THE EFFECT OF SULFUR, NITROGEN, AND PHOSPHORUS FERTILIZATION ON THE YIELD AND CHEMICAL COMPOSITION OF KIKUYUGRASS

(*Pennisetum clandestinum* Hochst. ex Choiv.)

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INTRODUCTION

The importance of sulfur for plant growth was first recognized by Sach (Meyer and Anderson, 1956) in the early nineteenth century. Arnon (Meyer and Anderson, 1956) later proved that sulfur obeyed his five laws of essentiality, which are discussed in the Literature Review of this thesis. The first field responses were recorded simultaneously by Benjamin Franklin and a Swiss worker (Sulfur The Essential Plant Food Element, 1962). Franklin, using gypsum, wrote "This Land Has Been Plastered" on the ground and found that bright green plants followed the pattern of each letter exactly. He then concluded that something in the gypsum made the plants grow vigorously.

Since the nineteenth century, much research has been done with sulfur as a fertilizer amendment. Unforeseen sources of sulfur have often caused some erratic results in field trials. Any of three sources of sulfur, atmospheric, fertilizer impurities, or organic matter, was usually associated with these erratic results.

The first and most often encountered naturally available source of sulfur is the atmosphere. Atmospheric industrial wastes, smoke from fossil fuel-burning home heaters, and volcanic eruptions add significant amounts of sulfur to the atmosphere. Sulfur in the atmosphere returns to the soil with rain. In industrial areas, rain often adds 20 pounds of sulfur per acre per year. The second source of sulfur is from the impurities in fertilizer. For many years these impurities supplied enough sulfur for adequate plant growth. The third source of sulfur is the decomposition of organic matter. Sulfur that is returned to the soil as plant material refuse is chemically transformed to a plant available form by various soil microorganisms, usually of the genus Thiobacillus.

Because of advances in technology the amount of sulfur that is added to the soil by these sources has rapidly decreased. Pure air regulations require that atmospheric industrial wastes meet certain purity standards. The source of energy for home heaters is rapidly being switched from fossil fuel to electricity produced by atomic energy. Thus, the amount of sulfur returned to the soil from the atmosphere is diminishing. Fertilizer research is putting emphasis on high analysis fertilizers manufactured without the use of sulfur-containing compounds. Thus, a second source of sulfur is being eliminated rapidly. Continuous cropping is decreasing the amount of organic matter returned to the soil. Thus, a third source of sulfur is also diminishing. Since these three sources of sulfur are rapidly diminishing, it is now necessary to consider supplemental sulfur additions for optimum crop production.

Two reports encouraged this research in Hawaii. Ranchers downwind from Hawaiian volcanoes reported that after an eruption the pastures appeared greener. The second was a report from two sugar plantations stating that sugar yields were increased by the addition of sulfur-containing fertilizers. Thus, it appears that a sulfur experiment would be warranted.

The objectives of this experiment are to:

1. Determine the effect of nitrogen, phosphorus, and sulfur fertilization on the yield of kikuyugrass (Pennisetum clandestinum Hochst. ex Choiv.), hereafter referred to as kikuyugrass.

2. Find the effect of nitrogen and phosphorus on the total and sulfate sulfur in kikuyugrass.

3. Attempt to find a significant N:P:S ratio that would indicate the nitrogen, phosphorus, and sulfur status of kikuyugrass.

4. Assess the nitrogen, phosphorus, and sulfur requirements of kikuyugrass from these ratios.

5. Assess the effect of fertilization on the protein content of kikuyugrass.

LITERATURE REVIEW

The three essential anionic macronutrients are sulfur, nitrogen, and phosphorus. There must be a readily available supply of these macronutrients if maximum production is to be obtained. When studying these anions most workers only use one or two at any one time. This paper is an attempt to study the effect of all three anions at once.

Sulfur

Sulfur is an essential element for the life processes of all living things, including microorganisms, higher plants, animals, and man (Texas Gulf Sulfur Company, 1961). About 1860, two German botanists, Sachs and Knops, declared that sulfur was an essential element for plant growth (Meyer and Anderson, 1956). In the 1940's, Arnon declared that sulfur obeyed his five laws of essentiality. These laws of essentiality are as follows (Schmid, Personal Communication):

1. The plant cannot complete a life cycle without the element in question.
2. The element must directly affect the metabolism of the plant.
3. Readdition of the element to the nutrient supply results in recovery of a plant showing deficiency symptoms.

4. Another element cannot substitute for the plant functions of the element in question.
5. The results must hold for a range of species and families.

Plant physiologists around the world generally agree that these are the best criteria presented to date.

Three sources supply sulfur to organisms, directly or indirectly. These sources are the lithosphere, which contains approximately 0.05% sulfur by weight; the sea, which contains approximately 0.09% sulfur by weight; and the atmosphere, which contains approximately 0.0000025% sulfur by volume (Texas Gulf Sulfur Company, 1961). The most often encountered forms of sulfur are S, SO_2, FeS_2, $CaSO_4 \cdot 2H_2O$, $CaSO_4$, H_2S and complexes of these forms. Plants take sulfur from the soil in the anionic $SO_4^{=}$ form and from the atmosphere as SO_2 gas (Freney, Barrow, and Spencer, 1962). Sources of sulfur that are important to agriculture production are the atmosphere, fertilizer impurities, and organic matter.

In recent years, the sulfur content of the environment has steadily declined. Sources that inadvertently supply sulfur to the environment are declining because new technological developments put emphasis on purity and maximum production. In some areas the atmosphere is responsible for supplying significant amounts of sulfur. The atmosphere supplies sulfur as SO_2 gas and in rain water as $SO_4^{=}$. Sulfur from rain water has been studied by Fox (1957), Eriksson (1960), and Drover (1960). Sulfate added from rain water ranged from less than 1 pound per acre per year to more than 20 pounds per acre per year, depending on the location. Any process that liberates any form of sulfur gas results in an increase in atmospheric sulfur. The burning of fossil fuels, manufacturing processes, and volcanic eruptions are generally the sources of atmospheric sulfur. Pure air regulations limit the amounts of sulfur wastes deposited in the atmosphere by reducing waste from industrial processes. Fossil fuels as a source of energy are rapidly being replaced by atomic energy. Thus, atmospheric sulfur is decreasing.

In the past, sulfur was inadvertently applied to the soil when fertilizers such as superphosphate and ammonium sulfate were applied. The technological push for maximum yields has put the emphasis on chemically pure high elemental analysis fertilizers. Instead of ammonium sulfate and superphosphate, new recommendations call for the use of anhydrous ammonia and ammonium polyphosphates, respectively. Thus, the high production and high analysis fertilizers compound the need for sulfur-containing fertilizers.

The push for maximum production has also resulted in the use of a continuous cropping system. Most high producing crops do not return much organic matter to the soil, especially if continuous cropping is used. Since the mineralization of organic sulfur is an important soil sulfur source (Starkey, 1966), the decline of organic matter due to continuous cropping is contributing to the need for sulfur fertilizers and research. Thus, high production and a decline in the amount of sulfur which has been inadvertently added to crops has brought about sulfur deficiencies.

In temperate soils sulfur occurs in both organic and inorganic forms. Plant and animal refuse is the source of most organic sulfur in the soil. Organic sulfur is oxidized to inorganic sulfate by microorganisms, usually of the genus Thiobacillus (Burns, 1967). Inorganic sulfur occurs as $SO_4^{=}$ in the soil. Although inorganic sulfur is rapidly leached from the rhizosphere (Chao, Harward, and Fang, 1962), that which is retained is believed to be complexed with aluminum. Thus, it is evident that sulfur should be supplied to the soil continuously, and not in one huge application. This is where organic matter is advantageous. The sulfur is released slowly by the microorganisms. Thus, it is available as the plant needs it.

Sulfur deficiencies inhibit metabolic pathways by preventing the formation of enzymatic proteins, cofactors, and the three sulfur containing amino acids, methionine, cystine, and cystiene (Wilson, 1962). Even though the plant is sulfur deficient, it continues to take up nitrogen and phosphorus. Since the metabolic pathways are inhibited, an accumulation of nitrogen and phosphorus is evident (Ødelien, 1963).

Significant sulfur responses have been recorded for many different genera and species of plants growing around the world. In Australia, Barrow (1968) recorded excellent sulfur responses with subterranean clover (Trifolium repens L.). At one site he recorded excellent responses even though single superphosphate had been applied for 40 years. In New South Wales, Johnson (1967) found that on a wide range of soils these crops, Phalaris tuberosa L., subterranean and white clover, and lucerne (Medicago sativa L.) responded well to 60 pounds of sulfur per acre; however, 80% of the response could be obtained with a 30 pound application. Beaton (1966) reported that good responses were obtained in Canada using oats (Avena sativa L.), wheat (Triticum spp.), and barley (Hordeum vulgare L.). In Canada the magnitude of most responses was 100% with the application of 20 pounds of sulfur per acre. Ground nut (Arachis hypogaea L.) responses to sulfur were obtained in Ghana (Stanford and Jordan, 1966). Sulfur responses were obtained with tobacco (Nicotiana tabacum L.) in Georgia and North Carolina, rape (Brassica napus L.) in France, oil palms (Elaeis guineenis L.) in Africa, sweet corn (Zea mays L.) in Michigan and Nebraska, soybeans (Glycine max L.) and grasses in Brazil, and tea (Camellia sinensis L.) in Ceylon and Assam (Sulfur The Essential Plant Food Element, 1962). Jones (1967) reported excellent sulfur responses for seed cotton (Gossypium spp.) in Brazil where 30 pounds of sulfur increased the yield from 1300 to 2000 kilograms per hectare. Fox and Hoover (1961) recorded positive responses to sulfur in corn and soybeans when it was added in conjunction with nitrogen and phosphorus. Yonemitsu (Personal Communication) reported excellent response in sugarcane (Succharum spp.) grown in Hawaii. Fox, Moore, Wang, Plucknett, and Furr (1965) showed that at high elevations in Hawaii, kikuyugrass yields could be increased up to 87% when sulfur was added to a complete fertilizer mixture.

The critical level of an element in a plant is the concentration of that element in the plant where addition of the element to the nutrient source does not increase the yield (Ensminger and Freney, 1966). The critical level for plant sulfur varies greatly among species. Yonemitsu (Personal Communication) reported that sugarcane was deficient when the sulfur content was about 1500 ppm S; however, when grown on adequately fertilized soil the sugarcane contained 3000 ppm S. Fox, Atesalp, Kampbell, and Rhodes (1964) reported that corn was deficient if the concentration of sulfur in the plant fell to about 900 ppm S and it was adequate when sulfur was approximately 2200 ppm S. Allaway and Thompson (1966) reported critical levels for wheat, oats, and barley to be 2500, 1720, and 1950 ppm S, respectively. They also reported that oats contain about 2600 ppm S when they are enjoying luxury consumption. Martin and Walker (1966) reported alfalfa to be deficient at about 1400 ppm S and adequate for good growth at about 2500 ppm S. Ensminger and Freney (1966) reported that the critical level in whole ryegrass (*Lolium perenne* L.) and timothy (*Phleum pratense* L.) was 2600 ppm S, while cocksfoot (*Dactylis glomerata* L.) was 300 ppm S. Fox, *et al*. (1965) reported excellent responses to sulfur with kikuyugrass, if the sulfur concentration in the plant was changed from 1700 to 2200 ppm S.

The applicability of the above concentrations is very limited because most investigators have not reported the stage of growth or the part of the plant analyzed. Work done by this investigator with sugarcane strongly suggests that the part of the plant analyzed is extremely important. In a plant receiving adequate sulfur, the concentration in the first leaf sheath was 5180 ppm S, while the millable cane contained only 400 ppm S. Thus, if different data are to be compared, many more factors about the plant sampling must be recorded.

Dijkshoorn, Lampe and Van Burg (1960) and Steward (1966) observed that the ratio of nitrogen to sulfur in the plant material was a better indicator of the sulfur status of that plant than was total sulfur. Their conclusion was based on the fact that protein is composed of nitrogen and sulfur in a 17:1 ratio. Since a plant at the critical sulfur level has just enough sulfur to satisfy all metabolic processes, it would follow that the critical nitrogen-sulfur ratio would be approximately 17:1. Allaway and Thompson (1966) used pot studies to show that the critical nitrogen-sulfur ratio in white clover and wheat was indeed 17:1. But Ødelien (1963) reported data from Sweden showing that barley and spring wheat grain had a nitrogen-sulfur ratio of 9.6:1 and 12.6:1, respectively, while barley, oats, and spring wheat grass had a nitrogen-sulfur ratio of 3.6:1, 4.3:1, and 4.8:1, respectively. His only comment was that some of the values should be taken with "a grain of salt". Yonemitsu (Personal Communication) reported that when the nitrogen-sulfur ratio in sugarcane goes above 13, the plant is sulfur deficient. He reported that as the cane grew the nitrogen-sulfur ratio was more constant than the total plant sulfur.

Nitrogen

The most frequently published fertilizer responses have been those for nitrogen. Most of the nitrogen work on grass pastures has been done in temperate areas. Most of the tropical pasture responses recorded have been done in Australia and South Africa. The degree and type of response depend on the form of fertilizer and mainly upon the genus and species of the pasture grass in question. Positive linear and curvilinear yield results have been recorded (Henzel, 1962).

In Southern Rhodesia at Marandellas, Weinmann (Henzel, 1962) showed that stargrass (Cynodon plectostachyus K. Schum.) responses were linear with nitrogen applications from 0 to 168 pounds of nitrogen per acre. In Kenya, kikuyugrass responded well to treatments of 141 pounds of nitrogen per acre (Henzel, 1962). Guineagrass (Panicum maximum Jacq.), mekergrass (Pennisetum purpureum Schumach.), and a mixed stand of paragrass (Brachiaria mutica Forsk.) and caribgrass (Eriochloa polystachya H.B.K.) doubled their yield when nitrogen was applied ranging from 0 to 200 pounds of N per acre (Vicente-Chandler, Silva, and Figarella, 1959). With most trials the nitrogen response follows a sigmoid curve (Henzel, 1962) if many rates of nitrogen fertilizers are used. In the tropics, minimum nitrogen fertilizer rates are often many times greater than those necessary in temperate areas. Tests with high nitrogen rates up to 2000 pounds per acre are warranted in the tropics, because tropical pastures grow 365 days a year while temperate pastures grow only 4 to 6 months a year. In Puerto Rico (Henzel, 1962), elephantgrass (Pennisetum purpureum Schumach.) fertilized with 1200 pounds of nitrogen and cut every 40 days produced a record yield of 34.2 tons of dry matter per acre per year.

The protein content of pasture grasses fertilized with nitrogen increased as the rate of nitrogen fertilizer increased (Henzel, 1962). Weinmann (Henzel, 1962) found that stargrass fertilized with 0 and 800 pounds of nitrogen contained 6.48% and 10.50% protein, respectively. At Santa Isabel, British West Indies (Henzel, 1962), the application of 1600 pounds of nitrogen to elephantgrass, pangolagrass (Digitaria decumbens Stent), and guineagrass resulted in a protein content of about 12%. In Georgia, Burton (1952) found that the protein content in coastal bermudagrass increased from 7% to 13% with the application of 400 pounds of nitrogen.

Sherrod and Ishizaki (1966) showed that in kikuyugrass as the length of time between harvests increased anywhere between 3 and 24 weeks, the protein content dropped from 15 to 5% on a dry matter basis. Increasing the time between cuttings increases the dry yield but lowers the protein content.

In the tropics the use of high nitrogen fertilizer application rates on tropical grasses will give very high yields.

Phosphorus

In the tropics, phosphorus fertilizer requirements are many times greater than those for temperate areas. De Datta, Fox, and Sherman (1963) reported that on Kauai a mixture of Desmodium intortum and Digitaria decumbens reached maximum production only after the application of 1000 to 1200 pounds of phosphorus per acre. These extremely high requirements are necessary because the fixation capacity of the soil must be satisfied before any phosphorus is available for uptake. Younge and Plucknett (1966) reported that 24 hours after the addition of a 10,000 ppm phosphorus solution, the soil suspension had fixed from 25 to 80% of the phosphorus added. Of course, not all tropical soils require such high phosphorus additions. For example, Younge and Plucknett (1966) also reported that dark magnesium clays and grey hydromorphic soils fixed less than 10% of the added phosphorus.

In Hawaii the economics of the crop determines how much phosphorus will be applied by a farmer (Younge and Plucknett, 1966). Sugarcane receives about 175 pounds of phosphorus per ratoon crop (2 years), pineapple (Ananas sativus) receives about 100 pounds of phosphorus per ratoon crop (1 year), while high monetary returns from vegetable crops warrant the application of 200 pounds of phosphorus per acre per year. Improved pastures receive only 50 pounds of phosphorus per acre per year. Thus, it is evident that phosphorus recommendations must be made only after evaluating the economics of the crop and the fixation capacity of the soil.

Plucknett and Fox (IX International Grassland Congress, 1964) showed that pangolagrass yields were increased by the addition of 132 pounds of phosphorus per acre. They also found that the yield decreased with the addition of 525 pounds of phosphorus per acre. These phosphorus responses held for nitrogen treatments of 0, 50, and 100 pounds of nitrogen per acre. Younge and Plucknett (IX International Grassland Congress, 1964) reported that over a five-year period, phosphorus treatments of up to 1200 pounds of phosphorus per acre gave excellent responses. Clements (1959) reported an increase of 2.1 tons of sugar at Paauhau, Hawaii, with application of 176 pounds of phosphorus per acre. He also reported similar responses at Pepeekeo, Hawaii. Younge and Plucknett (IX International Grassland Congress, 1964) reported that the addition of phosphorus up to 1200 pounds of phosphorus per acre increased the crude protein from 200 to 2000 pounds per acre.

Radet (1966) reported that the phosphorus-sulfur ratio should be about one. Work by Spencer (1966) suggested that the phosphorus-sulfur ratio may be a good indicator of the sulfur status of a plant. Hassan and Olson (1966) reported that as the phosphorus treatment increased, in the 35-day harvest of corn, the sulfur in the plant increased. However, at 75 days there was no effect of phosphorus on the sulfur in the plant.

Phosphorus responses in the tropics are not related to temperate conditions. Most responses in the tropics are due to very high rates of phosphorus application. If these high rates are used some soils considered unproductive can be brought into high production.

MATERIALS AND METHODS

Description of Soil and Site

The plot area was located on the Kahuku Ranch, Naalehu, Hawaii. The soil series is Moaula and classified as a Hydric Dystrandept. The soil was formed from recent ash that is only slightly weathered but highly leached because of the 80-inch rainfall. This was emphasized by the chemical analysis of this soil as shown in Table 1.

The plots were at an elevation of about 2200 feet. The native vegetation was Ohia (*Metrosideros polymorpha* Forst.) and Tree Fern (*Cibotium chamissoi* Kaulf.). About eight years ago the area was bulldozed and sown with kikuyugrass sprigs. Later the area was also seeded with big trefoil (*Lotus uliginosus* Schk.). The area was pastured for six years prior to the initiation of this experiment.

Experimental Design

The experimental design was a 3x3x3 factorial randomized block design with two replications. The variables were rates of nitrogen, phosphorus, and sulfur fertilizers. For statistical analysis the blocks were arranged such that the replication would account for variability due to slope. Each plot was 8 feet wide by 20 feet long. A block was 72 feet wide and 60 feet long, and thus consisted of three rows of nine plots each.

Table 1. Chemical Analysis of the Soil (Hydric Dystrandept) Used for This Experiment

$SiO_2:R_2O_3$ Ratio	0.825
Cation Exchange Capacity	40 meq/100 g soil
Potassium	0.15 meq/100 g soil
Sodium	0.70 meq/100 g soil
Calcium	8.10 meq/100 g soil
Magnesium	6.80 meq/100 g soil
Organic Matter	14%
Percent Organic Carbon	8.15%
Acid digestable Nitrogen	0.7%
Modified-Truog Extractable Phosphorus	1.4 ppm P
3:1 Water Extractable Sulfate-S	13.4 ppm S
pH	
1:1 H_2O	5.95
1:1 KCl	5.10
Lime Requirement for 6.5 pH	8.25 tons $CaCO_3$/acre
Oven Dry Moisture	110%

Application and Rates

The different rates of the nitrogen, phosphorus, and sulfur variables are presented in Table 2.

Nitrogen was applied as urea initially and after the first two harvests. Thus, at the high nitrogen rate, 600 pounds of nitrogen was applied during the three harvests.

Phosphorus was only applied initially. The phosphorus source was sulfur-free treble superphosphate that was specially prepared by the Tennessee Valley Authority.

Sulfur also was only applied initially in the form of gypsum ($CaSO_4 \cdot 2H_2O$).

Potassium, applied as KCl, was applied as a blanket application on all the plots. It was applied initially and after the second harvest at the rate of 100 pounds of potassium per acre per application.

All fertilizer amendments were distributed by hand. No tillage was used to work the fertilizer into the soil.

Harvesting and Plant Sampling

Harvesting intervals were determined by the amount of growth, not by a specific number of days. The plots were established on December 26, 1966. The first harvest was on February 23, 1967 after 62 days of growth, the second on April 27, 1967 after 63 days of growth, the third on July 13,

Table 2. Rates of Nitrogen, Phosphorus, and Sulfur Applied in a Complete Factorial Arrangement

Variable Treatment	Rate of Application
Nitrogen	50 pounds of N per acre
	100 pounds of N per acre
	200 pounds of N per acre
Phosphorus	0 pounds of P per acre
	100 pounds of P per acre
	500 pounds of P per acre
Sulfur	0 pounds of S per acre
	20 pounds of S per acre
	100 pounds of S per acre

1967 after 77 days of growth, and the fourth on November 3, 1967 after 112 days of growth. After the fourth harvest the plots were not mowed until November 29, 1967. The fifth harvest was on May 1, 1968 after 154 days of growth.

Before harvesting, the plots were rated according to their visual growth patterns. A Merri-Tiller sickle mower was used to harvest the plots. To open the plots, a 16-inch swath was cut from the ends of all the plots. All the cut material was removed and discarded. Then a 32-inch swath was cut lengthwise through the center of each plot. Thus, a 32x208-inch swath was harvested from each plot.

The cut swath was raked and the harvested grass gathered into a bag-shaped tarpaulin. A spring scale hung from a tripod was used to weigh the harvested grass. A 300-gram sample was taken at random from the harvested grass. This was put in a paper bag and brought to the laboratory for drying at 70°C for four days, and then weighed. The loss in weight was used to calculate the percent dry matter.

Samples were also collected for chemical analysis. The four terminal leaves and their corresponding sheaths and stems were plucked from approximately 75 plants per plot. The samples were put in a paper bag and brought to the laboratory to dry at 70°C for four days. The sample was then ground in a Wiley Mill containing a 20 mesh screen and stored in a 15-dram plastic vial until needed for analysis.

The borders were mowed with a tractor mower and removed. The plots were then staked out for the necessary fertilizer applications.

Analytical Methods

Total Nitrogen

The micro-Kjeldahl Method (Jackson, 1965), modified for nitrate reduction (Young, Pineapple Research Institute, Personal Communication), was used to determine total nitrogen.

For nitrate reduction, a 0.20-gram plant sample was put into a 100 ml micro-Kjeldahl flask. Ten ml of distilled water and 3 ml of 1:1 sulfuric acid were added to the flask. Then 0.75-gram of iron powder was added. After waiting 10 minutes the flask was put on a digestion rack and heated slowly until most of the water had evaporated. The flask was then allowed to cool.

Seven ml of concentrated sulfuric acid was added to the flask. Then 1-gram of sodium sulfate was added and the flask was gently swirled. Two drops of selenium oxichloride were added. The flask was put on a digestion rack and heated slowly to avoid excessive frothing. After frothing had stopped, high heat was maintained for about 1 hour or until the sample solution was a crystal-clear yellow. After a brief cooling period, the solution was quantitatively transferred to a digestion flask that was fitted specifically for the micro-Kjeldahl distillation apparatus. The distillation apparatus was adjusted such that condensed steam collected at the rate of 7 ml per minute. When this rate was attained, the distillation flask was attached. Then 50% sodium hydroxide was added until the solution turned a thick dark brown. The distillation continued for 10 minutes. The distillate was collected in 50 ml of 4% boric acid, which contained Jackson's mixed indicator (1965). It was then titrated with 0.1 normal sulfuric acid.

The following equation was used to calculate the percent nitrogen in the plant sample:

$$\text{Percent Nitrogen} = \left[\left(\begin{matrix}\text{Total ml for sample}\\ \text{titration}\end{matrix}\right) - \left(\begin{matrix}\text{ml to titrate}\\ \text{blank}\end{matrix}\right)\right] \times \begin{matrix}\text{normality}\\ \text{of acid}\end{matrix} \times \frac{1.4}{\begin{matrix}\text{sample}\\ \text{weight}\end{matrix}}$$

Nitric-Perchloric Acid Digest

Nitric-perchloric acid digestion was used to bring the total phosphorus and sulfur in the plant sample into solution. A 0.5-gram sample was put into a 100 ml micro-Kjeldahl digestion flask. Fifteen ml of a 2:1 nitric-perchloric acid mixture was added and allowed to predigest overnight. The flask was next put on a digestion rack and heated slowly for 30 minutes. The heat was next maintained on high until the white fuming stage was reached. Then the heat was turned to low and the sample was allowed to reflux for 15 minutes. When the sample was cool, it was quantitatively transferred to a 50 ml volumetric flask and made to volume with distilled water. The sample was then stored in a 15-dram plastic vial until needed for chemical analysis.

Total Phosphorus

The Molybdate-Vanadate Yellow color method found in Chapman and Pratt (1961) was used to determine total phosphorus. An aliquot of the nitric-perchloric acid digest was put into a 25 ml volumetric flask. After the addition of 15 ml of distilled water the flask was shaken. Then 3 ml of ammonium molybdate-ammonium vanadate in nitric acid was added to the flask. The solution was brought to volume and allowed to stand for 30 minutes. The color intensity was read with a Coleman Junior Spectrophotometer at a wavelength of 430 mμ.

Total Sulfur

The barium chloride turbidity method of Kacar (1962) was used to determine total sulfur. A suitable aliquot was put into a 25 ml volumetric flask. About 10 ml of distilled water was added to the flask. Three ml of 2N ammonium acetate was then added followed by one gram of 20-30 mesh barium chloride crystals. The flask was shaken by hand for exactly 1 minute and 15 seconds. Immediately after shaking, 1 ml of 0.25% gum acacia was added to the flask. The solution was brought to volume with distilled water. After 15 minutes the degree of turbidity was read with a Coleman Junior Spectrophotometer set at a wavelength of 430 mμ.

RESULTS AND DISCUSSION

Figure 1 illustrates the effect of each individual element on the dry matter yield. Each point is the mean for all treatment combinations of the other two elements. Each individual element is characterized by five curves. Each curve represents a different harvest as indicated by the numeral following the curve. Figures 2 through 6 illustrate the effect of the two elements averaged to form the corresponding curve in Figure 1. Each figure (2 through 6) represents a different harvest. Each curve on a figure represents a treatment level.

Dry Matter Yield Per Day

First Harvest

The nitrogen responses, for the first harvest, are far greater than those of either phosphorus or sulfur (Figure 1). The greatest yield increase (30 lb/A/day) occurs when 200 pounds of nitrogen per acre was applied. Figure 2 indicates that very good nitrogen responses were recorded at all sulfur levels, with the response being greatest at the 200 pounds of sulfur treatment. At the first two phosphorus rates, nitrogen increased the yield linearly. However, at the 500 pounds of phosphorus rate, there was no response to 100 pounds of nitrogen, but large responses were obtained from the addition of 200 pounds of nitrogen. The phosphorus response curve for the

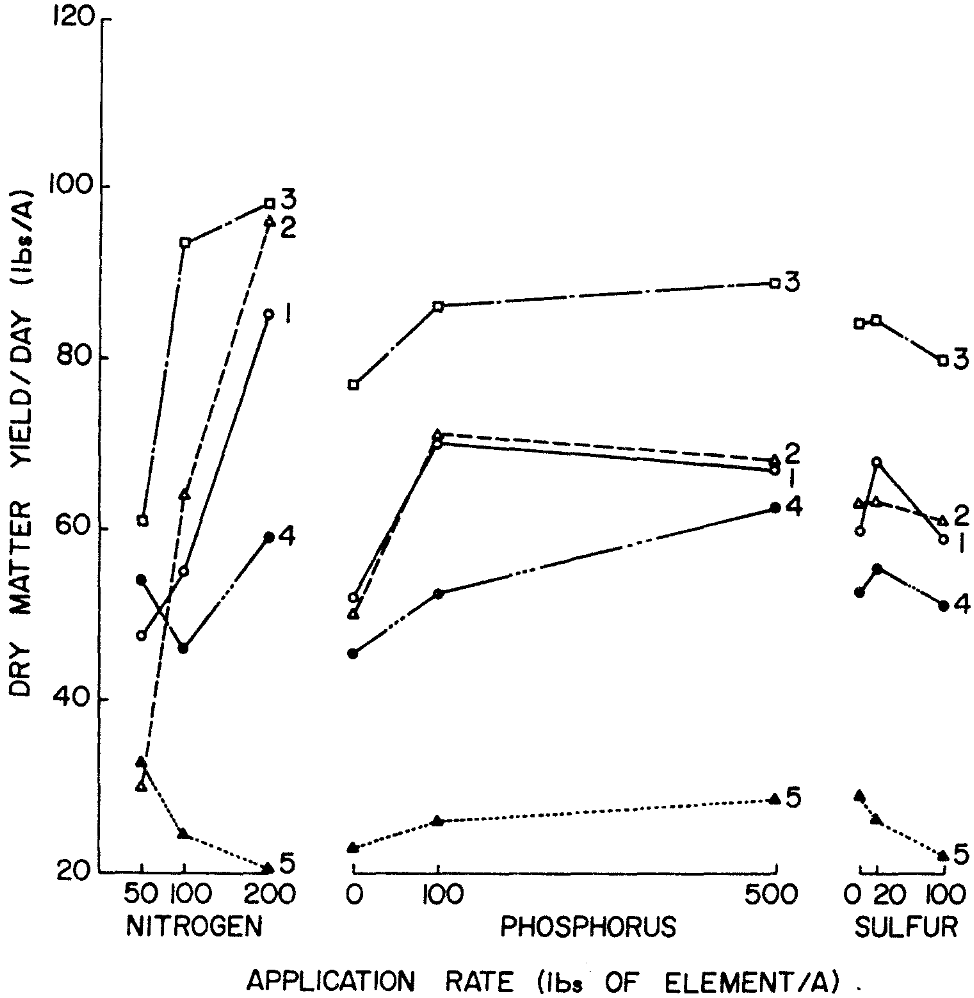

Figure 1. The Individual Effects of One Element (Averaged Over the Other Two Elements) on the Kikuyugrass Yield for All Harvests.

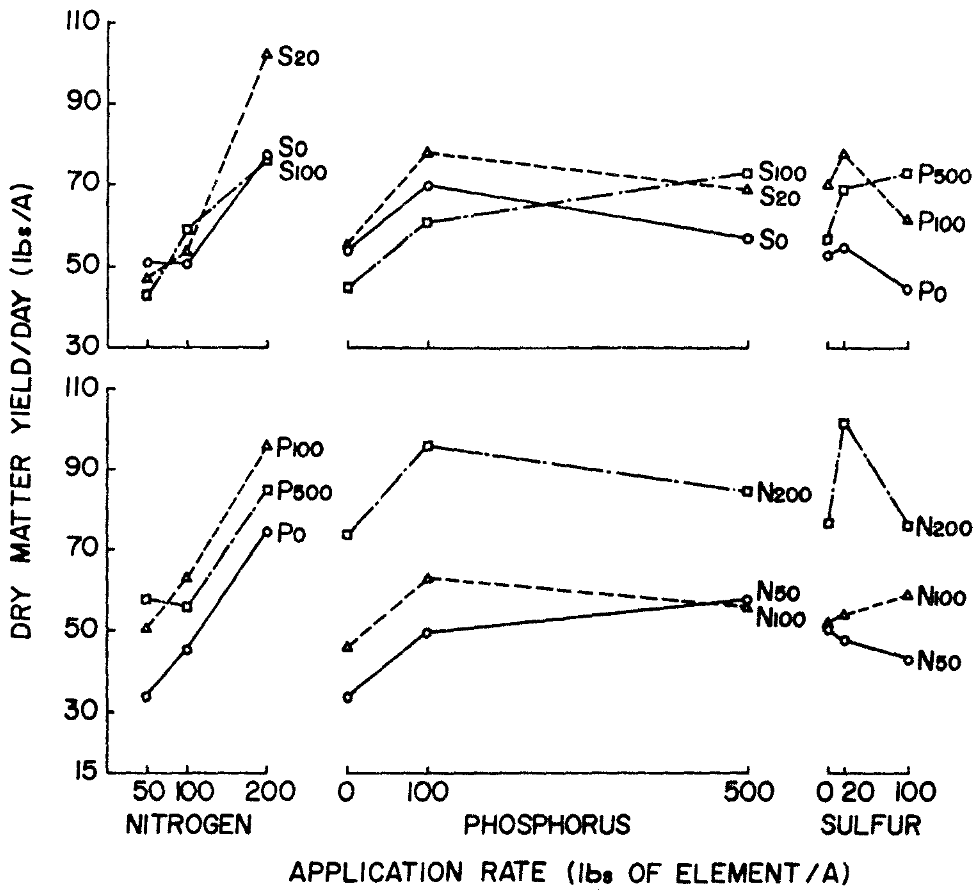

Figure 2. The Individual Effects of Two Elements (Averaged Over the Other Element) on the Kikuyugrass Yield for the First Harvest.

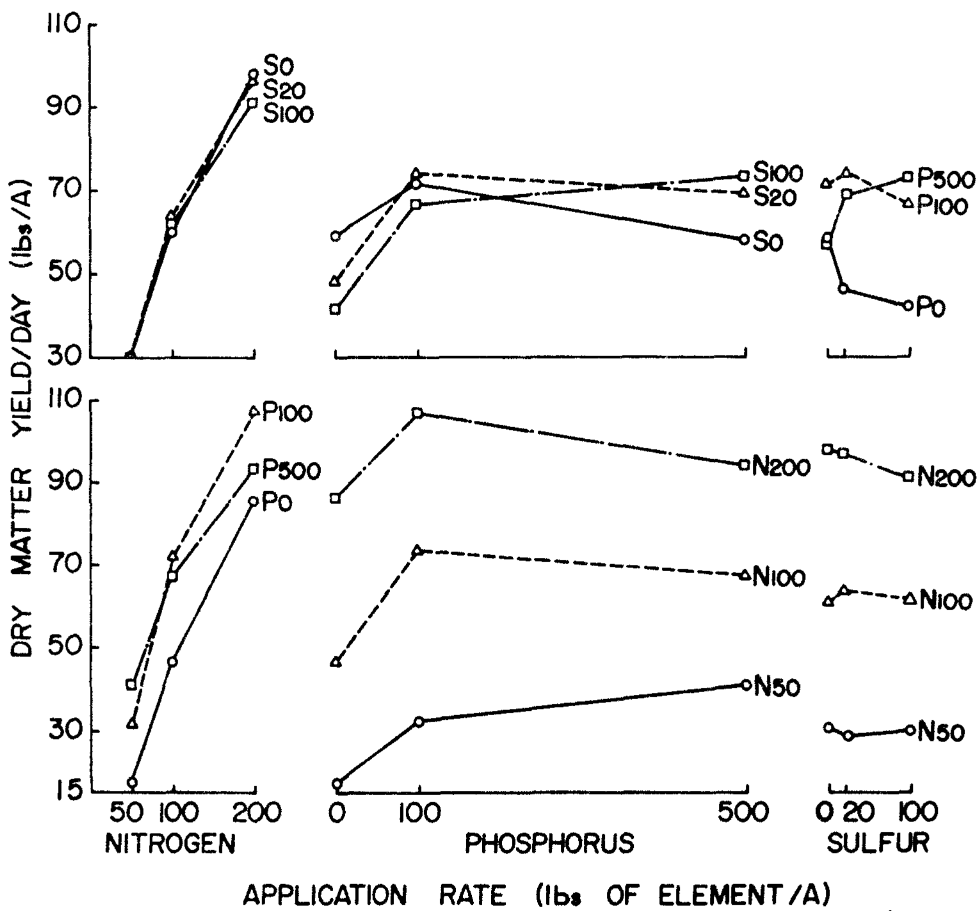

Figure 3. The Individual Effects of Two Elements (Averaged Over the Other Elements) on the Kikuyugrass Yield for the Second Harvest.

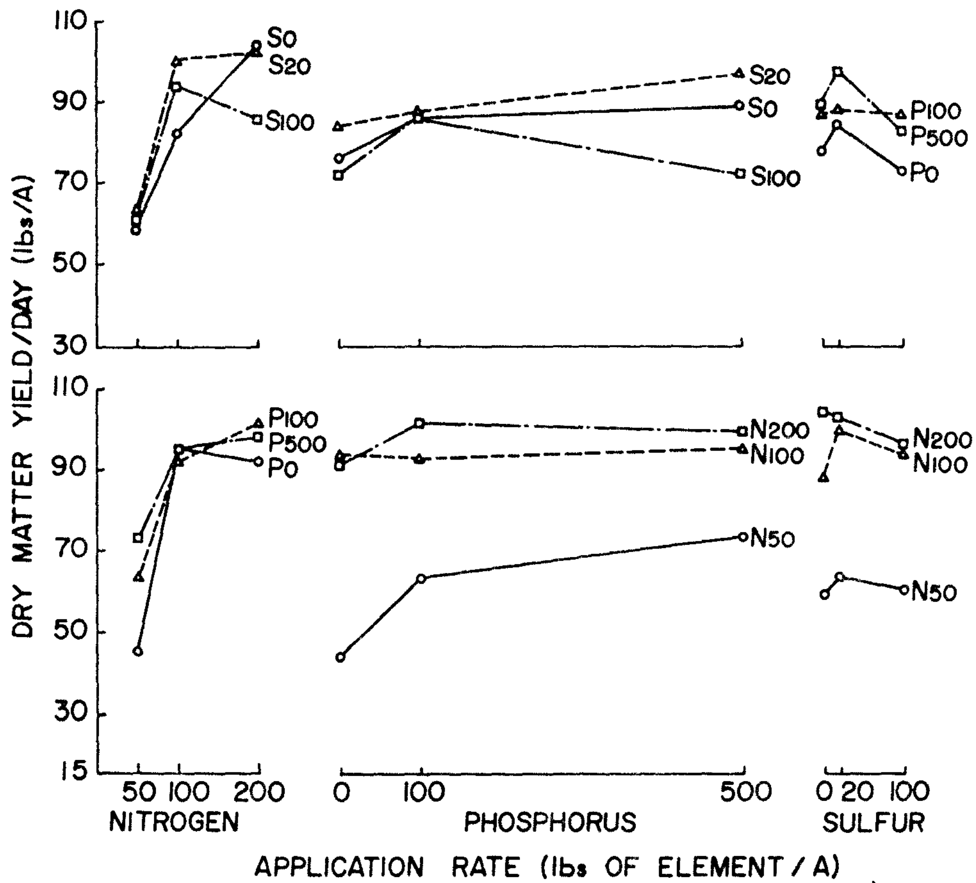

Figure 4. The Individual Effects of Two Elements (Averaged Over the Other Element) on the Kikuyugrass Yield for the Third Harvest.

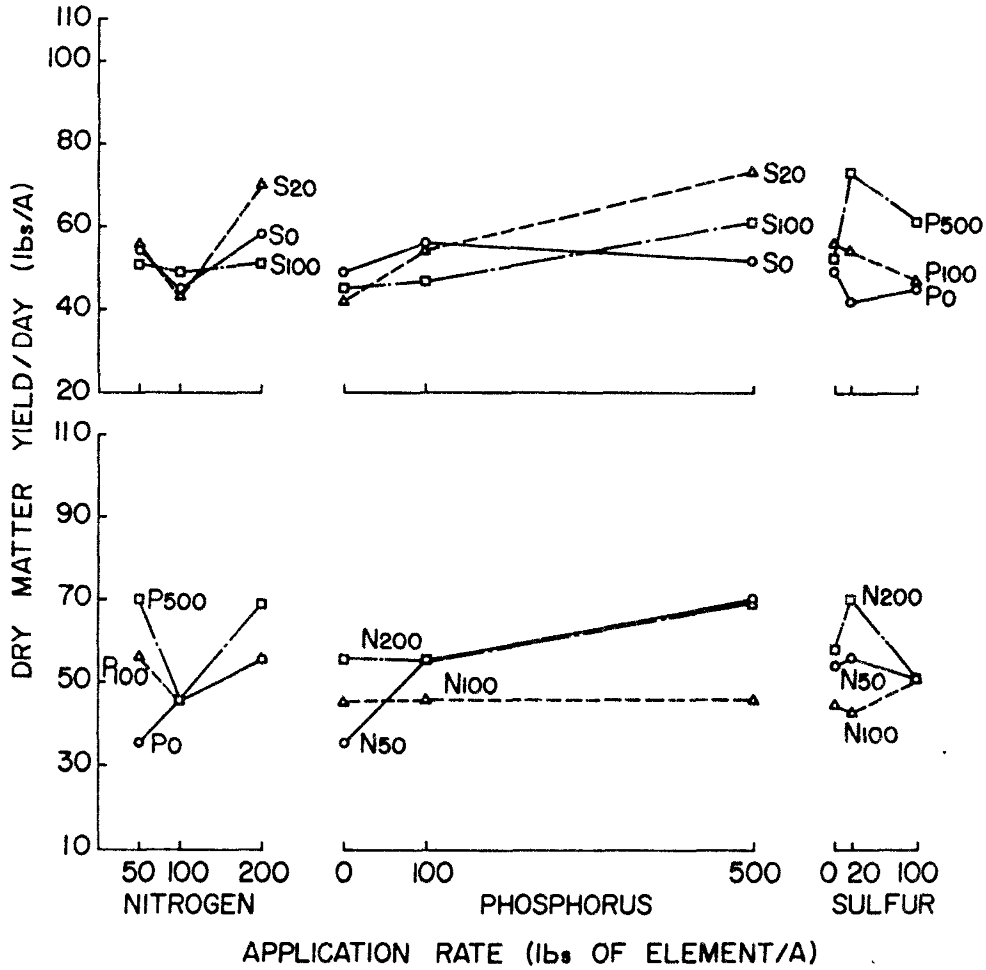

Figure 5. The Individual Effects of Two Elements (Averaged Over the Other Element) on the Kikuyugrass Yield for the Fourth Harvest.

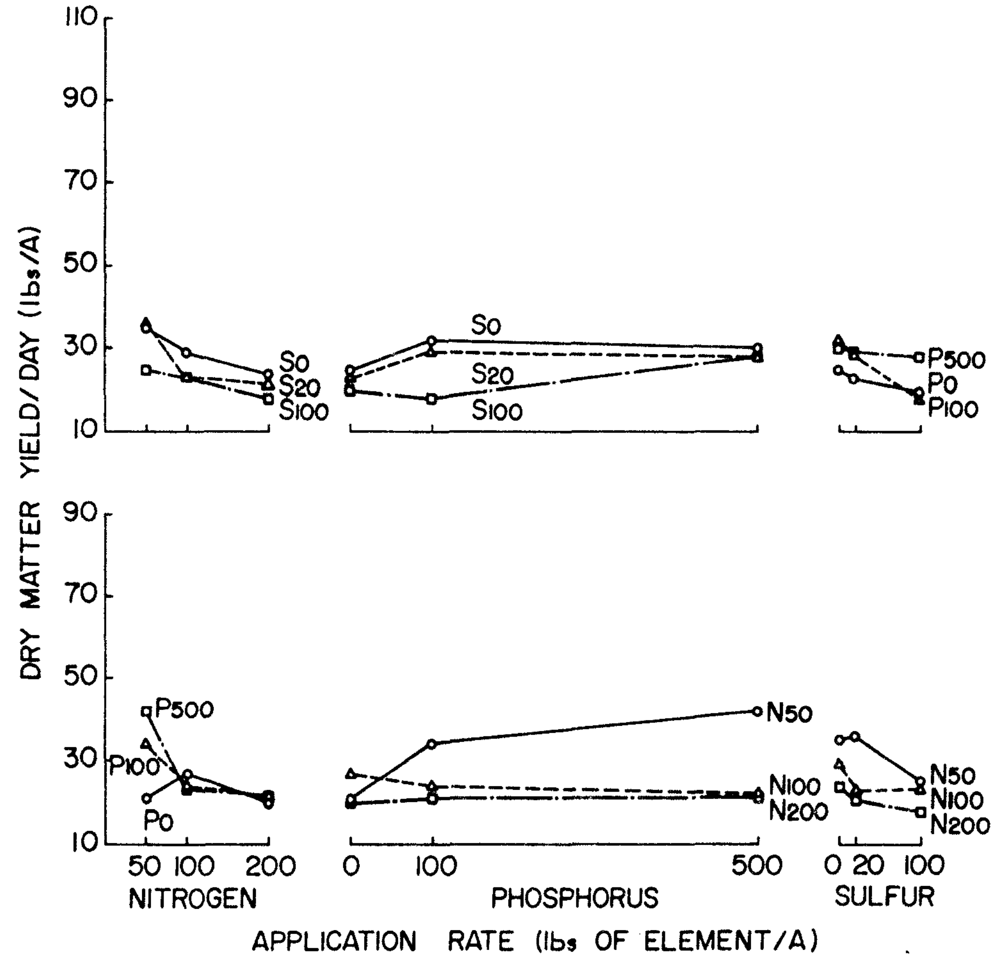

Figure 6. The Individual Effects of Two Elements (Averaged Over the Other Element) on the Kikuyugrass Yield for the Fifth Harvest.

first harvest shows a 20 pound per acre per day response to the 100 pounds of phosphorus treatment, but no additional response to the 500 pounds of phosphorus treatment (Figure 1). Figure 2 shows that a yield increase from the 100 pounds of phosphorus treatment was obtained at every nitrogen and sulfur level. Yield decreases occurred when 500 pounds of phosphorus was applied to the 100 and 200 pounds of nitrogen treatments and the 0 and 20 pounds of sulfur treatments. However, yield increases were obtained when 500 pounds of phosphorus was applied to the 50 pounds of nitrogen and the 100 pounds of sulfur treatments. The sulfur response curve for the first harvest (Figure 1) shows a slight increase in yield at the 20 pounds of sulfur treatment and a decrease when 100 pounds of sulfur was applied. The curve in Figure 2 shows that there is an increase in yield when 20 pounds of sulfur was applied with 100 and 200 pounds of nitrogen and with all three phosphorus rates, but the magnitude of the increase is greater at the higher levels of nitrogen and phosphorus. Yield increases to the 100 pounds of sulfur were obtained only with 100 pounds of nitrogen and 500 pounds of phosphorus treatments. At the 50 and 200 pounds of nitrogen and the 0 and 100 pounds of phosphorus rates, application of 100 pounds of sulfur resulted in yield decreases to levels below those of the 0 sulfur treatment.

The analysis of variance (Table 3) for the first harvest shows the nitrogen treatment to be highly significant. It also shows the phosphorus treatment to be significant. Using Figures 1 and 2 and Table 3, application of 200 pounds of nitrogen and 100 pounds of phosphorus may be expected to give significant dry matter yield responses if these fertilizers are applied for the first time to an established kikuyugrass pasture having similar experimental conditions.

Second Harvest

The nitrogen response curve for the second harvest (Figure 1) shows the most dramatic positive response. When the nitrogen application rate was increased from 50 pounds to 100 pounds, the dry matter yield increased by 34 pounds per acre per day, while increasing the nitrogen application from 100 pounds to 200 pounds increased the yield 32 pounds per acre per day. Figure 3 indicates that the dry matter yield response due to nitrogen was about the same at all sulfur and phosphorus levels. The second harvest phosphorus response curve (Figure 1) is almost identical in shape and magnitude to that of the first harvest. The response to 100 pounds of phosphorus was 20 pounds per acre per day, while there was no additional increase in dry matter yield when 500 pounds of phosphorus was applied. Figure 3 shows that 100 pounds of phosphorus increased the dry matter yield approximately 20 pounds per acre per day at all levels of nitrogen and sulfur.

Table 3. Analysis of Variance for Dry Matter Yield Per Day (lb/A) for All Five Harvests

Source	Degrees of Freedom	M.S.
	First Harvest	
Nitrogen	2	7144**
Phosphorus	2	1755*
Sulfur	2	384
NxP	4	160
NxS	4	512
PxS	4	344
NxPxS	8	112
Error	26	384
	Second Harvest	
Nitrogen	2	19214**
Phosphorus	2	2218**
Sulfur	2	39
NxP	4	228
NxS	4	38
PxS	4	428
NxPxS	8	90
Error	26	273
	Third Harvest	
Nitrogen	2	7389**
Phosphorus	2	718*
Sulfur	2	364
NxP	4	357
NxS	4	289
PxS	4	84
NxPxS	8	119
Error	26	173
	Fourth Harvest	
Nitrogen	2	881*
Phosphorus	2	1253**
Sulfur	2	138
NxP	4	496
NxS	4	245
PxS	4	346
NxPxS	8	279
Error	26	199

Table 3 (Continued)
Analysis of Variance for Dry Matter Yield Per Day (lb/A) for All Five Harvests

Source	Degrees of Freedom	M.S.
	Fifth Harvest	
Nitrogen	2	599**
Phosphorus	2	145
Sulfur	2	222*
NxP	4	274**
NxS	4	50
PxS	4	83
NxPxS	8	72
Error	26	62

* = Significant at .05 level
** = Significant at .01 level

The addition of 500 pounds of phosphorus increased the dry matter yield at the 50 pounds of nitrogen and 100 pounds of sulfur rates, while it decreased the dry matter yield at all other nitrogen and sulfur rates. The sulfur response curve (Figure 1) shows that there was no change in dry matter yield when sulfur was applied. However, sulfur application did affect the dry matter yield at different levels of nitrogen and phosphorus (Figure 3). Sulfur application did not affect the 50 pounds of nitrogen curve. Twenty pounds of sulfur slightly increased (4 lb/A/day) the dry matter yield at the 100 pounds of nitrogen and 100 pounds of phosphorus rates, while 100 pounds of sulfur decreased the yield at these rates. The application of sulfur decreased the yield 7 and 17 pounds per acre per day at the 200 pounds of nitrogen and 0 pounds of phosphorus rates, respectively. Sulfur applications increased the dry matter yield (15 lb/A/day) at the 500 pounds of phosphorus rate.

Analysis of variance for the second harvest (Table 3) shows that the response to nitrogen and phosphorus treatments are highly significant. Thus, using the graphs and analysis of variance table (Figures 1 and 3, Table 3) for the second harvest, the second application of nitrogen may be expected to give significant dry matter yield responses if 200 pounds of nitrogen and 100 pounds of phosphorus are applied to an established kikuyugrass pasture having similar experimental conditions.

Third Harvest

The mean dry matter yield for the third harvest (Table 4) is 84 pounds of dry matter per acre per day. This is an increase of 22 pounds of dry matter per acre per day over the first and second harvests. The nitrogen response curve for the third harvest shows a deviation from those of the first two harvests. The 100 pounds of nitrogen rate again showed a great increase in dry matter yield (32 lb/A/day), as in the previous two harvests, but the 200 pounds of nitrogen rate showed only a very small additional increase (5 lb/A/day) in dry matter yield. When 100 pounds of nitrogen was applied, varying degrees of dry matter yield increases were recorded at all levels of phosphorus and sulfur (Figure 4). The application of 200 pounds of nitrogen decreased the dry matter yield 2 and 8 pounds per acre per day at the 0 pounds of phosphorus and 100 pounds of sulfur rates, respectively. At 200 pounds of nitrogen, the dry matter yield increased to about the same level for the 100 and 500 pounds of phosphorus and 20 and 100 pounds of sulfur rates. The phosphorus response curve (Figure 1) shows an increase (9 lb/A/day) when 100 pounds of phosphorus was added, while there was very little additional response when 500 pounds of phosphorus was applied. When 100 pounds of phosphorus was applied (Figure 4), increases in dry matter yield were noted at all nitrogen and phosphorus levels except at the 100 pounds of

Table 4. Grand Means By Harvest for Dry Matter Yield/A/day, Percent Dry Matter, and Plant Composition of Kikuyugrass

Harvest Number	Date	Grand Mean: Dry Matter Yield lb/A/day	Dry Matter (%)	Nitrogen (%)	Phosphorus (ppm)	Sulfur (ppm)
1	February 23, 1967	62.55	21.14	1.734	3322	2714
2	April 27, 1967	62.47	22.98	1.620	3190	2627
3	July 13, 1967	84.24	20.05	1.862	3651	2292
4	November 3, 1967	53.37	23.13			
5	May 1, 1968	26.04	22.52			

nitrogen rate where there was no change. The dry matter yield increased (9 lb/A/day) when 500 pounds of phosphorus was added to the 50 pounds of nitrogen and 20 pounds of sulfur rates. The dry matter yield did not change when 500 pounds of phosphorus was added to the 100 and 200 pounds of nitrogen and 0 pounds of sulfur rates. There was a severe drop in dry matter yield (14 lb/A/day) when 500 pounds of phosphorus was applied to the 100 pounds of sulfur rate. The sulfur response curve (Figure 1) shows a slight decrease (4 lb/A/day) in dry matter yield when 100 pounds of sulfur was applied. Figure 4 shows responses to 20 pounds of sulfur at 50 and 100 pounds of nitrogen and 0 and 500 pounds of phosphorus rates. There was no change in dry matter yield when sulfur was applied to the 100 pounds of nitrogen and 100 pounds of phosphorus treatments. Decreases in dry matter yield (6 to 15 lb/A/day) occurred when 100 pounds of sulfur was added to the 100 and 200 pounds of nitrogen and 0 and 500 pounds of phosphorus rates.

The third harvest analysis of variance (Table 3) shows the nitrogen response to be highly significant and the phosphorus response to be significant. Using the graphs and analysis of variance tables (Figures 1 and 4, Table 3), it is evident that on an established kikuyugrass pasture with similar experimental conditions, the best responses would be obtained where 100 pounds of phosphorus had been applied initially and 100 pounds of nitrogen was applied before each growing period.

<u>Fourth and Fifth Harvests</u>

The fourth and fifth harvests were not planned to be part of this thesis, but the plots were carried along after the original three harvests as part of the grant from the Sulfur Institute. The data from the fourth and fifth harvests have been included because it was hoped that they would confirm the trends established by the first three harvests. Unfortunately, no plant tissue analyses were run for the fourth and the fifth harvests. It must be remembered that no nitrogen treatments were added to the plots before the fourth and fifth harvests. These two harvests were intended to investigate the residual effect of the treatments on the dry matter yield.

The grand means for the fourth and fifth harvests decreased to 53 and 26 pounds of dry matter per acre per day, respectively (Table 9). The nitrogen response curve (Figure 1) for the fourth harvest shows that the yield at 50 pounds of nitrogen rate was relatively high (54 lb/A/day). A decrease (8 lb/A/day) was obtained from the 100 pounds of nitrogen treatment, while the yield increased (14 lb/A/day) when the 200 pounds of nitrogen rate was applied. At the 100 pounds of nitrogen rate, the dry matter yield decreased (10 lb/A/day) at the 0 and 20 pounds of sulfur rates (Figure 5). Dry matter yields increased 12 and 27 pounds per acre per day with the 0 and 20 pounds of sulfur rates, respectively, at the 200 pounds of nitrogen treatment. There was no response to nitrogen rates at the 100 pounds of sulfur rate. Nitrogen rates increased the yield (20 lb/A/day) at the zero phosphorus rate. Where the 100 pounds of nitrogen treatment had been applied, the dry matter yield decreased 10 and 25 pounds per acre per day at the 100 and 500 pounds of phosphorus rates, respectively. Where the 200 pounds of nitrogen rate had been applied, the dry matter yield increased to the 50 pounds of nitrogen levels at 100 and 500 pounds of phosphorus rates. The phosphorus response curve (Figure 1) shows a linear dry matter yield increase as the rate increased (16 lb/A/day). There was no response (Figure 5) to 100 pounds of phosphorus where 100 and 200 pounds of nitrogen and 100 pounds of sulfur rates had been applied. The 100 pounds of phosphorus gave small increases (4 and 6 lb/A/day) at the 20 and 100 pounds of sulfur rates, while a very good response (10 lb/A/day) was obtained when 100 pounds of phosphorus was added to the 50 pounds of nitrogen treatments. The application of 500 pounds of phosphorus increased the yield at the 50 and 200 pounds of nitrogen and 20 and 100 pounds of sulfur rates, but gave no responses at the 100 pounds of nitrogen and 0 pounds of sulfur rates. The sulfur response curve for the fourth harvest (Figure 1) shows a slight increase (3 lb/A/day) at the 20 pounds of sulfur treatment followed by a decrease of 5 pounds per acre per day at the 100 pounds of sulfur treatment which was below the zero sulfur yield. The application of 20 pounds of sulfur increased dry matter yield 12 and 20 pounds per acre per day at the 200 pounds of nitrogen and 500 pounds of phosphorus rates, respectively (Figure 5). There was no change in yield when 20 pounds of sulfur was applied to the 50 and 100 pounds of nitrogen and 100 pounds of phosphorus rates, while it decreased the dry matter yield at the zero pounds of phosphorus rate. The application of 100 pounds of sulfur rate caused the dry matter yields to reach the same level for all nitrogen rates. The dry matter yield decreased when 100 pounds of sulfur was applied to the 100 and 500 pounds of phosphorus rates. The application of 100 pounds of sulfur did not affect the yield at the zero phosphorus rate.

The analysis of variance (Table 3) shows the responses due to phosphorus to be highly significant and the responses due to nitrogen to be significant.

A very large decrease in the mean yield per day is evident at the fifth harvest. The fifth harvest nitrogen response curve (Figure 1) is quite a surprise. As the nitrogen treatment increased, the dry matter yield decreased (13 lb/A/day). The analysis of variance for the fifth harvest (Table 3) shows a highly significant response to nitrogen, but it is a negative response. Application of nitrogen decreased the yield at all sulfur levels (Figure 6). The application of 100 pounds of nitrogen decreased the dry matter yield at the 100 and 500 pounds of phosphorus rate, but there was no change in dry matter yield when 200 pounds of nitrogen was applied. The application of 100 pounds of nitrogen increased the dry matter yield (6 lb/A/day) at the zero phosphorus level. The dry matter yields were the same when 200 pounds of nitrogen was applied at all phosphorus treatments. The phosphorus response curve (Figure 1) shows an increase (7 lb/A/day) in dry matter yield as the phosphorus rate increased. The application of 100 pounds of phosphorus increased the dry matter yield (6 lb/A/day) at the 0 and 20 pounds of sulfur rates (Figure 6), while there was no change in yield at the 100 pounds of sulfur rate. The application of 500 pounds of phosphorus did not change the dry matter yield at the 0 and 20 pounds of sulfur rate, while the yield at the 100 pounds of sulfur rate increased (10 lb/A/day). The application of phosphorus did not affect the dry matter yield at the 100 and 200 pounds of nitrogen rates. At the 50 pounds of nitrogen rate, the application of phosphorus increased the dry matter yield 13 and 8 pounds per acre per day at the 100 and 500 pounds of phosphorus rates, respectively. The sulfur response curve was completely negative (Figure 1). As the sulfur application increased to 100 pounds, the dry matter yield went down (7 lb/A/day).

The application of sulfur continuously decreased the yield at the 50 and 200 pounds of nitrogen and 0 and 100 pounds of phosphorus rates. The application of 20 pounds of sulfur decreased the yield at the 100 pounds of nitrogen, while the application of 100 pounds of sulfur did not change the yield. There was no response to sulfur at the 500 pounds of phosphorus rate.

An analysis of variance (Table 3) shows a highly significant nitrogen response, a significant sulfur response, and a highly significant nitrogen-phosphorus interaction. Using the graphs (Figures 1 and 6) shows that the nitrogen and sulfur responses are significantly negative. The nitrogen-phosphorus interaction is probably the result of Big Trefoil growth. Visual observations indicated that the growth of legumes was induced by phosphorus treatment, especially at the low nitrogen rates. Figure 6 shows that the yield response due to phosphorus was only evident at the 50 pounds of nitrogen rate. Thus, the induced growth of legumes could account for the nitrogen-phosphorus interaction.

Plant Tissue Analysis

Figures 7 through 11 represent the effect of an individual element on a specified plant element. Each curve represents a different harvest. The harvest is noted by the numeral next to the curve.

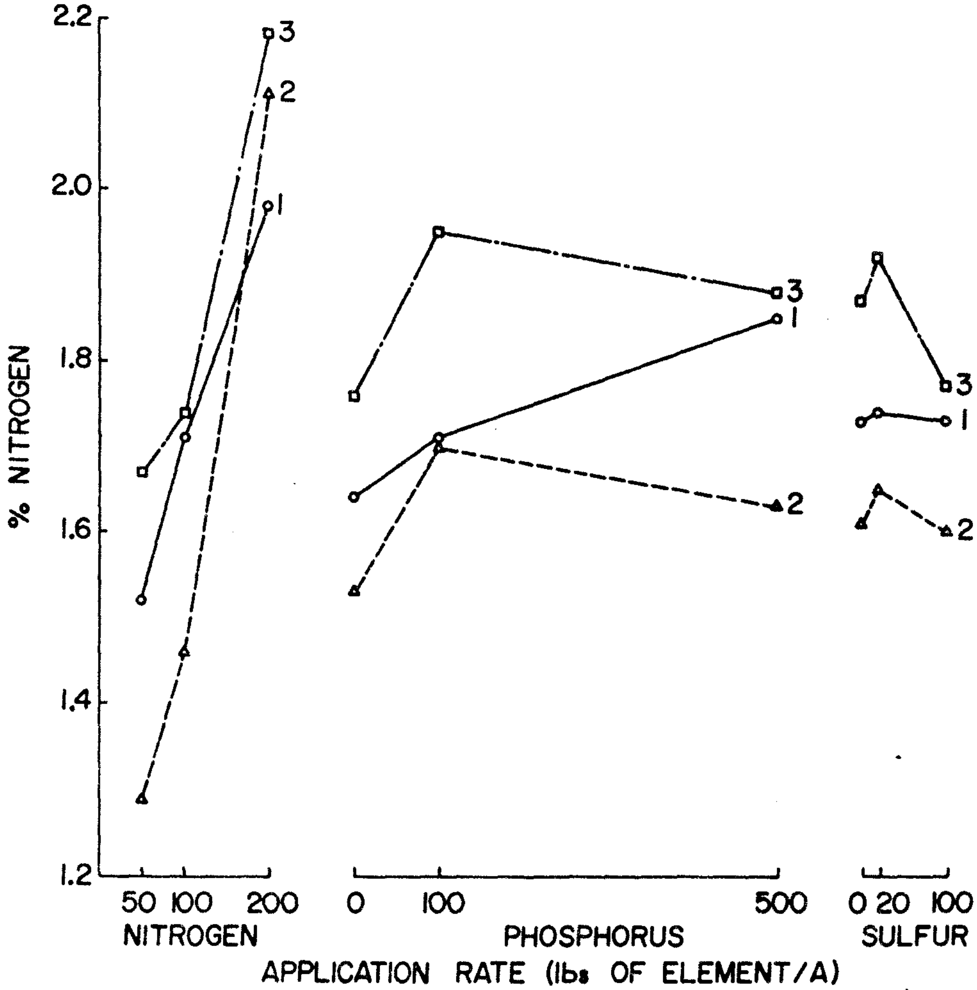

Figure 7. The Individual Effects of One Element (Averaged Over the Other Two Elements) on the Plant Nitrogen in Kikuyugrass for the First Three Harvests.

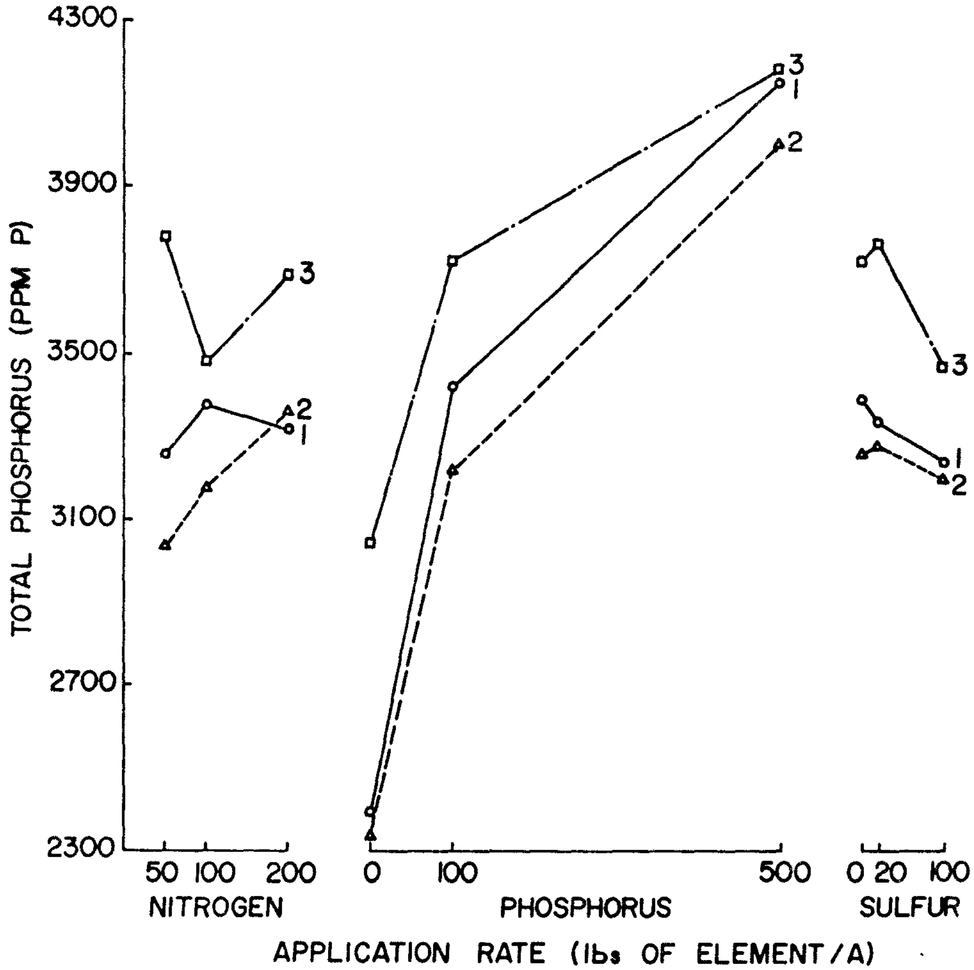

Figure 8. The Individual Effects of One Element (Averaged Over the Other Two Elements) on the Plant Phosphorus in Kikuyugrass for the First Three Harvests.

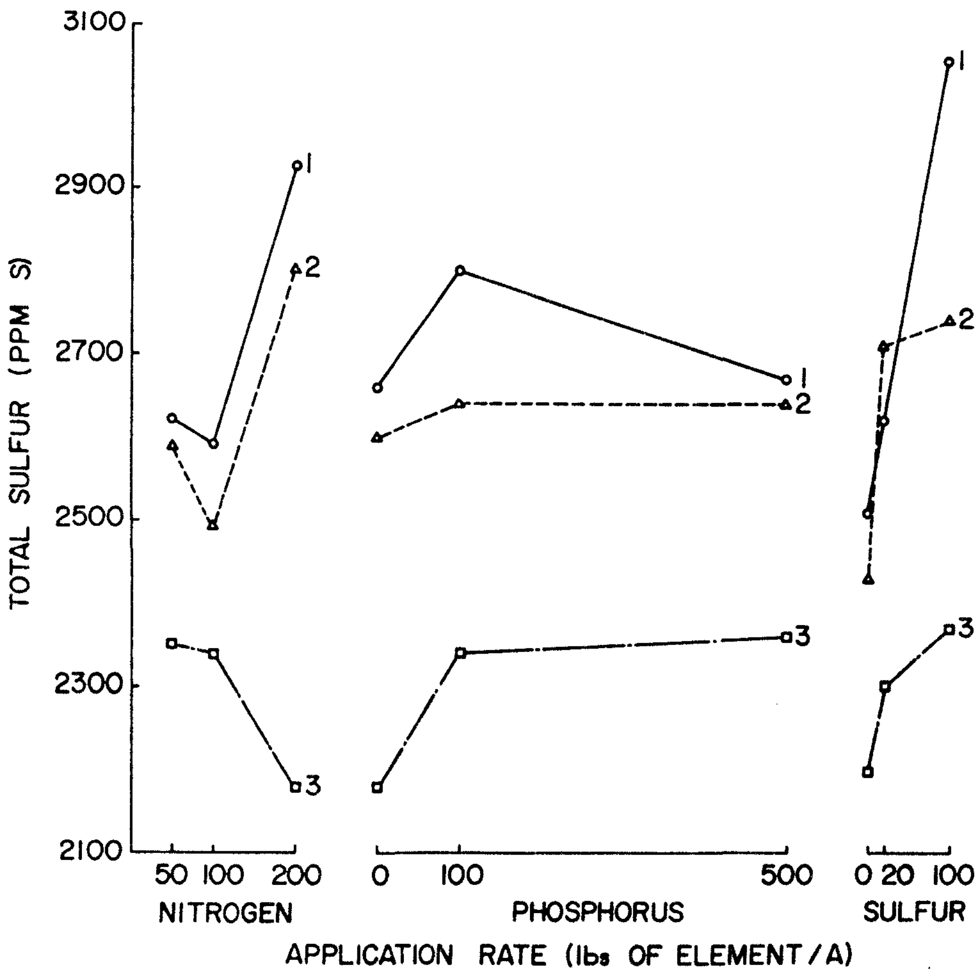

Figure 9. The Individual Effects of One Element (Averaged Over the Other Two Elements) on the Plant Sulfur in Kikuyugrass for the First Three Harvests.

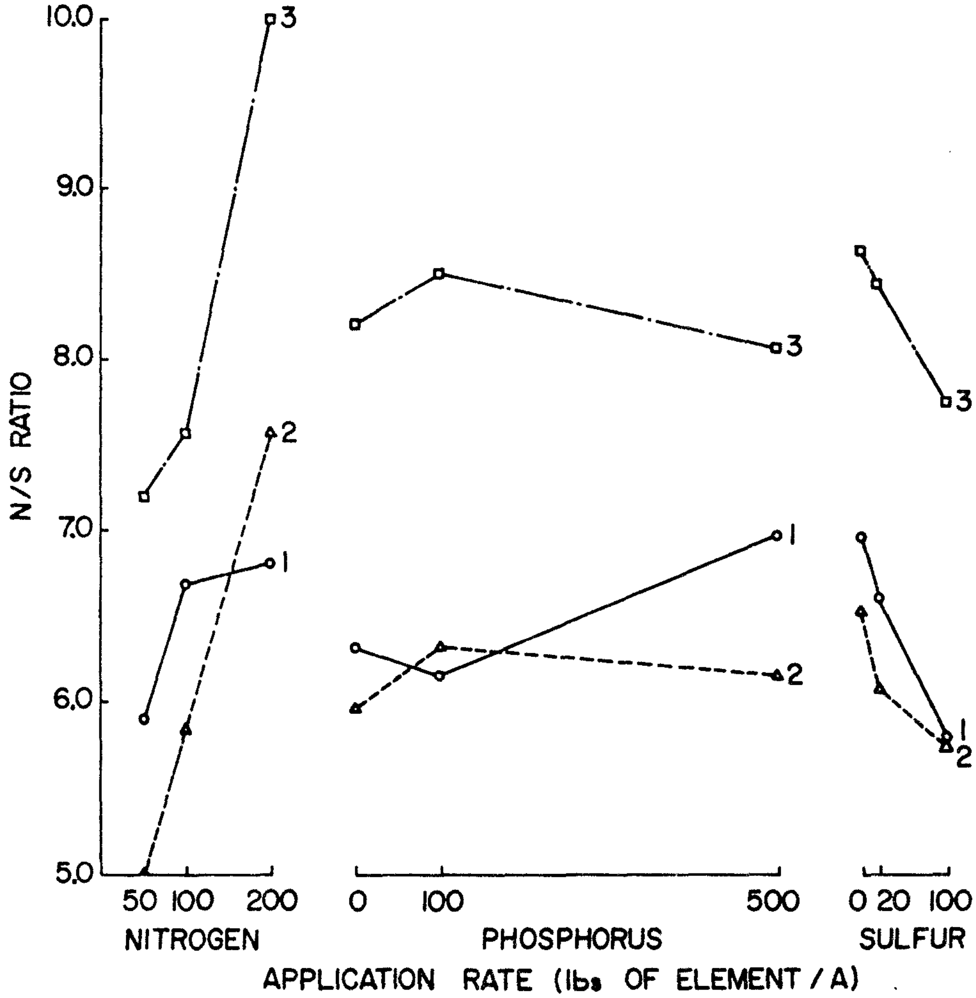

Figure 10. The Individual Effects of One Element (Averaged Over the Other Two Elements) on the Nitrogen-Sulfur Ratio in Kikuyugrass for the First Three Harvests.

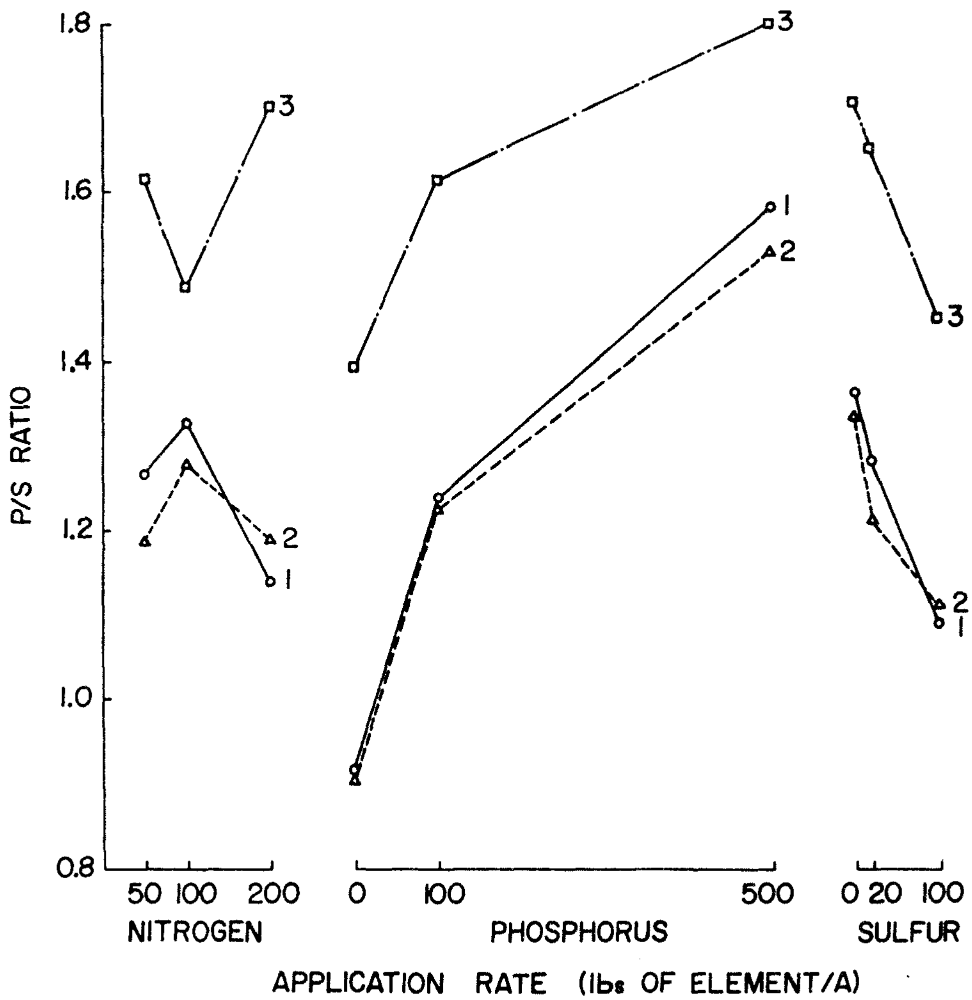

Figure 11. The Individual Effects of One Element (Averaged Over the Other Two Elements) on the Phosphorus-Sulfur Ratio in Kikuyugrass for the First Three Harvests.

Nitrogen

The curves for the effect of nitrogen treatment on the percent nitrogen in the plant tissue (Figure 7) resemble the dry matter yield response curves for nitrogen. They clearly show that as the nitrogen application rate increased, the percent nitrogen in the plant increased. The degree of response varies with the harvest. At the 200 pounds of nitrogen per acre rate, the percent nitrogen in the plant increased with time. The 50 pounds of nitrogen per acre rate gives rather inconsistent results for percent nitrogen in the plant as a function of time. At the first harvest, all phosphorus rates increased the percent nitrogen in the plant (Figure 7). The next two harvests show a good response to the 100 pounds of phosphorus per acre rate, while the addition of 500 pounds of phosphorus per acre decreases the percent nitrogen in the plant almost to the 0 pounds of phosphorus per acre level. The effect of sulfur on the percent nitrogen in the plant curves (Figure 7) also resembles the curves for dry matter yield. The 20 pounds of sulfur per acre rate increases the percent nitrogen in the plant, while the 100 pounds per acre rate decreases the percent nitrogen in the plant to below that of the 0 pounds of sulfur per acre rate. It is interesting to note that there is no response to sulfur at the first harvest.

Analysis of variance (Table 5) shows that the effect of nitrogen and phosphorus treatments on the percent nitrogen in the

Table 5. Analysis of Variance for Plant Nitrogen (%) for the First Three Harvests

Source	Degrees of Freedom	M.S.
	First Harvest	
Nitrogen	2	0.970**
Phosphorus	2	0.190**
Sulfur	2	0.000
NxP	4	0.007
NxS	4	0.010
PxS	4	0.034
NxPxS	8	0.008
Error	26	0.017
	Second Harvest	
Nitrogen	2	3.425**
Phosphorus	2	0.128**
Sulfur	2	0.016
NxP	4	0.079*
NxS	4	0.022
PxS	4	0.013
NxPxS	8	0.039
Error	26	0.023
	Third Harvest	
Nitrogen	2	1.286**
Phosphorus	2	0.164
Sulfur	2	0.083
NxP	4	0.136
NxS	4	0.024
PxS	4	0.116
NxPxS	8	0.064
Error	26	0.052

* = Significant at .05 level
** = Significant at .01 level

plant is highly significant for the first two harvests. The nitrogen-phosphorus interaction term is also significant for the second harvest. Only the nitrogen treatment is highly significant for the third harvest.

Phosphorus

The effect of nitrogen on the phosphorus in the plant (Figure 8) is not so clear. The shapes of the curves tend to indicate that there is no effect of nitrogen treatment on the phosphorus in the plant. The analysis of variance (Table 6) confirms this. The phosphorus in the plant greatly increases with the application of phosphorus treatments (Figure 8). As the rate of applied phosphorus increases, the amount of phosphorus in the plant increases. The analysis of variance (Table 6) for the effect of sulfur on the phosphorus in the plant is not significant. The sulfur response curves (Figure 8) show that the 20 pounds of sulfur per acre rate increases the phosphorus in the plant slightly at the second and third harvests, while the 100 pounds of sulfur per acre rate decreases the level below the 0 pounds of sulfur per acre rate. Thus, it is evident that in this experiment, only the phosphorus treatments significantly affect the phosphorus in the plant.

Sulfur

The effect of nitrogen on sulfur in the plant (Figure 9) is quite variable. The 100 pounds of nitrogen per acre rate

Table 6. Analysis of Variance for Plant Phosphorus (ppm) for the First Three Harvests

Source	Degrees of Freedom	M.S.
	First Harvest	
Nitrogen	2	66,187
Phosphorus	2	13,897,677**
Sulfur	2	130,021
NxP	4	147,541
NxS	4	39,629
PxS	4	399,325
NxPxS	8	130,664
Error	26	270,098
	Second Harvest	
Nitrogen	2	437,374
Phosphorus	2	12,465,587**
Sulfur	2	371,106
NxP	4	383,458
NxS	4	479,797
PxS	4	100,302
NxPxS	8	241,891
Error	26	274,999
	Third Harvest	
Nitrogen	2	413,071
Phosphorus	2	5,985,618**
Sulfur	2	448,094
NxP	4	214,670
NxS	4	74,693
PxS	4	96,064
NxPxS	8	163,429
Error	26	377,680

* = Significant at .05 level
** = Significant at .01 level

decreases the sulfur in the plant, while the first two harvests show the 200 pounds of nitrogen per acre rate to significantly increase the sulfur content of the plant. At the third harvest, the 200 pounds of nitrogen per acre causes the sulfur content in the plant to decrease even further. The analysis of variance (Table 7) also shows this variability. It shows a significant response for the second harvest, and no significant response for the third harvest. The effect of phosphorus on the sulfur content in the plant (Figure 9) shows a slight increase of sulfur in the plant at the 100 pounds of phosphorus per acre rate, while the 500 pounds of phosphorus per acre rate decreases the sulfur in the plant at the first harvest, remains constant for the second harvest, and slightly increases it for the third harvest. Analysis of variance (Table 7) shows no significant response to phosphorus, but it shows that there is a highly significant nitrogen-phosphorus interaction at the second harvest. The application of sulfur causes an increase in the sulfur content of the plant at every point (Figure 9). The most striking response to sulfur is in the first harvest. The plant sulfur increases linearly with sulfur application. The second harvest shows a tremendous increase in plant sulfur at the 20 pounds of sulfur per acre rate and a smaller response to both the 20 and 100 pounds of sulfur per acre applications. Analysis of variance (Table 7) shows the plant sulfur response to sulfur applications to be highly significant

Table 7. Analysis of Variance for Plant Sulfur (ppm) for the First Three Harvests

Source	Degrees of Freedom	M.S.
	First Harvest	
Nitrogen	2	608,421*
Phosphorus	2	120,395
Sulfur	2	1,206,184**
NxP	4	121,908
NxS	4	29,182
PxS	4	80,439
NxPxS	8	84,889
Error	26	110,154
	Second Harvest	
Nitrogen	2	468,227**
Phosphorus	2	10,287
Sulfur	2	514,878**
NxP	4	125,362**
NxS	4	112,245**
PxS	4	35,369
NxPxS	8	61,232*
Error	26	20,557
	Third Harvest	
Nitrogen	2	158,002
Phosphorus	2	172,086
Sulfur	2	139,007
NxP	4	111,944
NxS	4	239,417
PxS	4	45,438
NxPxS	8	75,815
Error	26	98,361

* = Significant at .05 level
** = Significant at .01 level

for the first two harvests. It shows no sulfur response at the third harvest. It also shows a highly significant nitrogen-sulfur interaction and a significant nitrogen-phosphorus-sulfur interaction for the second harvest. The sulfur content in the plant decreases with each harvest.

Nitrogen-Sulfur Ratio

As nitrogen rates increase the nitrogen-sulfur ratio increases (Figure 10). As nitrogen rates increase, the nitrogen content of the plant increases. As the nitrogen rates increase, the sulfur content of the plant does not increase in proportion to the plant nitrogen. Thus, the nitrogen-sulfur ratio is expected to increase in proportion to the nitrogen treatments. The analysis of variance (Table 8) shows that the nitrogen effect is always highly significant. The effect of phosphorus on the nitrogen-sulfur ratio (Figure 10) appears to be affected by time. Analysis of variance (Table 8) shows that the nitrogen-sulfur ratio is significantly affected by the phosphorus application only at the first harvest. By the third harvest, the nitrogen-sulfur ratio is at its highest values and shows the least effect of phosphorus treatments. Sulfur treatments decrease the nitrogen-sulfur ratio (Figure 10). Since the plant nitrogen is not a function of sulfur treatment, and plant sulfur is a function of sulfur treatment, the nitrogen-sulfur ratio is expected to decrease with sulfur application. The analysis of variance (Table 8) shows that sulfur treatment has a

Table 8. Analysis of Variance for N/S Ratio for the First Three Harvests

Source	Degrees of Freedom	M.S.
	First Harvest	
Nitrogen	2	4.572**
Phosphorus	2	3.369*
Sulfur	2	6.010**
NxP	4	0.585
NxS	4	0.172
PxS	4	1.196
NxPxS	8	0.593
Error	26	0.703
	Second Harvest	
Nitrogen	2	30.296**
Phosphorus	2	0.661
Sulfur	2	2.408**
NxP	4	1.017*
NxS	4	0.614
PxS	4	0.487
NxPxS	8	0.221
Error	26	0.276
	Third Harvest	
Nitrogen	2	42.387**
Phosphorus	2	0.668
Sulfur	2	4.943*
NxP	4	3.018
NxS	4	5.865**
PxS	4	1.298
NxPxS	8	2.031
Error	26	1.145

* = Significant at .05 level
** = Significant at .01 level

highly significant effect on the nitrogen-sulfur ratio at the first two harvests, but only a significant effect at the third harvest. It also shows that there is a significant nitrogen-sulfur interaction at the third harvest. The nitrogen-sulfur interaction is due to the erratic behavior at the 20 pounds of sulfur rate. As the nitrogen rate increases, the nitrogen-sulfur ratio increases linearly at the 0 and 100 pounds of sulfur rate. At the 20 pounds of sulfur rate the ratio shows a great decrease when 100 pounds of nitrogen was applied. There appears to be no explanation for this interaction.

Phosphorus-Sulfur Ratio

Nitrogen treatment appears to have no consistent effect on the phosphorus-sulfur ratio (Figure 11). The analysis of variance (Table 9) shows that the ratio is significantly affected by the nitrogen treatment only at the third harvest. There is a very large phosphorus effect on the phosphorus-sulfur ratio (Figure 11). There is a large response to both the 100 and 500 pounds of phosphorus per acre rates. Analysis of variance (Table 9) shows that the effect of phosphorus on the phosphorus-sulfur ratio is highly significant throughout the three harvests. As with the nitrogen-sulfur ratio, the sulfur applications decrease the phosphorus-sulfur ratio (Figure 11). The analysis of variance (Table 9) shows the effect of sulfur to be significant at the first harvest and highly significant at the second and third harvests. It also shows that there is a significant nitrogen-sulfur interaction at

Table 9. Analysis of Variance for P/S Ratio for the First Three Harvests

Source	Degrees of Freedom	M.S.
	First Harvest	
Nitrogen	2	0.167
Phosphorus	2	1.967**
Sulfur	2	0.354*
NxP	4	0.033
NxS	4	0.038
PxS	4	0.038
NxPxS	8	0.052
Error	26	0.078
	Second Harvest	
Nitrogen	2	0.047
Phosphorus	2	1.742**
Sulfur	2	0.223**
NxP	4	0.070
NxS	4	0.055
PxS	4	0.008
NxPxS	8	0.035
Error	26	0.034
	Third Harvest	
Nitrogen	2	0.204*
Phosphorus	2	0.741**
Sulfur	2	0.325**
NxP	4	0.063
NxS	4	0.206*
PxS	4	0.018
NxPxS	8	0.033
Error	26	0.054

* = Significant at .05 level
** = Significant at .01 level

the third harvest. It should be noted that the third harvest phosphorus-sulfur ratio is much greater than that for the first two harvests. The nitrogen-sulfur interaction was significant because as the nitrogen rate increased at the zero sulfur rate the phosphorus-sulfur ratio increased linearly, while at the 20 and 100 pounds of sulfur rate the ratios showed no pattern.

Statistical Methods for Further Interpretation

An IBM 360 computer was used to calculate stepwise multiple regression equations. The original equation was composed of 16 variables: yield per day, plant phosphorus, plant sulfur, plant nitrogen, percent dry matter, nitrogen-sulfur ratio, phosphorus-sulfur ratio, as well as nitrogen, phosphorus, and sulfur treatments, their products and squares. The product and squared terms were included to adjust for curvilinear response patterns. Two equations were calculated, one with yield per day as the dependent variable and the other with plant sulfur as the dependent variable. First, an equation was calculated using the variable which was most highly correlated with the dependent variable. Then, a partial correlation was calculated to find the next most important variable. That variable was added to the previous variables and a new equation was calculated. This process continued until every variable was added to the equation. As each variable was added to the equation, the contribution to the R^2 value was recorded.

The variables were then grouped with yield per day, plant phosphorus, plant sulfur, plant nitrogen, and percent dry matter as the variables in the first group. Nitrogen-sulfur and phosphorus-sulfur ratios were in the second group. Nitrogen, phosphorus, and sulfur treatments were in the third group. The products of the various treatment combinations were in the fourth group. The squares of the treatments were in the fifth group. Individual stepwise regression equations were calculated after specified groups were selectively dropped from the equation. The residuals were then used to calculate an F-value which was used to determine if there was a significant change in the predictive value of the equation when a group of variables was dropped. The full results of these calculations are found in Tables 10 and 11 and a summary can be found in Table 12.

Fifty-seven percent of the variation in the first harvest can be explained by the variables measured (Table 10). The percent dry matter in the plant, the squared terms for the nitrogen, phosphorus, and sulfur treatments, and the phosphorus and sulfur treatments explain most of the variability. It was found by excluding groups and re-calculating regression equations, that the addition of squared terms accounted for a significant amount of the yield variation (Table 10). It appears that the percent dry matter in the plant and the treatments or their squared values are necessary to formulate a regression equation that has any value

Table 10. Stepwise Multiple Regression Equations With Dry Matter Yield Per Day as the Dependent Variable and Plant Phosphorus, Plant Sulfur, Plant Nitrogen, Percent Dry Matter in the Fresh Plant Tissue, Nitrogen-Sulfur Ratio, Phosphorus-Sulfur Ratio, Nitrogen Treatment, Phosphorus Treatment, Sulfur Treatment, and the Treatment Products and Squared Terms as the Independent Variables.

First Harvest

r	r^2		Additional Group Dropped
.7547	.5695	$\hat{Y} = 79.92 - 3.5183(DM) + 0.0013(N^2) + 0.2472(P) + 0.61402(S) - 0.0005(P^2) - 0.0060(S^2)$	Full Model
.7009	.4913	$\hat{Y} = 114.09 - 3.0139(DM) + 0.2280(N) + 0.0006(PS) - 7.6018(N/S) - 0.00004(NS)$	-Squared Terms
586	.4700	$\hat{Y} = 132.41 - 3.4964(DM) + 0.1411(N) - 6.4225(N/S)$	-Products
.6639	.4407	$\hat{Y} = 76.54 - 4.5912(DM) + 0.02290(Sp) + 1.1884(N/S)$	-Treatments
.6585	.4336	$\hat{Y} = 122.16 - 4.5405(DM) + 0.0073(Sp)$	-Ratios

The squared terms have a significant F-value.

Second Harvest

r	r^2		Additional Group Dropped
.9117	.8311	$\hat{Y} = -10.36 + 0.8838(N) - 52.4601(P/S) + 0.2534(P) + 11.0816(N/S) - 0.0020(N^2) + 0.0004(PS)$	Full Model
.8814	.7769	$\hat{Y} = 112.02 + 0.3367(N) - 51.7156(P/S) - 1.2902(DM) + 0.0005(PS) - 0.1056(N/S)$	-Squared Terms
.8695	.7560	$\hat{Y} = 112.82 + 0.311(N) - 59.5576(P/S) - 1.8587(DM) + 4.8392(N/S)$	-Products
.8363	.6994	$\hat{Y} = -17.94 + 18.8023(N/S) - 5.1893(N_p) - 2.4696(DM)$	-Treatments
.8339	.6954	$\hat{Y} = 70.26 + 64.8410(N_p) - 2.4625(DM) - 0.0210(S_p)$	-Ratios

The squared and treatment terms have highly significant F-values.

Table 10 (Continued)

Third Harvest

r	r^2		Additional Group Dropped
.8602	.7399	$\hat{Y} = -79.35 + 1.3437(N) - 0.0041(N^2) - 0.0114(P_p) - 0.0002(NS) + 0.0114(S_p) - 0.0013(NP)$	Full Model
.7614	.5798	$\hat{Y} = -165.40 + 0.3068(N) + 0.0660(S_p) - 0.0002(NS) + 0.0602(P) + 2.6370(DM) - 0.0011(NP)$	-Squared Terms
.7363	.5421	$\hat{Y} = -175.10 + 0.2371(N) + 0.0740(S_p) - 0.1265(S) + 2.7671(DM) + 0.0237(P)$	-Products
.5407	.2933	$\hat{Y} = -62.96 + 53.1997(N_p) + 1.4470(DM)$	-Treatments
.5407	.2929	$\hat{Y} = -18.86 + 37.1466(N_p) + 1.4044(DM)$	-Ratios

The squared and treatment terms have highly significant F-values.

N_p, P_p, and S_p	= Plant nitrogen, phosphorus, and sulfur.
N/S and P/S	= Nitrogen-sulfur and phosphorus-sulfur ratios.
N, P, and S	= Nitrogen, phosphorus, and sulfur treatments.
NP, NS, and PS	= Nitrogen-phosphorus, nitrogen-sulfur, and phosphorus-sulfur treatment products.
N^2, P^2, and S^2	= Nitrogen, phosphorus, and sulfur squared terms.
DM	= Percent dry matter in fresh plant tissue.

Table 11. Stepwise Multiple Regression Equations With Plant Sulfur as the Dependent Variable and Yield Per Day, Plant Phosphorus, Plant Nitrogen, Dry Matter in Fresh Plant Tissue, Nitrogen Treatment, Phosphorus Treatment, Sulfur Treatment, and the Product and Squared Terms for Treatments as the Independent Variables.

First Harvest

r	r^2	Equation	Additional Group Dropped
.7482	.5601	$\hat{Y} = 2356 + 0.0053(NS) + 0.0224(N^2) + 7.4907(S) + 10.7951(DM) - 0.0071(NP) - 0.0095(PS) - 0.0063(P^2) + 3.4146(P) - 0.1433(P_p)$	Full Model
.7035	.4949	$\hat{Y} = 1528 + 0.0048(NS) + 6.9438(S) + 1.2358(N) + 21.2217(DM) - 0.0051(NP) - 0.0084(PS)$	-Squared Term
.6697	.4485	$\hat{Y} = 954 + 4.5340(S) + 3.2908(N) + 41.7746(DM)$	-Products
.3575	.1280	$\hat{Y} = 279 + 788.5173(N_p) + 48.5620(DM) + 2.6101(Y/D) - 0.0370(P_p)$	-Treatment

Second Harvest

r	r^2	Equation	Additional Group Dropped
.8082	.6532	$\hat{Y} = 2128 + 452.6453(N_p) + 13.3392(S) - 0.1181(S^2) - 0.6694(Y/D) + 0.0177(NP) + 0.0039(NS) - 8.6063 + 0.0247(N^2) - 1.4573(P)$	Full Model
.7268	.5282	$\hat{Y} = 1874 + 653.8896(N_p) + 0.7124(S) - 2.6217(Y/D) + 0.0160(NP) + 0.0036(NS) - 0.4563(P)$	-Squared Terms
.6911	.4776	$\hat{Y} = 1728 + 659.9155(N_p) + 2.4242(S) - 3.2588(Y/D)$	-Products
.5802	.3367	$\hat{Y} = 1651 + 585.8147(N_p) - 3.4961(Y/D)$	-Treatments

Table 11. (Continued)

Third Harvest

r	r^2		Additional Group Dropped
.6929	.4801	$\hat{Y} = 577.7986 + 0.3048(P_p) + 19.2375(DM) + 3.3716(S) - 0.0058(NP) + 0.0054(P) - 1.4087(P) - 0.0031(N^2) + 4.1613(Y/D)$	Full Model
.6895	.4754	$\hat{Y} = 701 + 0.2869(P_p) + 17.2779(DM) + 1.8800(S) - 0.0058(NP) + 0.0055(PS) - 0.7619(P) + 0.0017(NS) + 4.4594(Y/D) - 2.1583(N) + 50.6363(N_p)$	-Squared Terms
.6664	.4441	$\hat{Y} = 613 + 0.2794(P_p) + 18.0181(DM) + 2.2840(S) - 0.3278(P) - 2.1201(N) + 18.0181(Y/D) + 91.4327(N_p)$	-Products
.5629	.3169	$\hat{Y} = 182 + 0.27912(P_p) + 51.0554(DM) + 0.2791(DM) + 0.29412(N_p)$	-Treatments

N_p, P_p, and S_p = Plant nitrogen, phosphorus, and sulfur.
N, P, and S = Nitrogen, phosphorus, and sulfur treatments.
NP, NS, and PS = Nitrogen-phosphorus, nitrogen-sulfur, and phosphorus-sulfur treatment products.
N^2, P^2, and S^2 = Nitrogen, phosphorus, and sulfur squared terms.
DM = Percent dry matter in fresh plant tissue.
Y/D = Dry matter yield.

Table 12. Summary of the Significant Regression Equation Variables and Linear Correlation Variables Affecting Dry Matter Yield (lb/A/day) at the First Three Harvests

First Harvest

Correlation with yield = N_p**, N**, DM**, N/S*, NP*, N^2**.

Regression variables = DM + N^2 + P + S + P^2 + S^2.

Second Harvest

Correlation with yield = P_p*, N_p**, DM**, N/S**, N**, NP**, NS**, N^2**.

Regression variables = N + P/S + P + N/S + N^2 + PS.

Third Harvest

Correlation with yield = N_p**, N/S**, N**, NP**, N^2**.

Regression variables = N + N^2 + P_p + NS + S_p + N_p.

N_p, P_p, and S_p	= Plant nitrogen, phosphorus, and sulfur.
N/S and P/S	= Nitrogen-sulfur and phosphorus-sulfur ratios.
N, P, and S	= Nitrogen, phosphorus, and sulfur treatments.
NP, NS, and PS	= Nitrogen-phosphorus, nitrogen-sulfur, and phosphorus-sulfur treatment products.
N^2, P^2, and S^2	= Nitrogen, phosphorus, and sulfur squared terms.
DM	= Percent dry matter in fresh plant tissue.

*Significant at 0.05 level.
**Significant at 0.01 level.

for predicting yield. Simple correlation shows that the plant nitrogen, percent dry matter in the plant, nitrogen treatment, and the square of nitrogen treatment are highly significantly correlated with yield per day. The nitrogen-sulfur ratio and nitrogen-phosphorus treatment interactions are significantly correlated with yield per day (Appendix Table 1).

Eighty-three percent of the variation in the second harvest is explained by the variables measured (Table 10). The nitrogen treatment, phosphorus-sulfur ratio, phosphorus treatment, nitrogen-sulfur ratio, the squared term for nitrogen, and the phosphorus-sulfur treatment products explain most of the variability. By excluding groups of variables and recalculating regression equations, it was found that the squared terms and the fertilizer treatment terms caused a highly significant increase in the predictive value of the equation (Table 10). Simple correlation shows that plant nitrogen, percent dry matter in fresh tissue, nitrogen-sulfur ratio, nitrogen treatment, and the squared terms for the nitrogen treatment are all highly significantly correlated with yield per day (Appendix Table 2). Phosphorus in the plant and the nitrogen-sulfur treatment products are significantly correlated with the dry matter yield (Appendix Table 2).

Seventy-four percent of the variation in the third harvest is explained by the variables measured (Table 10). The nitrogen treatment, square of the nitrogen treatment, plant phosphorus, nitrogen-sulfur treatment products, plant sulfur, and the nitrogen-phosphorus treatment products account for most of the variability. By eliminating groups of variables and recalculating the equations, it is found that the treatment squared terms and the treatments caused a highly significant increase in the predictive value of the equation (Table 10). It also shows that the plant phosphorus and sulfur values contributed to the equation. Simple correlation shows that plant nitrogen, nitrogen-sulfur ratio, nitrogen treatment, nitrogen-phosphorus treatment products, and nitrogen squared terms are all highly correlated with the dry matter yield (Appendix Table 3).

The regression equation in Table 11 shows that sulfur in the plant is not consistently affected by the variables measured. Only 56% of the variability is explained in the first harvest, 65% in the second harvest, and 48% in the third harvest (Table 11). As expected, the sulfur treatment is the most consistent variable affecting plant sulfur. Some measure of nitrogen either applied or in the plant is also present in every equation. Sulfur in the plant correlates (Appendix Tables 1, 2, and 3) with the nitrogen treatment, sulfur treatment, nitrogen-sulfur treatment products, and the nitrogen and sulfur treatment squared terms at the first two harvests. However, they do not correlate at the third harvest (Appendix Tables 1, 2, and 3). The high initial plant sulfur values indicate that there is no sulfur deficiency at the first two harvests (Figure 9). Additional consumption of sulfur results when sulfur is applied (Figure 9). When this occurs, the limiting factor is not the supply of nutrients and their uptake by the plant. The growth is limited by the environmental conditions such as sunlight, rainfall, and soil moisture relationships. Thus, some unmeasured variables must be affecting the plant sulfur.

During the three harvests, the dry matter yield is affected by changing soil conditions brought about by the treatments. By the third harvest, nitrogen applications are mostly responsible for the yield response. The grand mean for dry matter yield (Table 4) is highest in the third harvest. The effect of time on the mean yield is a result of residual nitrogen and the reapplication of nitrogen after each harvest. The effect of season should also be noted. The first harvest grew during the winter months of January and February. The second harvest grew during the summer months of May, June, and July. Thus, the yields during the summer months should be greater as a result of the higher temperatures and longer days.

A very good phosphorus response (Figure 1) is always obtained at the 100 pounds of phosphorus per acre rates, while the 500 pounds of phosphorus per acre rate does not increase the yield in the first three harvests. This indicates that the best phosphorus responses were obtained at the 100 pounds of phosphorus per acre rate. Other field work done by this investigator using the same soil is concerned with the effect of phosphorus and sulfur on the establishment of Big Trefoil. It shows that there is no growth without the application of 100 pounds of phosphorus per acre, regardless of the sulfur treatment. It also shows that there is no response to the 500 pounds of phosphorus per acre treatment over that of the 100 pound rate.

The 200 pounds of nitrogen per acre rate at the third harvest shows a decrease in the rate of response (Figure 1). The plant sulfur (Figure 9) value corresponding to that point is low. It appears that sulfur may be the limiting factor. Thus, the yields from the first two harvests were high enough to cause the plant sulfur values to be lowest at the third harvest. The grand means for plant nitrogen and phosphorus values (Table 4) generally increase with each harvest, while the plant sulfur grand mean (Table 4) decreases. Field history and personal observation indicate other essential elements such as potassium and zinc could be deficient.

No nitrogen applications were applied after the third harvest. Thus, nitrogen responses are due to residual nitrogen. The dry matter grand mean (Table 4) drops rapidly at the fourth and fifth harvests, from 84 pounds per day for the third harvest to 26 pounds per day for the fifth harvest. At the fourth harvest, there is a nitrogen response at the 200 pounds of nitrogen per acre rate. By the fifth harvest, the effect of nitrogen is completely negative. Thus, the high nitrogen rates have caused severe deficiencies. At the fourth and fifth harvests, good phosphorus responses are noted, especially at the 50 pounds of nitrogen level. Where the nitrogen treatments were low, the application of phosphorus appeared to induce the growth of Big Trefoil which may have accounted for the apparent response to phosphorus, although there was no quantitative measure of this factor.

The element applied determines the range of mean yields. The range of nitrogen, phosphorus, and sulfur treatments causes a range in mean yields of about 40, 20, and 10 pounds of dry matter per acre per day, respectively. Thus, responses due to sulfur may sometimes be lost in the statistical analysis because the error term includes the variation due to the large nitrogen responses, as well as the variation from the small sulfur responses.

The plant nitrogen, phosphorus, and sulfur all increase rapidly as the nitrogen, phosphorus, and sulfur treatments increase. Thus, the nutrient value of the harvested material should be very high except for the zero phosphorus and sulfur treatments.

It appears that the yield potential may be reflected in the nitrogen-sulfur ratio. The severe drop in yield at the 200 pounds of nitrogen per acre rate for the third harvest is associated with a very high nitrogen-sulfur ratio (10:1), if it is compared to other nitrogen-sulfur ratios for this experiment (Figures 1 and 10). It is also interesting to note that a very low nitrogen-sulfur ratio of 5.0 is associated with a low yield (Figures 1 and 10). Thus, there may be an important upper and lower limit for evaluating yield with the nitrogen-sulfur ratio. For every harvest, the nitrogen-sulfur ratio is at least significantly correlated with the yield.

SUMMARY AND CONCLUSIONS

A field experiment was used to study the effect of three fertilization rates of nitrogen, phosphorus, and sulfur on the yield and chemical composition of an established kikuyugrass pasture. The treatments were: nitrogen at 50, 100, and 200 pounds per acre applied initially and after the first two harvests; phosphorus at 0, 100, and 500 pounds per acre applied initially; and sulfur at 0, 20, and 100 pounds per acre applied initially.

The dry matter yields were mainly the result of nitrogen treatments. There was also a very good dry matter yield response at the 100 pounds of phosphorus per acre treatment. The 500 pounds of phosphorus rate did not improve the yields over the 100 pound rate for the first two harvests. Initially, significant sulfur responses were not obtained. But, under heavy cropping at the 200 pounds of nitrogen rate, sulfur stress appeared by the third harvest. Yields for the fourth and fifth harvests, which were grown without the reapplication of nitrogen, showed good responses to phosphorus treatment at the 50 pounds of nitrogen rate, apparently because of the induced growth of Big Trefoil.

Plant analyses showed that as the treatment increased, the content of the element in the plant also increased. Plant nitrogen ranged from about 1.3% to 2.2% for the nitrogen treatments, plant phosphorus ranged from about 2400 to 4200 ppm phosphorus for the phosphorus treatments, and plant sulfur ranged from about 2200 to 3000 ppm sulfur for the sulfur treatments. Thus, nutrient value of the grass should be very high at the high treatment rates.

Nitrogen-sulfur ratios were calculated, and found to be correlated with yield. It appears that the nitrogen-sulfur ratio may be an indicator of both nitrogen and sulfur deficiencies. Yield decreases were obtained with nitrogen-sulfur ratios of 10:1 and 5.6:1 which were probably due to sulfur deficiency in the first case and nitrogen deficiency in the second.

In most cases, in the first three harvests as the nitrogen treatment was increased from 50 to 200 pounds of nitrogen per acre, the dry matter yield increased about 50 pounds of dry matter per acre per day. The application of 100 pounds of phosphorus per acre generally increased the yield about 20 pounds of dry matter per acre per day. Sulfur treatments had little effect on the yield.

There is an indication that phosphorus induced legume growth at the low nitrogen rate. This effect can be seen in the fourth and fifth harvests where there was a good phosphorus response at the 50 pounds of nitrogen treatment but not at the higher rates. This phosphorus response is due to the induced growth of legume. The survival of a grass-legume mixture appears to be related to growth rate and fertility.

Date of harvest also appears to be of importance in this experiment as harvest date was associated with season. The first harvest grew during the winter months and the third harvest during the summer. There was an increase in yield per acre per day as the day-length increased. This increase was related to increases in temperature and sunlight.

Multiple stepwise regression equations were used to evaluate the ability of the measured variables to predict the dry matter yield per day and sulfur in the plant. The results were also compared with the variables that correlated with the dry matter yield and sulfur in the plant. The measured variables could not be used to predict more than 65% of the plant sulfur variation. If all the variables measured were used, the equation would predict about 75 percent of the yield.

This experiment showed that for good production it was necessary to apply both nitrogen and phosphorus at rates greater than those being used at the present. It was necessary to supply at least 100 pounds of nitrogen per acre approximately every 2 months and phosphorus initially at the rate of 100 pounds of phosphorus per acre. As time passes it appears that the heavy production will induce deficiencies of other elements. Thus, the application of sulfur and micronutrients is probably necessary for continued production after 6 months.

APPENDIX TABLE 1. Correlation Coefficient Matrix for the First Harvest (February 23, 1967)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Yield/Day	1	1.000	0.173	0.174	0.575**	-0.643**	0.300*	0.051	0.620**	0.160	-0.054	0.335*	0.186	0.168	0.626**	0.117	-0.074
Plant P	2		1.000	-0.065	0.293*	-0.387**	0.278*	0.878**	0.019	0.771**	-0.081	0.657**	-0.070	0.289*	0.011	0.708**	-0.079
Plant S	3			1.000	0.238	-0.051	-0.652**	-0.512**	0.350**	-0.051	0.538**	0.182	0.558**	0.170	0.368**	-0.075	0.530**
Plant N	4				1.000	-0.781**	0.566**	0.100	0.797**	0.351**	-0.005	0.627**	0.324*	0.322*	0.788**	0.340*	-0.007
% Dry Matter	5					1.000	-0.555**	-0.269*	0.709**	-0.352**	0.148	-0.484**	-0.168	-0.198	-0.688**	-0.330*	0.140
N/S Ratio	6						1.000	0.515**	0.340*	0.312*	-0.452**	0.336*	-0.228	0.084	0.308*	0.329*	-0.444**
P/S Ratio	7							1.000	0.164	0.672**	-0.299*	0.448**	-0.302*	0.150	-0.180	0.620**	-0.291*
N Treatment	8								1.000	0.000	0.000	0.400**	0.400*	0.000	0.990**	0.000	0.000
P Treatment	9									1.000	0.000	0.808**	0.000	0.562**	0.000	0.988**	0.000
S Treatment	10										1.000	0.000	0.808**	0.562**	0.000	0.000	0.988**
NxP Treatment Interaction	11											1.000	0.160	0.454**	0.396**	0.799**	0.000
NxS Treatment Interaction	12												1.000	0.454**	0.396**	0.000	0.799**
PxS Treatment Interaction	13													1.000	0.000	0.555**	0.555**
N Treatment Curvilinearity	14														1.000	0.000	0.000
P Treatment Curvilinearity	15															1.000	0.000
S Treatment Curvilinearity	16																1.000

* = 0.05 level df = 53
** = 0.01 level df = 53

APPENDIX TABLE 2. Correlation Coefficient Matrix for the Second Harvest (April 27, 1967)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Yield/Day	1	1.000	0.319*	0.254	0.796**	-0.504**	0.797**	0.183	0.832**	0.149	-0.034	0.408**	0.286*	0.155	0.802**	0.110	-0.036
Plant P	2		1.000	0.196	0.352**	-0.413**	0.278*	0.912**	0.147	0.754**	-0.133	0.648**	-0.126	0.295*	0.142	0.688**	-0.136
Plant S	3			1.000	0.515**	-0.098	0.085	-0.197	0.378**	0.045	0.359**	0.267*	0.478**	0.158	0.416**	0.036	0.301*
Plant N	4				1.000	-0.413**	0.893**	0.114	0.888**	0.054	-0.027	0.392**	0.302*	-0.018	0.896**	0.028	-0.035
% Dry Matter	5					1.000	-0.419**	-0.363**	0.396**	-0.326*	0.188	-0.325*	-0.052	-0.129	-0.375**	-0.308*	0.198
N/S Ratio	6						1.000	0.204	0.848**	0.025	-0.217	0.310*	0.103	-0.101	0.837**	0.005	-0.199
P/S Ratio	7							1.000	-0.024	0.733**	-0.258	0.538**	-0.292*	0.234	-0.042	0.684**	-0.238
N Treatment	8								1.000	0.000	0.000	0.400**	0.400*	0.000	0.990**	0.000	0.000
P Treatment	9									1.000	0.000	0.808**	0.000	0.562**	0.000	0.988**	0.000
S Treatment	10										1.000	0.000	0.808**	0.562**	0.000	0.000	0.988**
NxP Treatment Interaction	11											1.000	0.160	0.454**	0.396**	0.799**	0.000
NxS Treatment Interaction	12												1.000	0.454**	0.396**	0.000	0.799**
PxS Treatment Interaction	13													1.000	0.000	0.555**	0.555**
N Treatment Curvilinearity	14														1.000	0.000	0.000
P Treatment Curvilinearity	15															1.000	0.000
S Treatment Curvilinearity	16																1.000

* = 0.05 level df = 53
** = 0.01 level df = 53

APPENDIX TABLE 3. Correlation Coefficient Matrix for the Third Harvest (July 13, 1967)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Yield/Day	1	1.000	0.212	0.113	0.525**	-0.101	0.354**	0.144	0.617**	0.192	-0.115	0.349**	0.079	0.013	0.546**	0.168	-0.133
Plant P	2		1.000	0.463**	0.434**	-0.476**	0.071	0.690**	-0.018	0.609**	-0.174	0.469**	-0.183	0.251	0.007	0.557**	-0.181
Plant S	3			1.000	0.128	0.061	-0.564**	-0.309*	-0.224	0.174	0.200	0.059	0.006	0.299*	-0.232	0.145	0.184
Plant N	4				1.000	-0.417	0.737**	0.354**	0.639**	0.083	-0.137	0.293*	0.167	0.056	0.651**	0.049	-0.150
% Dry Matter	5					1.000	-0.389**	-0.554**	-0.290*	-0.279*	0.357**	-0.299*	0.151	-0.002	-0.338*	-0.275*	0.373**
N/S Ratio	6						1.000	0.528**	0.666**	-0.048	-0.232	0.178	0.132	-0.122	0.679**	-0.058	-0.227
P/S Ratio	7							1.000	0.153	0.488**	-0.347**	0.425**	-0.202	0.021	0.184	0.452**	-0.342**
N Treatment	8								1.000	0.000	0.000	0.400**	0.400**	0.000	0.990**	0.000	-0.000
P Treatment	9									1.000	0.000	0.808**	0.000	0.562**	0.000	0.988**	0.000
S Treatment	10										1.000	0.000	0.808**	0.562**	0.000	0.000	0.988**
NxP Treatment Interaction	11											1.000	0.160	0.454**	0.396**	0.799**	0.000
NxS Treatment Interaction	12												1.000	0.454**	0.396**	0.000	0.799**
PxS Treatment Interaction	13													1.000	0.000	0.555**	0.555**
N Treatment Curvilinearity	14														1.000	0.000	0.000
P Treatment Curvilinearity	15															1.000	0.000
S Treatment Curvilinearity	16																1.000

APPENDIX TABLE 4
Fresh Weight Yields of Kikuyugrass (lb/acre) for the First Harvest (February 23, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	12521	8473	10497
		20	8096	9226	8661
		100	9414	1036	5225
	100	0	15251	11768	13504
		20	18263	12332	15298
		100	13744	6307	10040
	500	0	22970	13650	18310
		20	15439	13180	14310
		100	17133	22123	19626
100	0	0	9602	18451	14026
		20	19956	1130	10543
		100	12426	17510	14968
	100	0	28995	15816	22046
		20	16004	17416	16710
		100	20052	12614	16333
	500	0	19958	3295	11626
		20	18828	21840	20334
		100	20993	18828	19910
200	0	0	22217	24288	23252
		20	35961	25794	30878
		100	31631	5460	18546
	100	0	35773	30407	33090
		20	40480	42928	41704
		100	29842	24100	26871
	500	0	24853	25041	24947
		20	39068	28242	33655
		100	27112	34832	30972

APPENDIX TABLE 5
Fresh Weight Yields of Kikuyugrass (lb/acre) for the Second Harvest (April 27, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	11297	3766	7532
		20	941	5648	3294
		100	2824	2824	2824
	100	0	8473	6589	7531
		20	14121	5648	9884
		100	5648	11297	8472
	500	0	11297	8473	9885
		20	15062	10355	12708
		100	9414	13180	11297
100	0	0	15062	12238	13650
		20	19769	4707	12238
		100	11296	11296	11296
	100	0	26359	16945	21652
		20	18828	21652	20240
		100	14121	19769	16945
	500	0	20711	9414	15062
		20	18828	22593	20710
		100	22593	25418	24006
200	0	0	30125	30125	30125
		20	25418	25418	25418
		100	28242	12238	20240
	100	0	31066	26359	28712
		20	32008	36715	34362
		100	33890	25418	29654
	500	0	20711	31066	25888
		20	28242	24476	26354
		100	29183	27301	28242

APPENDIX TABLE 6
Fresh Weight Yields of Kikuyugrass (lb/acre) for the Third Harvest (July 13, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	19769	17887	18828
		20	16004	16004	16004
		100	12238	16004	14121
	100	0	33890	20711	27300
		20	30125	25418	27772
		100	19769	26359	23064
	500	0	25418	25418	25418
		20	39539	32949	36244
		100	29183	26359	27771
100	0	0	28242	32008	30125
		20	39539	37656	38598
		100	37656	25419	31538
	100	0	35773	27301	31537
		20	34832	29183	32008
		100	33890	33890	33890
	500	0	39539	36715	38127
		20	39539	36715	38127
		100	30125	36715	33420
200	0	0	40480	38597	39538
		20	46129	44246	45188
		100	39539	22549	31044
	100	0	46129	36715	41422
		20	54601	38597	46599
		100	36715	32949	34832
	500	0	37656	55543	46600
		20	39539	49894	44716
		100	37656	30125	33900

APPENDIX TABLE 7
Fresh Weight Yields of Kikuyugrass (lb/acre) for the Fourth Harvest (November 3, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	31066	16004	23535
		20	10355	31066	20710
		100	12238	11297	11768
	100	0	43304	29183	36244
		20	17887	33890	25888
		100	25418	25418	25418
	500	0	31066	31066	31066
		20	49894	40480	45187
		100	34832	39539	37186
100	0	0	17887	24476	21282
		20	23535	4707	14121
		100	37656	23535	30596
	100	0	25418	25418	25418
		20	18828	23535	21182
		100	17887	25418	21652
	500	0	32008	9414	20711
		20	32949	26359	29654
		100	16945	18828	17886
200	0	0	25418	29183	27300
		20	29183	33949	31566
		100	30125	16004	23064
	100	0	28242	23535	25888
		20	33890	36715	35302
		100	18828	17887	18358
	500	0	18828	33890	26359
		20	28242	45187	36714
		100	27301	30125	28713

APPENDIX TABLE 8
Fresh Weight Yields of Kikuyugrass (lb/acre)
for the Fifth Harvest (May 1, 1968)

Treatment			Replication		Mean
N	F	S	I	II	
50	0	0	25418	16945	21182
		20	7531	26359	16945
		100	4707	10355	7531
	100	0	32008	23535	27772
		20	24476	22594	23535
		100	11297	18828	15062
	500	0	27301	26359	26830
		20	37656	21652	29654
		100	27301	29183	28242
100	0	0	17887	17887	17887
		20	16945	13180	15062
		100	24476	17887	21282
	100	0	21652	22594	22123
		20	12238	16945	14592
		100	13180	15062	14121
	500	0	30125	17887	24006
		20	20711	16004	18358
		100	14121	9414	11768
200	0	0	15062	16945	16004
		20	14121	13180	13650
		100	15062	10355	12708
	100	0	18828	14121	16474
		20	20711	9414	15062
		100	10355	7531	8943
	500	0	11297	15062	13180
		20	12238	17887	15062
		100	16945	16004	16474

APPENDIX TABLE 9
Kikuyugrass Dry Matter Yields Per Harvest (lb/acre) for the First Harvest (February 23, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	2629	2203	2416
		20	2267	2399	2333
		100	2824	290	1557
	100	0	3355	3060	3207
		20	4018	3083	3550
		100	3711	1514	2612
	500	0	4594	3140	3867
		20	3088	2900	2994
		100	3427	4425	3926
100	0	0	2112	3874	2993
		20	4590	271	2430
		100	2609	3502	3055
	100	0	5219	3163	4191
		20	3681	3832	3756
		100	4812	2901	3856
	500	0	4191	758	2474
		20	3201	4586	3893
		100	4618	3577	4097
200	0	0	4443	4615	4529
		20	6473	4643	5558
		100	6326	1201	3763
	100	0	6081	5169	5625
		20	6882	7727	7304
		100	5670	4097	4883
	500	0	3976	4507	4241
		20	7032	5084	6058
		100	5151	5921	5536

APPENDIX TABLE 10
Kikuyugrass Dry Matter Yields Per Harvest (lb/acre) for the Second Harvest (April 27, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	2485	1054	1769
		20	273	1299	786
		100	791	762	776
	100	0	2033	1713	1873
		20	2824	1130	1977
		100	1582	2824	2203
	500	0	2033	2203	2118
		20	3163	2485	2824
		100	2165	3295	2730
100	0	0	3464	2815	3139
		20	4547	1271	2909
		100	2598	2824	2711
	100	0	6063	3897	4980
		20	4330	5197	4763
		100	3389	4547	3968
	500	0	4556	1977	3266
		20	3954	4970	4462
		100	4970	4829	4899
200	0	0	6627	6025	6326
		20	5592	5084	5338
		100	5931	3060	4495
	100	0	6524	6590	6557
		20	6402	8077	7239
		100	7117	5846	6481
	500	0	4142	7145	5643
		20	6213	5385	5799
		100	6712	5733	6222

APPENDIX TABLE 11
Kikuyugrass Dry Matter Yields Per Harvest (lb/acre) for the Third Harvest (July 13, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	3954	3577	3765
		20	3361	3361	3361
		100	2815	3681	3248
	100	0	5422	4556	4989
		20	5121	4829	4975
		100	4152	5799	4975
	500	0	5338	4575	4956
		20	6326	6260	6293
		100	5253	6030	5641
100	0	0	6213	7362	6787
		20	8303	7908	8105
		100	7908	6100	7004
	100	0	7155	6279	6717
		20	6618	7296	6957
		100	8134	7456	7795
	500	0	7512	5874	6693
		20	7908	8444	8176
		100	6025	8077	7051
200	0	0	7286	6562	6924
		20	7842	7964	7903
		100	7512	5196	6354
	100	0	8303	8077	8190
		20	9282	6948	8115
		100	7710	6590	7150
	500	0	6778	1108	8943
		20	7117	8482	7799
		100	6778	5724	6251

APPENDIX TABLE 12
Kikuyugrass Dry Matter Yields Per Harvest (lb/acre)
for the Fourth Harvest (November 3, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	6213	3681	4947
		20	2796	5902	3789
		100	2815	2372	2593
	100	0	8661	6128	7450
		20	3756	7456	5606
		100	5592	6100	5845
	500	0	5902	5902	5902
		20	8482	9310	8895
		100	8708	9094	8901
100	0	0	4650	5385	5018
		20	4707	1224	2966
		100	8661	5884	7272
	100	0	5592	5338	5464
		20	4519	5413	4966
		100	3935	6100	5016
	500	0	6722	2634	4678
		20	6260	6853	6556
		100	4067	4895	4480
200	0	0	5592	7296	6443
		20	7004	6919	6962
		100	6627	4001	5313
	100	0	6496	5648	6073
		20	7119	8112	7616
		100	5084	4650	4866
	500	0	5648	8473	6724
		20	6213	11749	8980
		100	7098	7230	7164

APPENDIX TABLE 13
Kikuyugrass Dry Matter Yields Per Harvest (lb/acre) for the Fifth Harvest (May 1, 1968)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	5083	3558	4320
		20	1732	6063	3898
		100	988	2071	1531
	100	0	6402	5648	6024
		20	6364	6326	6345
		100	2485	4142	3314
	500	0	6002	5799	5900
		20	8661	4330	6496
		100	6279	7588	6933
100	0	0	3756	3756	3756
		20	4236	3427	3832
		100	6119	4114	5116
	100	0	4330	5422	4876
		20	2815	3897	3587
		100	2768	3012	2889
	500	0	5724	3577	4651
		20	2521	3681	3095
		100	2965	2448	2707
200	0	0	3587	3558	3571
		20	3248	2900	3074
		100	3314	2278	2795
	100	0	4895	3389	4141
		20	4970	1883	3426
		100	2382	1732	2057
	500	0	2824	3464	3143
		20	2570	4114	3342
		100	3220	3681	3450

APPENDIX TABLE 14
Kikuyugrass Dry Matter Yields (lb/A/day)
for the First Harvest (February 23, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	42.40	35.53	38.96
		20	36.56	38.69	37.62
		100	45.55	4.68	25.11
	100	0	54.11	49.35	51.73
		20	64.81	49.72	57.26
		100	59.85	24.42	42.13
	500	0	74.10	50.64	62.37
		20	49.81	46.77	48.29
		100	55.27	71.37	63.32
100	0	0	34.06	62.48	48.27
		20	74.03	4.37	39.20
		100	42.08	56.48	49.28
	100	0	84.18	51.02	67.60
		20	59.37	61.81	60.59
		100	77.61	46.79	62.20
	500	0	67.60	12.22	39.91
		20	51.63	73.97	62.80
		100	74.48	57.69	66.08
200	0	0	71.66	74.44	73.05
		20	104.40	74.89	89.64
		100	102.03	19.37	60.70
	100	0	98.08	83.37	90.72
		20	111.00	124.63	117.81
		100	91.45	66.08	78.76
	500	0	64.13	72.69	68.41
		20	113.42	82.00	97.71
		100	83.08	95.50	89.29

APPENDIX TABLE 15
Kikuyugrass Dry Matter Yields (lb/A/day)
for the Second Harvest (April 27, 1967)

| Treatment | | | Replication | | Mean |
N	P	S	I	II	
50	0	0	39.44	16.73	28.08
		20	4.33	20.62	12.48
		100	12.56	12.10	12.33
	100	0	32.27	27.19	29.73
		20	44.82	17.94	31.38
		100	25.11	44.82	34.96
	500	0	32.27	34.97	33.62
		20	50.21	39.44	44.82
		100	34.36	52.30	43.33
100	0	0	54.98	44.68	49.83
		20	72.17	20.17	46.17
		100	41.24	44.82	43.03
	100	0	96.24	61.86	79.05
		20	68.73	82.49	75.61
		100	53.79	72.17	62.98
	500	0	72.32	31.38	51.85
		20	62.76	78.89	70.82
		100	78.89	76.65	77.77
200	0	0	105.19	95.63	100.41
		20	88.76	80.70	84.73
		100	94.14	48.57	71.36
	100	0	103.56	104.60	104.08
		20	101.62	128.21	114.91
		100	112.97	92.79	102.88
	500	0	65.75	113.41	89.58
		20	98.62	85.48	92.05
		100	106.54	91.00	98.77

APPENDIX TABLE 16
Kikuyugrass Dry Matter Yields (lb/A/day)
for the Third Harvest (July 13, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	51.35	46.45	48.90
		20	43.65	43.65	43.65
		100	36.56	47.80	42.18
	100	0	70.42	59.17	64.80
		20	66.51	62.71	64.61
		100	53.92	75.31	64.61
	500	0	69.32	59.42	64.37
		20	82.16	81.30	81.73
		100	68.22	78.74	73.48
100	0	0	80.69	95.61	88.15
		20	107.83	102.70	105.26
		100	102.70	79.22	90.96
	100	0	92.92	81.54	87.23
		20	85.95	94.75	90.35
		100	105.64	96.83	101.23
	500	0	97.56	76.28	86.92
		20	102.70	109.66	106.18
		100	78.25	104.90	91.58
200	0	0	94.62	85.22	89.92
		20	101.84	103.43	102.63
		100	97.56	67.48	82.52
	100	0	107.83	104.90	106.36
		20	120.54	90.23	105.38
		100	100.13	85.58	92.85
	500	0	88.02	144.26	116.14
		20	92.43	110.16	101.29
		100	88.02	74.34	81.18

APPENDIX TABLE 17
Kikuyugrass Dry Matter Yields (lb/A/day)
for the Fourth Harvest (November 3, 1967)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	55.47	32.87	44.17
		20	24.96	52.70	38.83
		100	25.13	21.18	23.15
	100	0	77.33	55.71	66.52
		20	33.54	66.57	50.05
		100	49.93	54.46	52.19
	500	0	52.70	52.70	52.70
		20	75.73	83.12	79.42
		100	77.75	81.20	79.47
100	0	0	41.52	48.08	44.80
		20	42.03	10.93	26.48
		100	77.33	52.54	64.93
	100	0	49.93	47.66	48.79
		20	40.35	48.33	44.34
		100	35.13	54.46	44.79
	500	0	60.02	23.52	41.77
		20	55.89	61.19	58.54
		100	36.31	43.70	40.00
200	0	0	49.93	65.14	57.53
		20	62.54	61.78	62.16
		100	59.17	35.72	47.44
	100	0	58.00	50.43	54.22
		20	63.56	72.43	68.00
		100	45.39	41.52	43.45
	500	0	50.43	75.65	60.04
		20	55.47	104.90	80.18
		100	63.38	64.55	63.96

APPENDIX TABLE 18
Kikuyugrass Dry Matter Yields (lb/A/day)
for the Fifth Harvest (May 1, 1968)

Treatment			Replication		Mean
N	P	S	I	II	
50	0	0	33.01	23.10	28.05
		20	11.25	39.37	25.31
		100	6.42	13.45	9.94
	100	0	41.57	36.68	39.12
		20	41.32	41.08	41.20
		100	16.14	26.90	21.52
	500	0	38.97	37.66	38.21
		20	56.24	28.12	42.18
		100	40.77	49.27	45.02
100	0	0	24.39	24.39	24.39
		20	27.51	22.25	24.88
		100	39.73	26.71	33.22
	100	0	28.12	35.21	31.66
		20	18.28	28.30	23.29
		100	17.97	19.56	18.76
	500	0	37.17	23.23	30.20
		20	16.31	23.90	20.10
		100	19.25	15.90	17.58
200	0	0	23.29	23.10	23.19
		20	21.09	18.83	19.96
		100	21.52	14.79	18.15
	100	0	31.78	22.01	26.89
		20	32.27	12.23	22.25
		100	15.47	11.25	13.36
	500	0	18.34	22.49	20.41
		20	16.69	26.27	21.70
		100	20.91	23.90	22.40

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