 22. On October 15, Treatment 10 has a much higher sod strength than Treatment 9.

The results of Treatments 13 through 16 (Figure 10) are erratic with large differences. The low value for rhizome lengths for Treatment 14

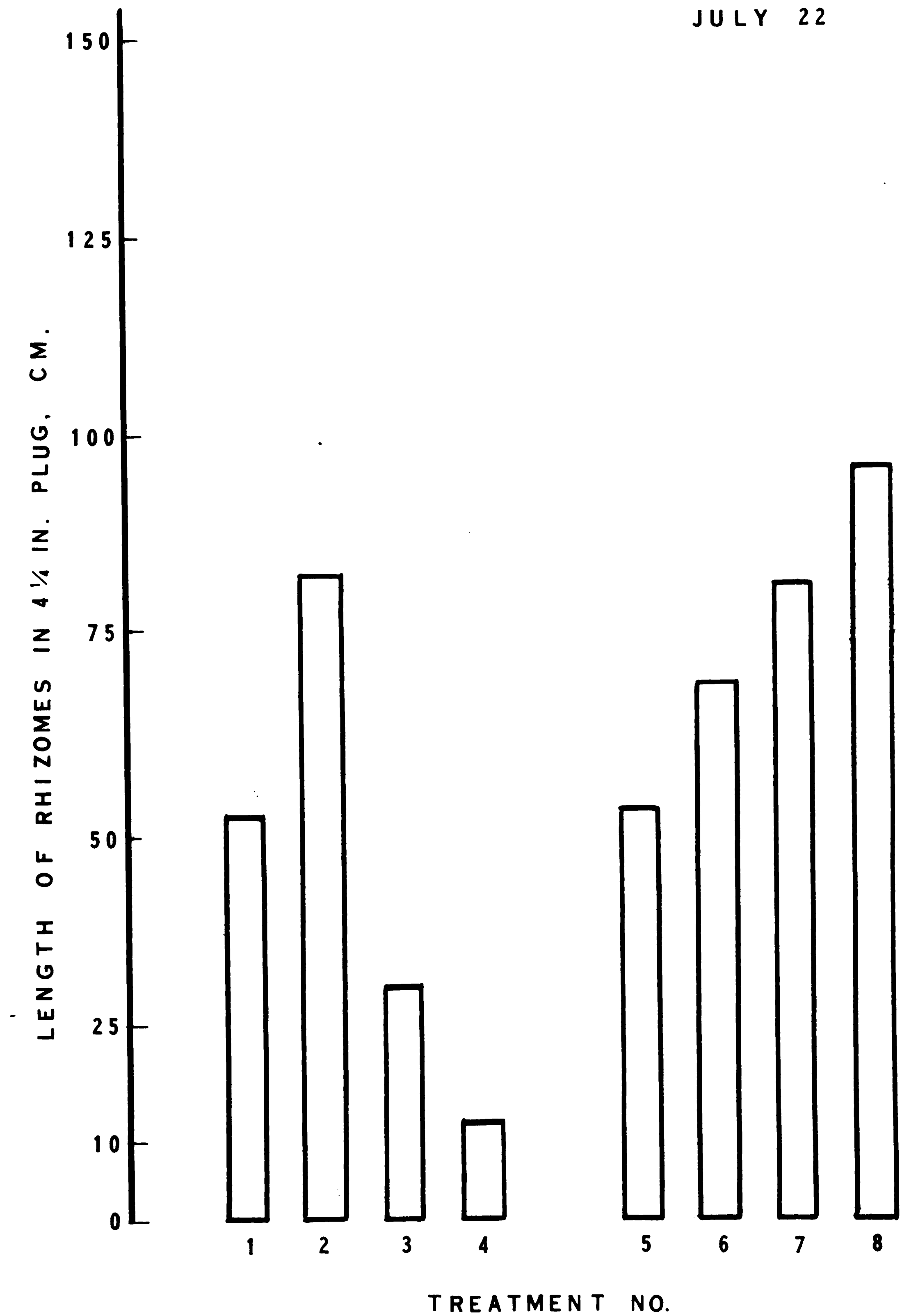


Figure 9. Length of rhizomes in a 4 1/4 inch plug for Treatments 1 through 8 on July 22, 1970.

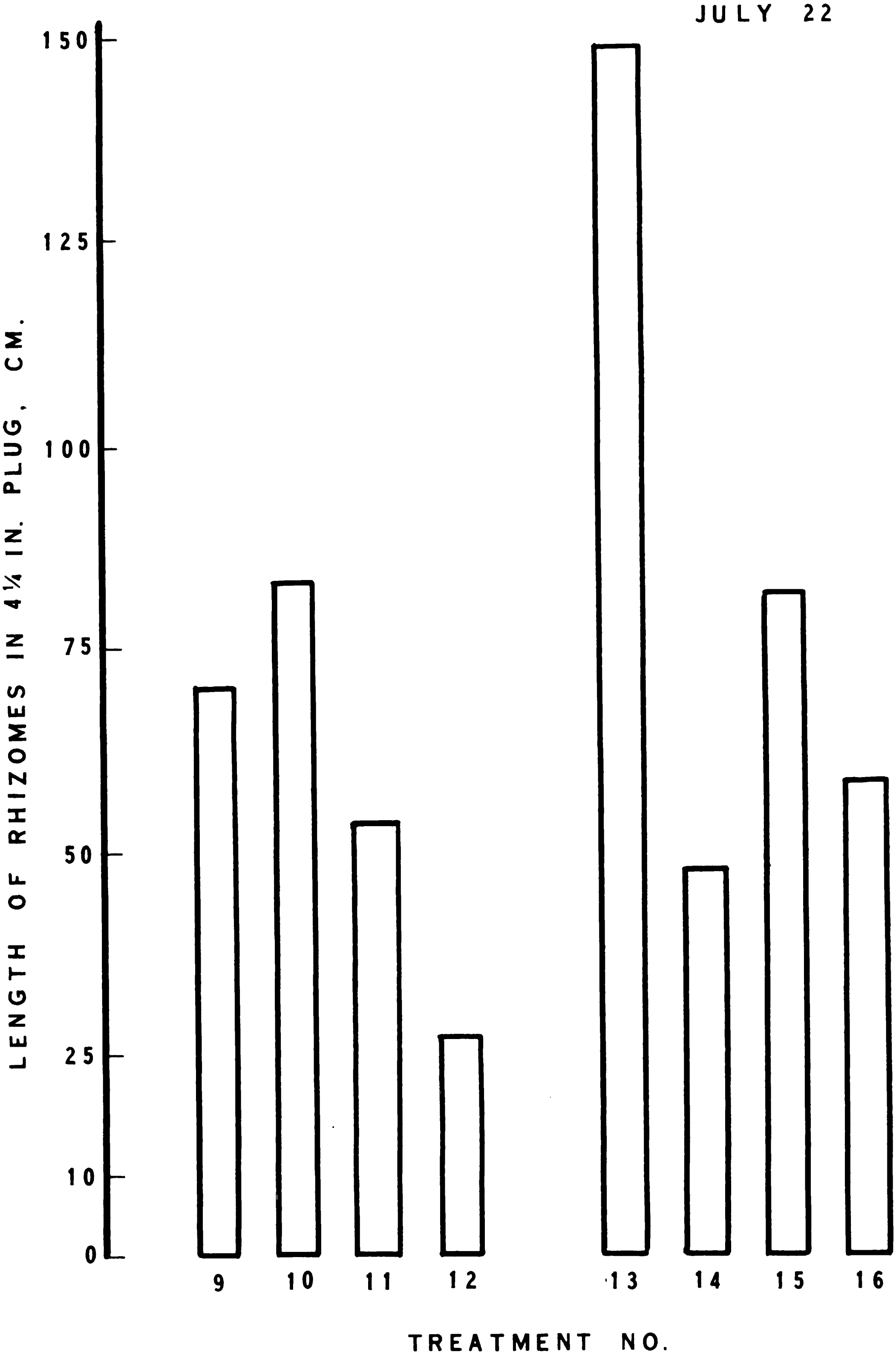


Figure 10. Length of rhizomes in a 4 1/4 inch plug for Treatments 9 through 16 on July 22, 1970.

does not compare to Treatments 2 and 10 and were not consistent with sod strengths for this treatment. The most obvious result was the significant increase in rhizome length of Treatment 13 over Treatments 14, 15, and 16. This did not compare well with sod strengths on July 22 although on October 15 sod strengths were the highest of any treatment.

The weights of rhizomes obtained July 22 are given in Table 7 and summarized in Figures 11 and 12. These are weights of those rhizomes previously measured for length. The rhizome weights showed very similar trends to those for rhizome lengths except for fewer singificant differences due to greater variability.

Dividing rhizome weight by rhizome length would give a measure of apparent rhizome diameter if weight density of rhizomes is disregarded. The lower nitrogen treatments resulted in somewhat larger apparent diameter rhizomes. This was most pronounced in Treatments 1 through 4 which received the widest range in nitrogen rates. There was also a trend for fall topdressing to decrease the apparent diameter of the rhizome with higher nitrogen rates.

V. Percent total nitrogen of the clippings.

The data for the total nitrogen is reported in Table 8. These results are only for Treatments 1 through 5, which represent the widest range of nitrogen treatments.

On nearly every date of sampling there was a significant difference among treatments with increased nitrogen application causing increased nitrogen content in the clippings. The greatest differences occurred immediately following nitrogen fertilizer application. Then the nitrogen content decreased until the next fertilizer application. This decrease was significant in most instances. The higher the nitrogen fertilizer

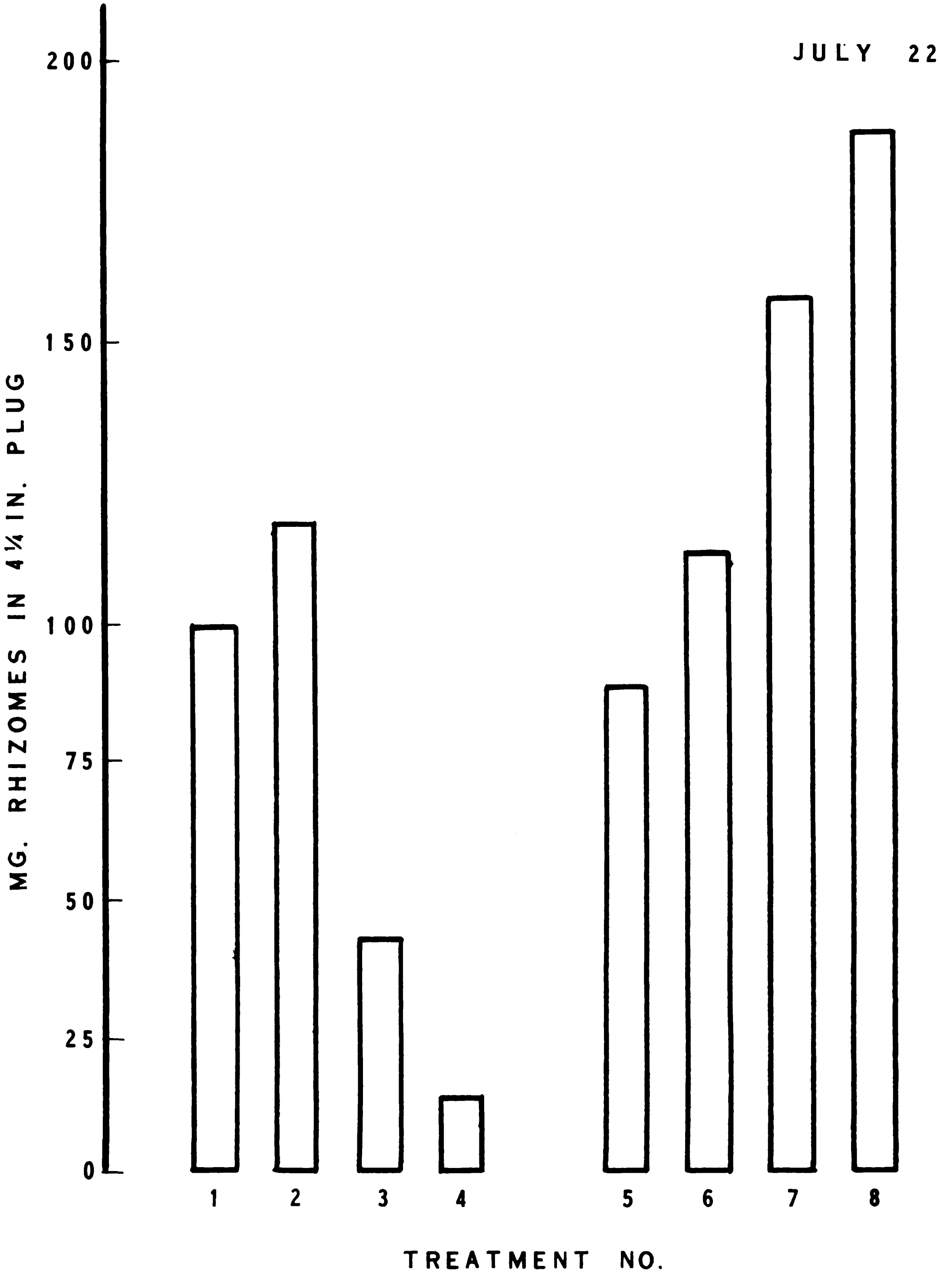


Figure 11. Mg rhizomes in 4 1/4 inch plug for Treatments 1 through 8 on July 22, 1970.

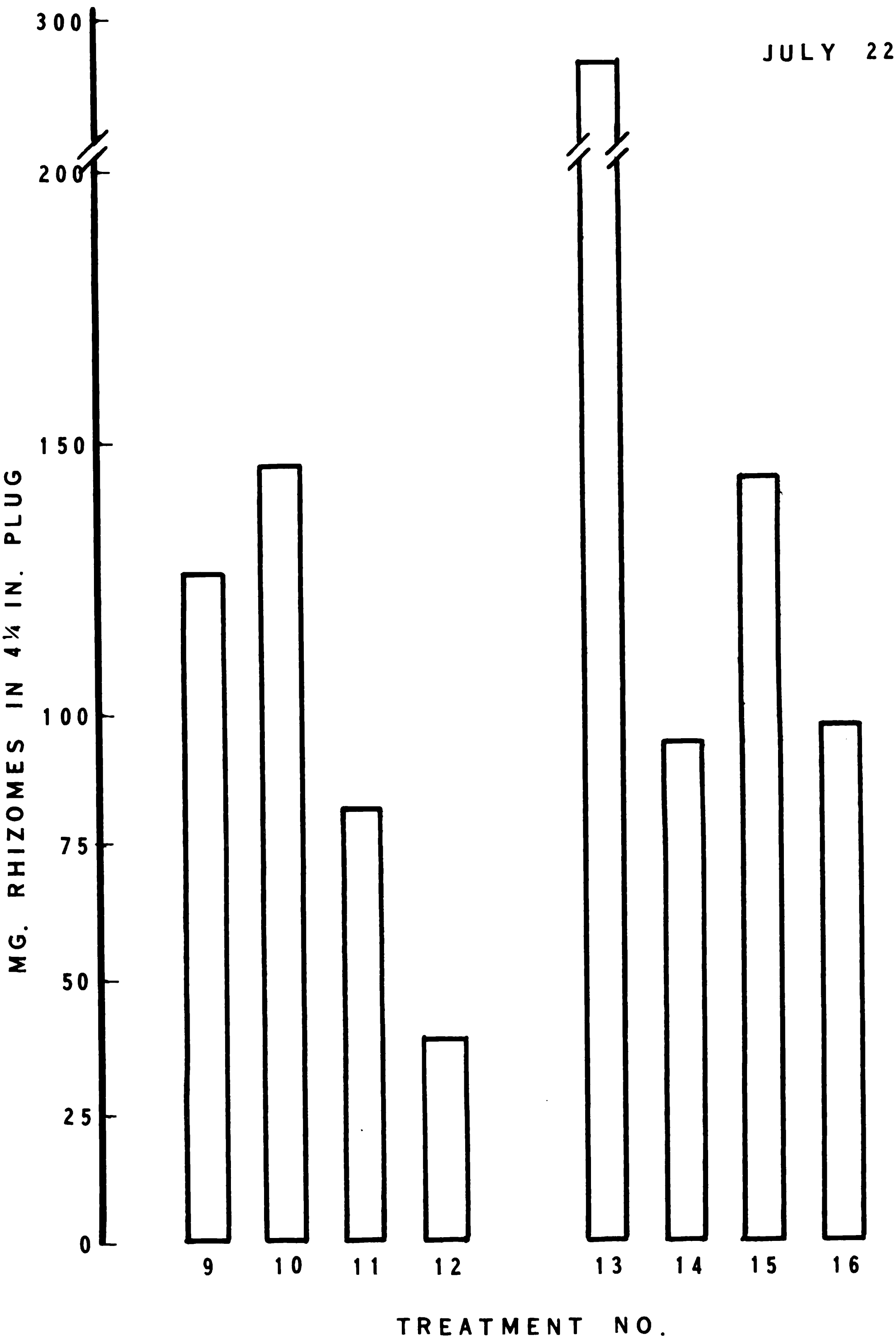


Figure 12. Mg rhizomes in 4 1/4 inch plug for Treatments 9 through 16 on July 22, 1970.

application the wider the range in total nitrogen content between fertilizer applications.

Clippings from the check increased in nitrogen content through the growing season having a maximum in late August and early September which is consistent with soil nitrate tests. In some cases, in the latter part of the season the nitrogen content of the check was higher than some of the treatments receiving low nitrogen rates. This occurred during the time that fertilization was delayed until September 30. Treatment 4 had a significantly higher nitrogen content in the clippings than other treatments with a maximum of 6.1% nitrogen on June 9.

The composition of the clippings were determined for several elements on four selected dates. Analyses were conducted spectrographically by the International Minerals and Chemical Corporation (Table 9). The percentages of phosphorus and potassium increased with increasing rates of nitrogen application on the dates. Differences are marked but statistical analyses were not made. There was not a trend for percent calcium or magnesium. Copper increased with increasing nitrogen especially on the first two dates. Of the other micronutrients, zinc content showed the most consistent trend with a tendency to increase when the higher nitrogen rates were applied. Manganese increased with increasing nitrogen for the first two dates but the results were not consistent in the last two dates.

VI. Total nitrogen content of the soil.

The results for total nitrogen of the soil for the first five treatments on four selected dates are given in Table 10.

Table 8. Percent of nitrogen in clippings for Treatments 1 through 5.

	Treatment No.					
Date of clipping	1	2	3	4	5	lsd
5-18	2.4	3.5	4.5	5.7	2.9	.3
5-23	1.8	3.2	3.9	5.2	2.5	.2
5-26	2.4	3.0	3.6	5.3	2.7	.2
5-28	2.2	2.8	3.4	4.6	2.4	.4
6-4	2.2	2.8	3.7	4.7	2.4	.3
6-9	1.9	3.9	4.8	6.1	3.3	.3
6-11	2.4	4.4	5.6	6.0	3.7	.2
6-16	2.5	4.2	4.6	5.9	3.6	.1
6-19	2.1	4.2	5.0	5.9	3.6	.2
6-22	2.3	3.3	4.3	5.5	3.0	.2
6-25	2.8	3.2	4.3	5.1	3.0	.3
6-29	3.0	2.2	2.9	3.3	2.8	.2
7-2	3.5	4.2	5.2	5.8	3.7	.4
7-6	3.0	4.0	5.0	5.7	3.5	.3
7-9	2.9	3.8	4.8	5.7	3.4	.2
7-13	3.4	3.9	4.8	5.8	3.6	.2
7-16	3.2	3.7	4.7	5.7	3.3	.3
7-21	2.9	3.0	4.1	4.3	2.8	.2
7-25	3.0	3.6	4.3	5.3	3.2	.3
7-30	2.8	2.8	3.2	5.1	2.8	.3
8-6	2.9	4.4	5.2	5.6	4.0	.3
8-13	4.2	4.0	5.2	5.6	4.0	.3
8-20	4.4	4.0	4.9	5.6	3.7	.2
8-26	4.3	4.0	5.1	5.7	3.6	.2
9-1	4.4	3.5	4.2	4.9	3.0	.2
9-4	4.1	3.6	4.4	5.2	4.3	ns
9-8	4.4	3.7	4.5	5.3	3.2	.3
9-11	3.2	3.2	4.1	5.1	3.0	.2
9-16	3.9	4.0	4.6	5.6	3.7	.3
9-21	2.5	3.7	4.6	5.3	3.3	.2
10-1	3.0	3.8	5.4	5.5	3.7	.2
10-6	3.4	3.9	5.3	5.9	3.7	.2
10-15	2.8	3.5	5.1	5.7	3.5	.3
10-27	2.4	3.3	3.4	5.4	2.9	.3
11-12	3.6	4.0	4.8	5.5	3.7	.3
Average	3.0	3.6	4.5	5.4	3.3	.2

Table 9. Spectrographic analyses for several elements of clippings for Treatments 1 through 4 on four selected dates.

Treatment No.	Date	%P	%K	%Ca	%Mg	Cu ppm	Zn ppm	B ppm	Mn ppm
1	5-23	.32	2.15	.45	.19	20.3	34.5	31.3	49.7
2		.44	2.96	.53	.25	23.6	40.1	29.6	60.7
3		.46	2.86	.46	.24	22.8	37.3	22.4	61.1
4		.51	3.17	.54	.31	24.1	41.1	21.2	67.1
1	6-29	.29	1.82	.55	.25	17.9	32.8	21.8	70.6
2		.33	2.11	.54	.23	18.5	39.5	21.4	78.8
3		.39	2.14	.46	.24	19.7	38.7	18.9	90.4
4		.41	2.30	.46	.26	22.0	45.5	18.9	121.4
1	9-11		not analyzed - insufficient sample						
2		.39	2.61	.49	.22	20.8	36.6	19.4	66.3
3		.46	2.85	.35	.19	22.1	40.2	16.9	53.6
4		.47	3.09	.34	.21	22.4	43.7	22.3	54.4
1	10-6		not analyzed - insufficient sample						
2		.38	2.70	.44	.20	21.2	38.0	16.4	60.4
3		.46	3.08	.38	.21	20.7	41.2	15.3	54.5
4		.49	3.17	.42	.21	18.9	43.5	19.7	61.3

Table 10, Percent nitrogen of Houghton muck for four selected dates.

Treatment No.	Date of Sampling 4-24	7-6	8-11	10-7
1	2.8	2.9	2.8	2.8
2	2.8	2.9	2.8	2.8
3	2.8	2.9	2.8	2.8
4	2.9	3.0	2.8	2.9
5	2.0	2.9	2.7	2.7
lsd .05	ns	ns	ns	ns

There are no differences in nitrogen content, ranging from 2.7 to 3.0 percent with no variation due to treatment of date of sampling. These results would be expected for a reed-sedge peat.

VII. Greenhouse rooting study.

The results of the rerooting study in the greenhouse are given in Table 10 and summarized in Figure 13. Sod plugs were transplanted on October 16, 1960 and grown for 37 days. There was no difference in root production between Treatments 1, 5, and 2 (0, 15, and 30 pounds nitrogen per month, respectively). Increasing the nitrogen to 60 or 120 pounds (Treatments 3 and 4) caused significant reductions in roots, however, The results of Treatments 5 through 8 show no significant differences with only small, nonsignificant increases over the check.

Root production was also significantly decreased by the higher nitrogen applications on Treatments 11 and 12 compared to 9 and 10. In Treatments 13 through 16, 13 was significantly higher in root production than all other treatments, while Treatments 14, 15, and 16 had low root production. Again, this points out that Treatment 14 was not comparable to other treatments receiving the same nitrogen fertilization program. Although correlation data were not determined, the root

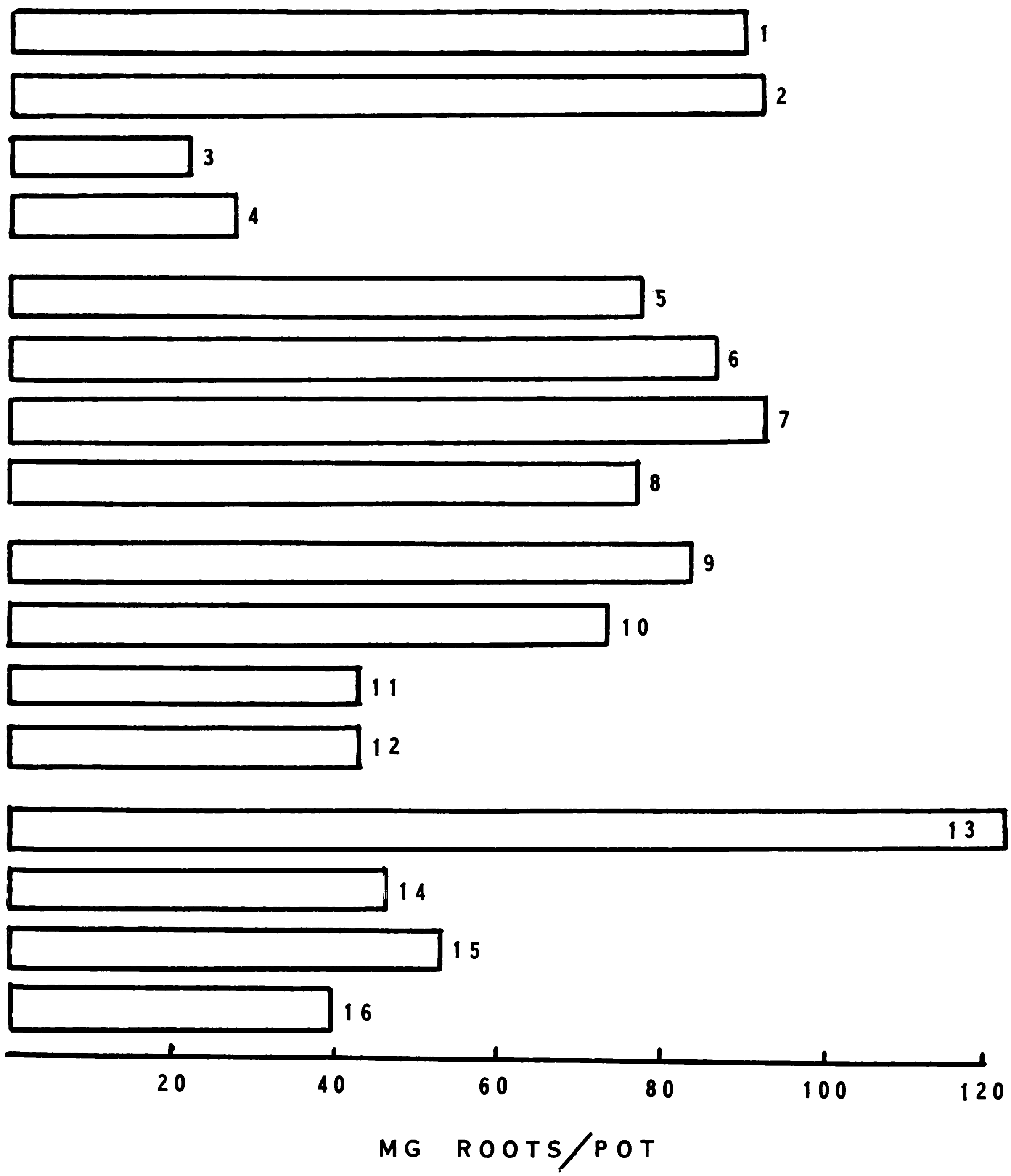


Figure 13. Roots produced by 4 1/4 inch plug of sod in 37 days in the greenhouse on a sandy loam soil.

production increases related rather well to increases in sod strengths taken in October just prior to the start of the greenhouse study.

Table 11. Root and clipping weights from the greenhouse rooting study, averages for three replications.

Treatment No.	Roots	Greenhouse clippings	
	(mg)	(mg)	(mg)
1	70.1	340	515
2	73.0	774	674
3	22.1	846	557
4	28.3	711	490
5	77.6	601	550
6	87.2	607	573
7	92.3	722	659
8	77.0	664	561
9	82.9	579	554
10	73.0	799	611
11	43.2	910	669
12	43.3	905	522
13	121.7	633	580
14	52.6	790	600
15	46.2	742	598
16	38.6	716	614
lsd .05	25.1	66	55

The greenhouse clipping results were somewhat consistent with clipping weights in the field studies. In general, those treatments receiving higher nitrogen applications produced significantly more top growth on the first clipping date. The clippings were reduced for those treatments which received the highest nitrogen rate (120 pounds nitrogen per month) compared to other treatments. On the second clipping date this trend was even more marked. Those treatments receiving the intermediate nitrogen rates prior to the greenhouse study had increased clipping weights relative to the higher nitrogen treatments. Those treatments that had received high rates of nitrogen were spending most of their energy in the production of shoots while the lower nitrogen rates enhanced rerooting of the turf.

SUMMARY

The principal objective of this study was to aid the sod grower in determining the nitrogen fertilizer need for rapidly producing a high quality sod on organic soils. Ammonium nitrate was applied at different levels and dates. These treatments were evaluated using sod strength, rhizome length and weight, clipping weights, and rerooting ability. Nitrate nitrogen level in the soil and nitrogen content of the clippings were determined to examine their usefulness as adequate means for predicting nitrogen needs for sod.

I. Nitrate soil test.

The results of the nitrate soil tests indicated that this is not an effective tool for predicting nitrogen fertilizer needs of turf in sod production. There was very little difference in soil nitrate levels between treatments receiving 0, 15, 30, and in some instances 60 pounds nitrogen per acre per month. Although significant differences could be attained with 120 pounds nitrogen per month, the data were quite variable depending on the length of time after application. However, this rate of application would be excessive for practical sod production practices.

The data does show that there was a general increase in the nitrate level of the soil during the season. The increases in nitrates were the result of soil decomposition by microbial activity, nitrogen in rainfall, and nitrogen recycled by the return of the clippings. Another important observation was the large loss of nitrates from the soil within three weeks after nitrogen was applied at rates of 60 and 120 pounds nitrogen per acre per month.

The increase to 60 and 120 pounds of nitrogen per month during the season significantly increased the nitrate level of the soil. This not only increased the nitrate levels but also increased yield of clippings. The study also showed some residual carryover between monthly applications for the 120 pounds nitrogen per acre rate because the nitrate level stayed significantly higher than those treatments receiving lower monthly applications of nitrogen even though marked declines were observed.

The heavy rate of 120 pounds nitrogen per acre applied in the fall was not detected by the nitrate soil test the following spring. The nitrogen fertilizer that the turfgrass does not use in the fall is lost before growth is resumed the next year.

The 15 and 30 pounds nitrogen per acre per month treatments produced the strongest sod. The nitrate soil test is of little value since the nitrate levels in the soil were not consistently different from the check for these treatments.

II. Fresh clipping weights.

The data for the fresh clipping weights showed that increased rates of nitrogen application increased the top growth of the turfgrass. The amount of clippings was very small without nitrogen fertilizer with a total of only 1400 pounds per acre produced mostly in the early part of the season. The production of clippings for the 15, 30, 60 and 120 pounds nitrogen per month was approximately 3, 4 1/2, 11, and 18 tons per acre, respectively.

The timing of nitrogen fertilization had an important effect on the amount of clippings produced as well as the turfgrass plants' ability to withstand environmental stress. The application of fertilizer early in the season resulted in increased clippings. The even application of fertilizer throughout the season (Treatment 5) produced less clippings than heavy applications of a similar amount of nitrogen in the early part of the season (Treatment 9).

The growth of the turfgrass can be effectively changed by altering the nitrogen fertilization. Increasing the nitrogen applied during the season had the effect of increasing top growth while altering sod development. An increase from 30 to 60 or 120 pounds of nitrogen effectively reduced the sod development. For growth, nitrogen fertilizer must be continuously supplied to the turfgrass and discontinuance reduces the top growth of the plant while the plant makes effective use of growth materials for root and rhizome development. The increase in nitrogen for Treatment 16 applied just prior to the environmental stress period was more detrimental than a continuous supply of nitrogen even at the highest rate (Treatment 4).

Topdressing nitrogen in the fall (October 6) did have an effect on clippings produced the following spring (Treatments 9 through 12) but seedbed applications (August 29) produced no differences in growth (Treatments 5 through 8). This occurred even though soil tests did not show these differences.

III. Sod strength.

Sod strength measurements showed that the amount of nitrogen supplied continuously or a change in amount of nitrogen can effectively alter sod strengths. The treatment which received 15 pounds nitrogen per month consistently had the greatest sod strength and a well developed root and rhizome system. In addition, Treatment 13 which received two 30 pound nitrogen applications in May and June had a sod strength in October equal to that of the 15-pound treatments.

Although the difference on July 22 between the check and the 60 pounds nitrogen per month was not significant there was a very important difference in the appearance of the turfgrass. The check was very chlorotic, had slow growth and was subject to weed invasion while the 60 pounds nitrogen per month treatment was much more acceptable in appearance and had the ability to compete with weeds. Nitrogen generally improved the appearance of the turfgrass. It was evident from October 15 sod strength measurements that this improvement in appearance was at the expense of developing sod strength. The excessive rate of 120 pounds per month had the lowest sod strength on both dates although it appeared to be a high quality turf.

The sod strength can be effectively changed by altering the nitrogen fertilizer rate. In general sod strength can be improved by withholding nitrogen after the sod is well established which is evident from Treatment 13. Increasing the nitrogen decreased sod strength once turf was established as shown by Treatments 11, 12, 15 and 16. However, it does take some time to effectively change the sod strength because Treatments 13 through 16 did not show any differences on July 22, three weeks after nitrogen rates were changed.

III. Length and weight of rhizomes.

Nitrogen efffects rhizome development as well as sod strength. Rhizomes aid in holding the sod together. Generally, the higher nitrogen treatments resulted in lower rhizome production (both length and weight) although some nitrogen was apparently needed for optimum rhizome growth. This was evidenced by the larger rhizome values for Treatment 2 (30 pounds nitrogen per month) compared to the check. An interesting exception to this observation was the greater rhizome growth for Treatment 8 compared to Treatment 5. Both received 15 pounds nitrogen per month during 1970 but differed in the higher rate of seedbed nitrogen for Treatment 8.

Timing of nitrogen application also significantly affects rhizome growth as suggested by the extremely high rhizome production by Treatment 13 compared to Treatments 10 or 14.

IV. Nitrogen content of the clippings.

The percent nitrogen in the clippings indicated that treatments receiving higher nitrogen fertilizer resulted in more nitrogen in the plant as would be expected. The results also showed that the amount of nitrogen in the soil which is available to the plant decreased from the time of one application to the next. This was reflected in both soil nitrate tests and nitrogen in the clippings. The nitrogen content in clippings for the check increased during the season, supporting the soil nitrate test observations.

The variability in nitrogen content during the season and in response to fertilization may be significant. The nitrogen content of clippings from Treatment 2 (30 pounds nitrogen per month), for example, varied from as low as 2.8 to as high as 4.4%. This extreme occurred between the July 30 and August 6 sampling dates in response to a nitrogen treatment. The ranges were even wider for the higher nitrogen treatments. An increase in frequency of nitrogen application would reduce the differences that occurred within a treatment.

V. Total nitrogen in the soil.

The results showed that total nitrogen is not an important factor in determining the nitrogen available to the turfgrass plant. There was no difference in total nitrogen of the soil, regardless of season or rate of nitrogen applied.

VI. Rerooting study in greenhouse.

The results of this study showed that there were differences in the rerooting ability of the sod depending on previous nitrogen fertilizer application. There was little difference between the low nitrogen rates but those treatments receiving 60 and 120 pounds of nitrogen per month significantly reduced rerooting ability of the turfgrass plant. The longer these high rates were applied the slower the rerooting ability of the plant. Obviously the nitrogen fertilization program on the sod farm has a significant effect on the ability of the sod to reestablish on the new site.

CONCLUSIONS

1. The use of the nitrate soil test for predicting the nitrogen needs of the turfgrass plant for sod is not yet practical. It is impossible to determine differences in nitrate levels between no nitrogen and low rates applied. This is especially true for the relatively low nitrogen rates which can be practically used by the sod grower. The results for higher nitrogen applications are widely variable and of no use to the sod producer. It is apparent that loss of nitrates from the soil and additions of nitrogen to the soil complicate the use of the nitrate soil test.

2. The clipping weights showed that there was an increase in top growth with increased nitrogen fertilizer. It was evident that nitrogen treatment had an influence on the ability of the turfgrass plant to recover from environmental stress. The addition of increased nitrogen prior to the stress period delayed turf recovery.

3. The application of between 15 and 30 pounds nitrogen per acre per month produced the highest quality sod. The root system developed best under these rates and the ability of the turf to compete with weeds was improved over the check. Although the sod did not have as attractive an appearance as higher nitrogen treatments, it was stronger and had more rhizomes. Sod strength and rhizome growth can deteriorate in just a few months with heavy nitrogen applications.

4. In general, the increase in rhizome length and weight corresponded to an increase in sod strength. Lower nitrogen rates tended to result in larger rhizomes than higher rates.

5. Timing of nitrogen application has an influence on sod development. Discontinuing nitrogen application during summer resulted in a very strong sod.

6. The percent nitrogen in the clippings increased with increasing rates of nitrogen applied. Between applications there was a steady decline on the nitrogen content of the clippings receiving nitrogen. The turfgrass that did not receive any nitrogen showed an increase in nitrogen content as the season progressed which was consistent with soil nitrate test observations. The amount of nitrogen in the clippings varied widely in response to seasonal and fertilization effects.

7. The total nitrogen content of the soil does not provide any useful information concerning the nitrogen-supplying power of the soil. There were no differences in the total nitrogen content of the soil due to nitrogen applications.

8. The rerooting ability of the turfgrass plant depended on previous nitrogen applied. The high rates of nitrogen produced less roots than the check or lower rates. Discontinuing nitrogen applications for one to two months prior to sodding may improve the rerooting ability of the sod.

LIST OF REFERENCES

1. Alexander, M. 1967. Introduction to Soil Microbiology. John Wiley & Sons, Inc. pp. 248-292.

2. Avnimelech, Yoram. 1971. Nitrate transformation in peat. Soil Sci. 111:113-118.

3. Beard, J. B. and P. E. Rieke. 1969. Turfgrass Science. Amer. Soc. Agron. Agronomy Monograph No. 14. pp. 442-461.

4. Beard, J. B., P. E. Rieke, and J. W. King. 1969. Sod production of Kentucky bluegrass. Proc. 1st Inter. Turf Res. Conf. pp. 509-513.

5. Bosemark, Nils Olof. 1954. The influence of nitrogen in root development. Physiol. Plantarum. 7:497-501.

6. Bremner, J. M. 1964. Methods of Soil Analysis. Amer. Soc. Agron. Monograph No. 9. Academic Press, New York. pp. 1215-1216 and pp. 1171-1175.

7. Broadbent, F. E. and B. R. Stojanovic. 1952. The effect of partial pressure of oxygen on some soil nitrogen transformations. Soil Sci. Soc. Amer. Proc. 16:359-363.

8. Buckman, H. O. and N. C. Brady. 1960. The Nature and Properties of Soils. The Macmillan Company, New York. pp. 334-356.

9. Carroll, J. C. 1954. Effects of drought, temperature and nitrogen on turf grasses. Plant Physiol. 18:19-36.

10. Daniel, W. H. 1962. Principles and practices of sod production. Proc. Midwest Reg. Turf Foundation Turf. Conf. pp. 71-73.

11. Davis, J. F. and R. E. Lucas. 1959. Organic Soils (Their Formation, Distribution, Utilization and Management). Mich. State Agric. Exp. Sta. Special Bull. 425.

12. Dawson, J. E. 1936. Organic Soils. Advances in Agron. Vol. VIII. Amer. Soc. Agron. Academic Press, Inc., Pub. New York.

13. Dotzenko, A. D. 1961. Effect of different nitrogen levels on the yield, total nitrogen content, and nitrogen recovery of six grasses grown under irrigation. Agron. J. 53:131-133.

14. Dunn, J. H. and R. E. Engel. 1970. Rooting ability of Merion Kentucky bluegrass sod grown on mineral and muck soil. Agron. J. 62:517-520.

15. Grable, A. R. and D. D. Johnson. 1960. Efficiency of recovery of applied nitrate nitrogen by perennial ryegrass from different soils. Soil Sci. Soc. Amer. Proc. 24:503-507.

16. Harrison, C. M. 1934. Response of Kentucky bluegrass to variation in temperature, light, cutting and fertilizing. Plant Physiol. 9:83-106.

17. Juska, F. V. and A. A. Hanson. 1967. Effect of nitrogen sources, rates, and time of application on the performance of Kentucky bluegrass turf. Amer. Soc. Hort. Sci. 90:413-419.

18. King, J. W. and J. B. Beard. 1967. Soil and management factors affecting the rooting capability of organic and mineral grown sod. Amer. Soc. Agron. Abstr. p. 53.

19. Kurtz, K. W. 1967. Effect of nitrogen fertilization on the establishment, density, and strength of Merion Kentucky bluegrass sod grown on a mineral soil. Thesis for M.S. degree at Western Mich. Univ.

20. Lowe, R. H. and J. L. Hamilton. 1967. Rapid method for determination of nitrate in plant and soil extracts. J. Food Chem. 15:359-361.

21. Madison, J. H. 1962. Turfgrass Ecology. Effects of mowing, irrigation, and nitrogen treatments of _Agrostis palustris_ Huds., Seaside and _Agrostis tenuis_ Sibth., "Highland" on population, yield, rooting, and cover. Agron. J. 54:407-412.

22. McLean, E. O. 1957. Plant growth and uptake of nutrients as influenced by levels of nitrogen. Soil Sci. Soc. Amer. Proc. 21:219-222.

23. Michigan Agricultural Statistics. July 1971. Michigan Department of Agriculture.

24. Miller, C. E., L. M. Turk, and H. D. Foth. 1965. Fundamentals of Soil Science. John Wiley & Sons, Inc. pp. 201-203.

25. Mortimer, G. B. and H. L. Ahlgren. 1936. Influence of fertilization, irrigation, and stage and height of cutting on yield and composition of Kentucky bluegrass (_Poa pratensis_ L.). J. Amer. Soc. Agron. 28:515-533.

26. Musser, H. B. and J. M. Duich. 1958. Response of creeping bentgrass putting green to urea-form compounds and other nitrogenous fertilizers. Agron. J. 50:881-884.

27. Oswalt, D. L., A. R. Bertand, and M. R. Teel. 1959. Influence of nitrogen fertilization and clipping on grass roots. Soil Sci. Soc. Amer. Proc. 23:228-230.

28. Pellet, H. M. and E. C. Roberts. 1963. Effects of mineral nutrition on high temperature induced growth retardation of Kentucky bluegrass. Agron. J. 55:473-476.

29. Puustjarvi, V. 1970. Mobilization of nitrogen in peat culture. Peat and Plant News 3:35-42.

30. Ramage, C. H., C. Eby, R. E. Mather, and E. R. Purvis. 1958. Yield and chemical composition of grasses fertilized heavily with nitrogen. Agron. J. 50:59-62.

31. Rieke, P. E. 1968. A technique to measure sod strength for use in sod production studies. Amer. Soc. Agron. Abstr., p. 60.

32. Rieke, P. E. and J. B. Beard. 1969. Factors in sod production of Kentucky bluegrass. Proc. 1st Inter. Turf. Conf., pp. 514-521.

33. Rieke, P. E., J. B. Beard, and R. E. Lucas. 1968. Grass sod production on organic soils in Michigan. 3rd Inter. Peat Cong. pp. 350-354.

34. Rieke, P. E. and R. E. Lucas. 1967. Sod for turf. Weeds, Trees, and Turf 6(10:14-17).

35. Roberts. E. C. 1966. Nitrogen-growth relationships in turfgrass. Amer. Soc. Agron. Abstr., p. 36.

36. Satari, Achmad M. 1967. Effects of various rates and combinations of nitrogen, phosphorus, potassium and cutting heights on the development of rhizome, root, total available carbohydrate and foliage composition of Poa pratensis L. Merion grown on Houghton muck. Thesis for Ph.D. Michigan State University.

37. Scarsbrook, C. E. 1970. Regression of nitrogen uptake on nitrogen added from four sources applied to grass. Agron. J. 62: 618-620.

38. Schmidt, R. E. 1967. Growing a vigorous, strong, root system on cool season turfgrass. Weeds, Trees, and Turf 6(7:22-23).

39. Schmidt, R. E. 1969. Nitrogen nutrition of turfgrasses. Proc. 1st Inter. Turf Res. Conf. pp. 191-195.

40. Steel, R. G. and J. H. Torrie. 1960. Principles and procedures of Statistics. McGraw-Hill Book Company, Inc.

41. Stuckey, Irene H. 1941. Seasonal growth of grass roots. Amer. J. Botany 28:486-491.

42. Tisdale, S. L. and W. L. Nelson. 1966. Soil Fertility and Fertilizers. The Macmillan Company, New York. 2nd Ed. pp. 477-478.

43. Troughton, Arthur. 1957. The underground organs of herbage grasses. Commonwealth Bureau of Pastures and Field Crops, Hurley, Berkshire Bull. 44.

44. Volk, G. M. and G. C. Horn. 1965. Response of Tifgreen bermudagrass to soluble and slowly available nitrogen sources as measured by visual ratings and turf weights. Proc. Univ. Fla. Turf Management Conf. 13:147-152.

45. Walker, T. M., A. F. Adams, and H. D. Orchiston. 1956. Fate of labeled nitrate and ammonium nitrogen when applied to grass and clover grown separately and together. Soil Sci. 81: 339-351.

46. Ward, C. H. and R. E. Blaser. 1961. Effect of nitrogen fertilizer on emergence and seedling growth of forage plants and subsequent production. Agron. J. 53:115-120.

47. Wolcott, A. R., F. Maciak, L. N. Shepherd, and R. E. Lucas. 1960. Effects of telone on nitrogen transformations and on growth of celery in organic soil. Down to Earth (summer) pp. 1-5.

48. Wyler, J. and C. C. Delwiche. 1954. Investigations on the denitrifying process in soils. Plant and Soil 5:155-169.

APPENDIX

Table 12. Accumulative dry clipping weights, pounds per acre, Treatments 1 through 8.

	Treatment No.							
Date	1	2	3	4	5	6	7	8
5-18	101	342	715	934	316	376	398	411
5-23	158	506	1091	1402	486	581	600	602
5-26	200	602	1253	1645	603	718	707	714
5-28	215	638	1328	1743	644	771	754	758
6-4	251	736	1531	2119	733	955	856	864
6-9	270	818	1693	2380	813	1045	941	941
6-11	284	869	1797	2516	853	1094	988	983
6-16	298	1000	2035	2792	921	1183	1070	1048
6-19	307	1059	2155	2985	956	1238	1109	1079
6-22	314	1130	2285	3167	990	1296	1143	1110
6-25	323	1176	2390	3297	1015	1333	1174	1135
6-29	331	1221	2489	3466	1043	1373	1203	1158
7-2	334	1262	2593	3625	1063	1404	1224	1182
7-6	337	1322	2772	3856	1093	1454	1261	1214
7-9	339	1363	2877	4033	1109	1478	1281	1231
7-13	344	1435	3043	4315	1146	1526	1320	1264
7-16	349	1481	3152	4506	1180	1563	1351	1290
7-21	353	1537	3259	4718	1204	1589	1376	1314
7-25	357	1570	3342	4894	1222	1610	1395	1333
7-30	357	1573	3361	4966	1223	1611	1395	1334
8-6	357	1578	3396	5065	1224	1612	1396	1334
8-13	358	1592	3517	5262	1226	1613	1398	1336
8-20	358	1617	3690	5578	1229	1616	1401	1340
8-26	361	1656	3867	5910	1241	1624	1410	1350
9-1	363	1696	4016	6157	1252	1635	1423	1361
9-4	367	1735	4115	6328	1278	1655	1442	1382
9-8	375	1790	4238	6514	1310	1688	1476	1408
9-11	391	1901	4408	6733	1382	1757	1546	1480
9-16	405	1971	4539	6929	1431	1812	1598	1530
9-21	419	2066	4709	7146	1496	1877	1662	1600
10-1	438	2213	4992	7524	1608	1991	1772	1707
10-6	442	2286	5125	7702	1659	2042	1824	1756
10-15	447	2392	5286	7878	1725	2113	1899	1824
10-27	461	2516	5542	8233	1789	2174	1975	1895
11-12	463	2555	5676	8447	1807	2195	1990	1916

Table 13. Accumulative dry clipping weights, pounds per acre, Treatments 9 through 16.

	Treatment No.							
Date	9	10	11	12	13	14	15	16
5-18	212	527	462	523	337	469	541	513
5-23	371	749	708	852	514	685	834	742
5-26	481	876	841	1046	602	820	963	888
5-28	524	920	897	1115	641	877	1026	941
6-4	617	1052	1019	1261	760	1007	1170	1065
6-9	725	1164	1120	1377	860	1135	1312	1183
6-11	782	1230	1177	1448	921	1214	1392	1262
6-16	950	1391	1309	1612	1053	1385	1562	1416
6-19	1035	1472	1389	1703	1116	1482	1644	1494
6-22	1115	1556	1463	1783	1177	1581	1738	1590
6-25	1168	1622	1509	1834	1238	1642	1793	1643
6-29	1227	1689	1566	1895	1295	1708	1853	1705
7-2	1286	1745	1615	1946	1340	;763	1905	1759
7-6	1386	1850	1688	2081	1395	1856	1997	1897
7-9	1448	1913	1742	2163	1434	1912	2099	1977
7-13	1557	2041	1828	2235	1486	2003	2199	2126
7-16	1637	2111	1895	2294	1521	2074	2271	2236
7-21	1705	2160	1951	2335	1550	2137	2334	2329
7-25	1755	2200	1992	2376	1577	2183	2381	2402
7-30	1759	2203	1996	2379	1578	2185	2385	2410
8-6	1765	2207	2001	2386	1580	2191	2393	2437
8-13	1770	2221	2043	2483	1582	2209	2443	2573
8-20	1775	2244	2138	2756	1586	2248	2557	2856
8-26	1808	2276	2255	3086	1594	2270	2717	3159
9-1	1819	2309	2355	3318	1607	2314	2835	3359
9-4	1843	2347	2431	3464	1628	2353	2908	3503
9-8	1876	2406	2530	3614	1659	2418	3015	3650
9-11	1944	2506	2675	3812	1720	2519	3169	3830
9-16	1996	2583	2784	3959	1769	2601	3287	3981
9-21	2062	2682	2921	4152	1829	2709	3435	4159
10-1	2170	2840	3145	4456	1922	2882	3679	4459
10-6	2201	2920	3289	4616	1951	2972	3819	4606
10-15	2245	3029	3458	4796	1989	3091	3997	4774
10-27	2295	3162	3670	5050	2053	3207	4230	5049
11-12	2306	3213	3786	5173	2066	3258	4353	5207

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