The effect of different N:K2O fertilizer ratios on the drought tolerance and quality of creeping bentgrass (Agrostis palustris L.) cultivar Penncross.

THE EFFECT OF DIFFERENT N:K_2O FERTILIZER RATIOS ON THE DROUGHT TOLERANCE AND QUALITY OF CREEPING BENTGRASS (*AGROSTIS PALUSTRIS L.*) CULTIVAR PENNCROSS

A Thesis Presented

By

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DEDICATION

To my beloved wife Meg. Thank you.

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INTRODUCTION

Creeping bentgrass, *Agrostis palustris* L. cultivar Penncross, is one of the most widely planted turfgrasses used on golf greens built in America today. It is often subjected to many stresses. When growing in golf greens it is maintained at a height of cut lower than nature intended, and is mowed 4 to 7 times per week. Top growth of creeping bentgrass is often overstimulated by excessive applications of nitrogen fertilizer; thus these maintenance factors contribute to stress. Nitrogen increases grass shoot growth at the expense of root growth. In addition, the plant's carbohydrates are used for new shoot growth, which can also affect the root system. High summer temperatures can increase plant respiration, which further reduces its carbohydrate reserves. Still another summer stress that may occur is drought. Any stress or combination of stresses can have a detrimental effect on the turfgrass community and lessen the playability of a golf green. With the use of Penncross creeping bentgrass becoming more popular in the southern states, and water shortages occurring more often in the northeastern states, a need for improving drought tolerance through cultural practices has become necessary. A maintenance practice which may help in increasing the drought tolerance of Penncross is a well balanced nitrogen to potassium ratio in the fertilization program. Nitrogen has long been recognized as the most needed macronutrient necessary for producing the best quality turf sward. Little attention has been given to the use of potassium in the fertilization program, but some investigators have noted that an increase in potassium fertilization has led to an increase in root growth (9). Other investigators (48,14,3,40,6) have found that increases in potassium prolonged the time until wilt of turfgrasses when drought conditions existed.

The purpose of this research is to (1) evaluate the effects of different $N:K_2O$ ratios in fertilizers on the drought tolerance of Penncross creeping bentgrass and, (2) to determine the effects of these fertilizer ratios on the growth and quality of the turfgrass.

LITERATURE REVIEW

Creeping bentgrass (Agrostis palustris L. cultivar Penncross) a native of Eurasia and a cool season turfgrass, is grown primarily on highly cultured sites such as golf greens. It forms stolons from which lateral growth can ensue. Creeping bentgrass produces medium-fine textured leaf blades that are usually dark green in color, and it renews its root system annually (6). When grown in a golf green it is mowed to a height of 0.50 cm. to 0.80 cm., much shorter than nature intended it.

Fertilization of golf greens suggested by either turfgrass researchers or turf managers are concerned with nitrogen applications without citing the other major and minor plant nutrients. Beard (6) stated that creeping bentgrass requires 0.8 to 1.4 pounds of nitrogen per one thousand square feet per growing month. Goss and Gould (25) found that a balanced fertilization program of 12 lbs. of nitrogen, 4 lbs. of phosphorus (P_2O_5) and 8 lbs. of potassium (K_2O) per thousand square feet per season produced quality putting green turf.

Requirements for phosphorus on established turfgrass stands have been shown to be needed only in small quantities. Christens et al. (15) reported that under varying levels of nitrogen, phosphorus, and potassium, quality bentgrass was achieved at the lowest phosphorus rate which was less than 2 ppm. Bell and DeFrance (9) observed a decrease in root weights of creeping bentgrass when phosphorus was applied in large amounts. Turgeon as cited by Voykin (61) found that annual bluegrass turf subjected to phosphorus fertilizers were of better quality than when only nitrogen was applied. He also noted that phosphorus deficiencies rarely occur in established turf. Waddington et al. (63) showed that annual bluegrass invasion of Penncross creeping bentgrass was favored by phosphorus and potassium fertilization.

The third major plant growth element, potassium, has been found to exist in plants as either soluble inorganic or organic salts, with the greater portion being in the inorganic form (18, 36). Potassium is believed to be involved in various metabolic and growth processes within the plant, but its actual functions are not fully understood. It is known to be an activator of enzymes such as those that affect carbohydrate formation, translocation, and storage. In addition, it may also function in regulating the use of nitrogen in the resynthesis of protein from its breakdown products. It has also been hypothesized that potassium may play a role in the maintenance of protein stability and membrane permeability (6,30,36,59). Recently potassium has been reported to function in the osmotic processes of plants and in the maintenance of cell turgor. Potassium is believed to affect the cell sap and aid in regulating the degree of swelling and water economy of plant cells (3,18,36). Studies carried out on sugarcane (3) showed that plants receiving high rates of potassium fertilization maintained higher moisture levels throughout the top thirteen leaves than did plants receiving lower amounts of potassium.

Beard (6) stated that the wilting tendency of certain turfgrass species may be due to low osmotic pressure in the plant cells, and that drought hardy turfgrass species generally have high cell sap concentrations and high osmotic pressure. High osmotic pressure increases the ability of plant cells to retain water, lessening the degree of cell contraction. Recent research has also revealed that potassium may be responsible for the opening and closing of the stomatal apparatus in plants. Potassium ions effect the opening of stomates when they move into the guard cells. The ions cause a more negative osmotic potential, and as a result water moves into the guard cells causing them to expand and the stomates to open (50).

Optimum potassium fertilization practices for Penncross creeping bentgrass are still not known. Investigators have found that sites of intensely cultured turf are almost always potassium deficient. Brown (11) showed that out of 5500 soil samples taken from bentgrass golf greens, 84 percent needed more potassium. Goss (24) noted similar results, out of 227 putting green soil samples 108 were potassium deficient. These deficiencies could be related to the soil in which the grass is growing. Golf greens are most often constructed on sandy soils and receive heavy irrigation. When these conditions are present, potassium may readily leach from the root zone (4,18). Other maintenance practices can also lead to potassium deficient turf. Clipping removal will cause great losses of potassium as well as other growth elements (18,26). Potassium loss to golf greens can be attributed to high and frequent applications of nitrogen fertilizer, especially if these fertilizers are in the form of NH_4. The ammonium ion is known to exchange sites on soil colloids with potassium resulting in its loss by leaching (11,26). Goss and Gould (25) observed a decline in soil potassium levels on putting green turf fertilized with 12 and 20 pounds of nitrogen per 1000 square feet, and 4 and 8 pounds of potassium per 1000 square feet respectively. However, on turf where the above potassium rates were applied with nitrogen at a six pound per 1000 square foot rate, soil potassium levels remained constant.

Christens _et al_. (15) reported that when different nutrient rates; 6 to 294 ppm N, 2 to 98 ppm P, and 4 to 196 ppm K, were applied to Penncross creeping bentgrass, maximum turf quality was obtained with less than 2 ppm P, 54 ppm N, and 196 ppm K. They noted that when the potassium rate was less, nitrogen was needed to gain maximum turf quality. Dry weights of clippings were highest at 96 ppm N, and 196 ppm K. Maximum root production occurred at

6 ppm nitrogen and 196 ppm potassium, while minimum production was at 150 ppm N and 64 ppm K. Goss (24) found that better quality putting green turf occurred on plots that received high rates of potassium versus low. Similar results were seen by Barrios and Jones (4) on Tifgreen Bermudagrass. Bell and DeFrance (9) working with colonial, velvet, and creeping bentgrass noted that potassium fertilization increased the quality of turf. They also observed that with higher rates of applied potassium, an increase in root weight occurred.

The potassium to nitrogen relationships in sunflower plants were investigated by Eaton (21). He stated that plants which received potassium from a Hoagland solution had higher fresh weights than those grown in a minus potassium media. Both total and soluble nitrogen were higher in leaves and stems of plants which received potassium compared to the plants that did not receive potassium. Potassium was also shown to affect the carbohydrate status of sunflowers. Leaves were higher in total sugars and reducing sugars for the potassium starved plants than those which received potassium. The same held true for the stems, but as the plant matured and potassium deficiencies increased, the trend reversed, and more carbohydrates were found in the stems of the plants that received potassium.

Carbohydrates in grasses vary as to the species of grass and the type of carbohydrate stored. Grasses in the temperate regions (cool season grasses) store sucrose, glucose and fructose, while warm season grasses store sucrose and starch (46,51,56). Fructosan has been proven to be the predominant soluble carbohydrate in many cool season grasses and correlates best to the total available carbohydrates present (2,27,46,55).

Reserve available carbohydrates are essential to the survival and production of plant tissue during periods when carbohydrate utilization exceeds photosynthetic activity (56). A turf management practice that has been shown to reduce the available carbohydrates of grasses is fertilization. Carroll (12) reported that the carbohydrate content of bentgrasses were reduced with high nitrogen fertilization. MacLeod (39) investigated the interaction of nitrogen to potassium on orchard grass and timothy. He noted that when the rate of nitrogen applied to timothy was increased to the rate of 50 lbs., the total available carbohydrates in the plant increased, but at the 50 lb. rate of nitrogen per acre, a reduction of carbohydrates occurred. Working with orchard grass, he observed that when no nitrogen was applied and potassium was given at increasing increments, the percentage of total available carbohydrates decreased. However, on plots where two hundred pounds of nitrogen per acre was added, total available carbohydrates increased with increasing rates of potassium. These results indicated that potassium was essential for storage of carbohydrates, and that higher rates of potassium in the absence of nitrogen proved detrimental to the storage of carbohydrate reserves. Colby _et al_. (17) showed that fructosan levels in orchard grass varied throughout the year, and increasing the amounts of nitrogen, lowered the levels of fructosan in the plant tissue. They also noted that high air temperatures caused reductions in fructosan levels. Griffith _et al_. (29) found that both nitrogen and potassium lowered the level of total fructose in the stubble or orchard grass, but believed it to be due to increased plant growth, and the need for more photosynthate in the leaves. Other investigators (27,45) noted that nitrogen treatments had little effect on the soluble sugars, glucose, fructose, and sucrose, but greatly decreased the amount of fructosan in the plant tissue of annual ryegrass and Merion Kentucky bluegrass. Zanoni (71) observed similar results on bluegrass and bentgrass species growing in the field. He also reported that potassium fertilization did not significantly increase the total carbohydrates within the plant tissue.

Turfgrass carbohydrates are not only effected by fertilization practices, but can also be affected by stress. Both high temperature and drought stress have received little attention by investigators, particularly in relation to the effects of potassium fertilization. High temperature and drought stress are difficult to separate from one another.

High temperatures will undoubtedly increase the rates of evapotranspiration. The rate at which evapotranspiration occurs can be further increased when the relative humidity is low, and light radiation is high. This in turn could lead to a decrease in soil moisture. Many researchers (33, 58,65,67) have observed that with increasing air temperatures, total available carbohydrates in grasses decreased. This, as explained by Watschke et al. (66) is due to a drop in the photosynthetic rates, and an increase in respiration. As a consequence CO_2 fixation cannot supply the metabolic demands of the plant for carbon; depleting carbon reserves, resulting in a reduction of growth. Sullivan and Sprague (58) experimenting with perennial ryegrass at four different temperatures showed that at temperatures lower than optimum (<15-25° C), synthesized carbohydrates were stored. When temperatures were above the optimum for growth, carbohydrates were not stored.

Pellet and Roberts (47) experimented with two rates of each nitrogen phosphorus and potassium, on Kentucky bluegrass. They found that with high nitrogen and high potassium there was an increase in heat resistance with plants as compared to high nitrogen and low potassium. When all three elements were applied per se, and not in conjunction with one another, resistance to high temperature was low in all cases. Phosphorus had negative effects on heat resistance when applied with nitrogen at either high or low rates. High temperatures have also been reported to affect root growth of creeping bentgrass. Beard and Daniel (7) using four different temperatures 16°C, 21°C, 27°C, and 32°C, noted that root growth was not affected at the three lower temperatures, but at 32°C root growth was reduced for both cut and uncut turf. Watschke et al. (65) observed similar results with five varieties of Kentucky bluegrass and three different temperature regimes: 18°C/10°C, 27°C/18°C, and 33°C/20°C (day/night). All five varieties produced good yields of roots and foliage at the two lower temperatures, but all varieties had reduced foliage at the highest temperature. In other studies (8) it was shown that during the summer root elongation followed sharp drops in temperature.

Research investigating the affects of high temperature (35°C) and different nitrogen to potassium fertilization applications on Penncross creeping bentgrass showed that the highest potassium level and the lowest nitrogen level produced the turf with the most vigor and highest dry weight (1).

Krans (35) reported that when bentgrass was sub-irrigated, root development increased, and the turf stand did not require periodic syringing on hot windy days.

Carroll (12) working with velvet bentgrass, colonial bentgrass, and South German mixed bentgrass observed greater survival of velvet bentgrass and colonial bentgrass subjected to high air temperatures (35°C) and drought conditions (5% soil moisture) for turf that did not receive nitrogen, as compared to that turf which received high rates of nitrogen. No differences in the survival of South German mix were seen with regards to nitrogen fertility until the soil moisture level decreased to 3%. At this point the turf that received the low levels of nitrogen exhibited better survival. It can be concluded from Carroll's work that high nitrogen applications decreased the summer survival of the bentgrasses, and that the affects of drought at 35°C were greater than the affects of just temperature.

Drought stress is known to occur when the transpiration rates of plants exceeds the absorption of water from the soil by the roots. Three different types of drought stress are known to exist: a) atmospheric drought, which may appear when soil moisture is adequate, but high air temperatures, winds and low humidity cause transpiration rates to exceed absorption rates (6,13,14); b) physiological drought, occurs when there is a high salt concentration in the growing media. The salt providing for a greater osmoticum in the soil than that which exists in the plant, reversing the flow of water causing it to move out of the root instead of being absorbed by the plant (14); c) soil drought, this occurs when there is a lack of soil moisture, and water absorption by the plant is reduced.

Wilson and Livingston (70) experimenting with creeping bentgrass observed that as the growing media dried out and the water supplying power of the soil decreased the plants began to show growth retardation, followed by complete cessation of growth, after which wilt symptoms appeared.

Wilson (69) observed drought symptoms to occur in red fescue when the water supplying power of the soil was 13 mg. of water per hour as determined by the soil point method. Creeping bentgrass drought symptoms occurred when rates were 33 mg. of water per hour, and Kentucky bluegrass had the least drought tolerance at 39 mg. of water per hour. Welton and Wilson (68) showed similar results and concluded that the reasons for fescues ability to withstand drought conditions better than Kentucky bluegrass and creeping bentgrass, was related to the xeromorphic features of the leaf, such as leaf blade width. Another xeromorphic feature that may affect water use rates of turfgrasses may be stomatal number. Shearman and Beard (54) reported that an increase in light intensity of air temperature can cause an increase in stomatal densities of Penncross creeping bentgrass. However, they also showed that stomatal densities decrease with increases in nitrogen fertilization and/or irrigation frequencies. Meusal (44) experimenting with bentgrass and annual bluegrass observed the opposite. He noted that plants watered six times per week had higher stomatal densities, and wilted sooner than plants that were watered twice a week.

Madison and Hagen (41) found that Kentucky bluegrass mowed at a low height of cut and irrigated frequently produced a shallower root system than turf which was cut higher and watered less often. Dernoeden and Butler (19) also working with Kentucky bluegrass reported increases in drought resistance when the height of cut was raised from 1.9 cm to 3.8 cm. Julander (34) showed drought injury was correlated with plant carbohydrate reserves, which in turn can be effected by frequency and height of cut, temperature, and fertilization. Funk et al. (22) have observed poor summer survival of red fescue and Kentucky bluegrass varieties under conditions of high nitrogen fertility. Schmidt (52) stated that applications of iron to bentgrass turf will reduce summer dessication and enhance development.

Carrow (14), Madison (40), Beard (6), all agreed that potassium will promote water retention and reduce wilting during stress periods. Researchers (48,63) have observed less summer wilting on creeping bentgrass with increased potassium fertilization.

PILOT STUDIES A AND B

Pilot studies were initiated to determine the effects of two different temperatures and four different watering regimes on the wilting tendencies of Penncross creeping bentgrass.

Materials and Methods (A and B)

Plant Growth. Three 21 day old Penncross creeping bentgrass seedlings were transplanted into each one of 80 semi-conical plastic tubes, 4 cm in diameter and 21 cm long, each containing an 80:20 sand:peat (v/v) mixture. The soil pH in each tube was adjusted to 5.5 by the addition of dolomitic limestone. Plants were grown in the greenhouse for a four month period. Day temperatures were maintained at 21°C, and night temperatures at 17°C. Grow lights were used to extend the photoperiod to 16 hours. Plants were watered three times per week using a complete Hoagland nutrient solution (42) receiving a total of 20 ml/week. Turf was cut to a height of 1.27 cm and then watered.

After four months of growth in the greenhouse the eighty semi-conical tubes were placed in one of two Percival growth chambers, Model MB-60. Both chambers were maintained at a 16/8 (day/night) period with a light intensity of 5.5 milliwatts cm^2. To prevent atmospheric drought the relative humidity was kept at 75% with the aid of humidifiers, controlled by a humidistat. Plants were mowed three times per week and all fertilizer practices were halted.

Pilot Study A

Treatments. A 2 x 4 factorial design with ten replicates per treatment was used. Treatments consisted of two different day temperatures and four different water regimes. Ten replicates of each treatment were placed in one of two growth chambers maintained at 24°C and 35°C, respectively. Each group of replicates received one of four water regimes: a) no water; b) 20 ml/week; c) watered to one half container capacity nightly; and d) watered to container capacity nightly. All containers were allowed to drain.

Time until visual wilt occurred was recorded in days, by dividing the total hours to wilt by 24. Root lengths were measured and recorded after plants wilted.

Results A

Water withheld plants and those that received 20 ml/week wilted within twelve days. Turf growing in the growth chamber at 35°C wilted sooner than those plants that received the same amounts of water but were kept at 24°C. Temperature and water each significantly effected time until wilting occurred, but there was no significant interaction (Table 1).

Water regimes and temperatures did not significantly effect root lengths.

TABLE 1

PILOT STUDY A

DAYS UNTIL WILT OF PENNCROSS CREEPING BENTGRASS UNDER TWO DIFFERENT TEMPERATURES AND TWO DIFFERENT WATER LEVELS[1]

	Days to Wilt	
Temperature	No H_2O	20 ml H_2O
35°C	8.1	9.8
24°C	9.5	12.0

ANALYSIS OF VARIANCE

Source	Df	SS	MS	F
Temperature (T)	1	32.4	32.4	55.5**
Water (W)	1	44.1	44.1	75.6**
TW	1	1.6	1.6	2.7n.s.
w	36	21.0	0.6	

[1]Data is the mean of ten replications.

**Significant at the 1% level.

N.S. No significance.

Plants that were watered to one-half saturation and saturation nightly did not show any signs of wilt even after five weeks. However, plants that received the above water regimes, in the 35°C maintained growth chamber, showed a reduction in vegetative growth when compared to turf growing at 24°C.

Pilot Study B

Treatments. A 2 x 2 factorial design with ten replicates per treatment was used. Treatments consisted of growing turf in one of two different day temperatures and receiving one of two different water regimes for a five week period. Temperatures were maintained at 24°C for one growth chamber and 35°C for the other. Water regimes were: a) plants watered to one-half container capacity nightly; b) plants watered to container capacity nightly. After the five week growth period water was withheld from all turf. The length of time until grass wilted was recorded in days.

Plant root lengths were measured and recorded after plants wilted.

Results B

Plants in all treatments wilted within seven days after witholding water. Statistical analysis showed that temperature and water each had a highly significant effect on the time until wilting occurred, and that the interaction of the two can significantly effect the time until wilt occurs (Table 2).

Temperature significantly effected root growth. Plants grown for five weeks at 35°C had shorter root systems than turf grown at 24°C.

TABLE 2

PILOT STUDY B

DAYS UNTIL WILT OF PENNCROSS CREEPING BENTGRASS AFTER WITHHOLDING WATER FROM TURF PRECONDITIONED AT TWO DIFFERENT WATER REGIMES AND TEMPERATURES FOR A FIVE WEEK PERIOD[1]

	Days to Wilt	
Temperature	Saturation Nightly	One-Half Saturation Nightly
35°C	5.0	5.5
24°C	5.8	7.0

ANALYSIS OF VARIANCE

Source	Df	SS	MS	F
Temperature (T)	1	13.2	13.2	58.8**
Water (W)	1	7.2	7.2	32.1**
TW	1	1.2	1.2	5.4*
w	36	8.1	0.2	

1 Data is the mean of ten replications.

* Significant at the 5% level.

** Significant at the 1% level.

EXPERIMENT II

GREENHOUSE STUDY

Greenhouse studies were initiated to determine the effects of different $N:K_2O$ ratios of fertilizer on the wilting tendencies and turfgrass quality of Penncross creeping bentgrass, *Agostis palustris* L.

Materials and Methods

Growing the turf. The growing media consisted of an 80:20 (v/v) sand:peat mixture (Appendix A). The pH of the soil mix was corrected to 5.5 by the addition of dolomitic limestone. The soil potassium level was low as determined by the Morgan method (38).

Twenty-eight clay crocks (17.8 cm deep by 16.5 cm in diameter) filled with the sand:peat mixture were each seeded with 1.5 grams of Penncross creeping bentgrass. Pots were then placed in the greenhouse for seed germination and seedling growth, for a period of 24 weeks. The growing plants were subjected daily to 16 hours of light which was achieved with the aid of grow lights. Greenhouse temperatures were maintained at 21°C/18°C (D/N). Plants were watered by volume three times per week for a total of 3.8 cm per pot. Mowing of turf was performed at the time of watering to a height of 0.64 cm. Clippings were removed by using a Black and Decker Dust Buster vaccum.

Treatments. A complete randomized design with four replications of each treatment was used. Treatments consisted of seven different $N:K_2O$ ratios (Table 3) applied every ten days for a total of 16 applications. Micro-nutrients were applied at the time of each fertilizer application using a Hoagland nutrient solution (42). All fertilizer was applied to the pots as a liquid drench. Nitrogen was applied in the form of urea and K_2O applied as muriate of potash.

Turfgrass quality determination. Turfgrass stands were evaluated for overall quality after the last treatment was applied. A numerical rating system of one through nine based on color, density, and texture of the topgrowth was employed. A rating of one was considered the poorest quality and nine the best. Ratings were conducted separately by two evaluaters. Scores were averaged and recorded in the same manner as other investigators (4,15,19,22).

Time until wilt. After evaluating, crocks were placed in water for 24 hours and then removed and allowed to drain, to achieve "field capacity". The turf was then placed in the growth chamber and watering practices were halted. Growth chamber temperatures were maintained at 35°C/18°C (D/N), relative humidity was kept at 75-85%, light duration was 16/8 (D/N) and intensity was 5.5 milliwatts cm^2.

Time until wilting occurred was observed and recorded in days by using the equation:

TABLE 3

EXPERIMENT II

NITROGEN TO POTASSIUM FERTILIZER RATIOS AND RATES APPLIED TO PENNCROSS CREEPING BENTGRASS EVERY TEN DAYS

$N:K_2O$ Ratios	Rates in Grams Per $93m^2$	
	N	K^2O
1:0	113.4	0
1:1	113.4	113.4
1:2	113.4	226.8
1:3	113.4	340.2
1:4	113.4	453.6
1:5	113.4	567.0
1:6	113.4	680.4

$$\text{Days until wilt} = \frac{\text{total hours until wilt occurred}}{24}$$

Fresh and dry weights. After the turf in each crock wilted, the top growth was removed at the soil surface by cutting it below the crowns with a razor blade. Fresh weights of the top growth were measured and then placed in a forced air draft oven at 70°C for 48 hours. Dry weights were obtained. The dried plant material was then ground through a 40 mesh screen using a Wiley mill for nutrient and fructosan determination.

Nutrient and fructosan determination. Analysis of the tissue for total nitrogen, phosphorus, potassium, calcium, magnesium, and fructosan were made. Total nitrogen was obtained using a Micro-Kjeldahl procedure (57). Phosphorus was determined colorimetrically at 882 nm by the reduction of ammonium-molybodiphosphate complex by ascorbic acid (64). Calcium and magnesium were found by atomic absorption spectrophotometry and potassium by emission spectrophotometry. Percent fructosan was obtained by using McRary and Slattery's modified alcohol resorcinol method (37,43).

Results

Nitrogen content. No significant trends were found in the nitrogen content of the plant tissue as related to increased amounts of potassium fertilization (Table 4). The turf

TABLE 4

EXPERIMENT II

$N:K_2O$ TREATMENT RATIOS % NUTRIENTS AND FRUCTOSAN IN TISSUE OF PENNCROSS CREEPING BENTGRASS[1]

	Percentage recovered in Tissue					
$N:K_2O$ Ratios	N	P	K	Ca	Mg	Fructosan
1:0	1.28	0.22	1.02	0.62	0.38	1.43
1:1	1.28	0.22	1.34	0.67	0.35	1.34
1:2	1.40	0.23	1.71	0.72	0.38	1.08
1:3	1.22	0.20	2.11	0.60	0.31	1.14
1:4	1.19	0.22	2.32	0.72	0.35	1.10
1:5	1.28	0.22	2.65	0.69	0.35	1.11
1:6	1.35	0.22	3.26	0.76	0.35	1.29
Trend	n.s.	n.s.	linear**	n.s.	n.s.	Quadratic*
$S_{\bar{x}}$	.065	.009	.127	.045	.025	.100

1 Data average of four replications/treatment.

n.s. No significant trend.

** Significant trend at 1%.

* Significant trend at 5%.

that had received the 1:4 $N:K_2O$ fertilizer ratio contained the lowest percent of nitrogen. While the turf that received the 1:2 ratio contained the highest percentage of total nitrogen.

A positive correlation was observed between nitrogen tissue levels and the percentage of phosphorus, magnesium, and calcium recovered in the tissue (Appendix B).

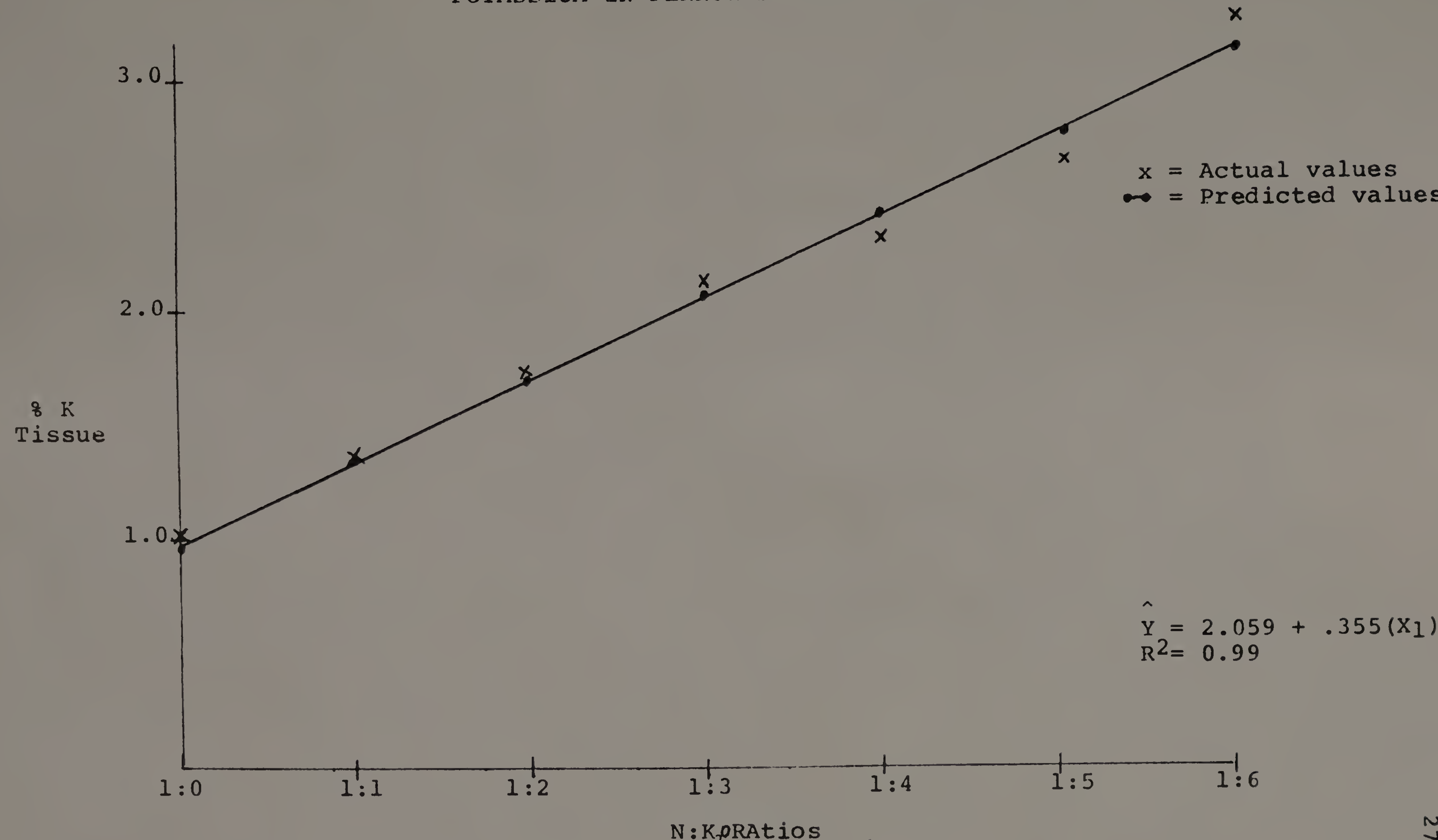
<u>Phosphorus content</u>. Increased amounts of potassium fertilization did not effect the phosphorus content in the turfgrass tissue (Table 4). However, a positive correlation was found between phosphorus tissue levels and calcium and magnesium tissue levels (Appendix B).

<u>Potassium content</u>. Statistical analysis of the potassium content in the tissue indicated that a linear trend existed between the seven different $N:K_2O$ fertilizer ratio treatments (Table 4, Figure 1). The lowest levels of potassium in the tissue were found in turf which had not received any potassium fertilizer, while plants that received the greatest amount of potassium contained the highest percentage in their tissue.

Time until wilt correlated positively with potassium tissue levels (Appendix B).

<u>Calcium and magnesium content</u>. No significant trends were found in the calcium and magnesium contents in the plant

FIGURE 1
$N:K_2O$ FERTILIZER RATIOS, PERCENT
POTASSIUM IN PENNCROSS CREEPING BENTGRASS



tissue with respect to the different $N:K_2O$ ratios applied (Table 4).

A positive correlation existed between the potassium plant tissue content recovered and the calcium content, also a positive correlation between the magnesium and calcium content in the tissue was found (Appendix B).

Fructosan content. A quadratic trend was observed with fructosan levels in the plant tissue in relation to the fertilizer ratios applied to the turf (Table 4, Figure 2). The highest fructosan levels were found in turf that had received the 1:0 fertilizer ratio. The lowest amounts were observed in plants which received the 1:4 ratio. Fructosan levels again increased in the plant as the level of potassium fertilization was increased to the 1:6 rate.

Fresh and dry weight. No significant differences occurred with fresh and dry weights with respect to the different $N:K_2O$ ratios (Table 5).

Calcium, magnesium, phosphorus, and nitrogen were all negatively correlated to fresh and dry weights of the turfgrass stand (Appendix B).

Days until wilt. Regression analysis revealed a highly significant quadratic trend between time until wilt of the total turfgrass stand and the ratio of $N:K_2O$ applied. Turf to which potassium was not applied (1:0) wilted first, where as turf that received the 1:3 and 1:4 ratios wilted last.

TABLE 5

EXPERIMENT II

$N:K_2O$ FERTILIZER TREATMENT RATIOS

FRESH AND DRY TOP GROWTH WEIGHTS, TURFGRASS QUALITY AND DAYS TO WILT OF PENNCROSS CREEPING BENTGRASS[1]

$N:K_2O$ Ratios	Fresh wt. Grams	Dry wt. Grams	Turfgrass[2] Quality	Days Until Wilt
1:0	8.40	5.95	5.6	11.7
1:1	8.70	6.61	6.1	13.0
1:2	8.85	6.26	6.4	13.7
1:3	9.90	7.36	8.1	14.5
1:4	10.14	7.34	7.3	14.6
1:5	9.02	6.12	5.2	13.9
1:6	9.13	6.37	5.1	14.2
Trend	n.s.	n.s.	quadratic**	quadratic**
$S_{\bar{x}}$	.781	.594	.527	.365

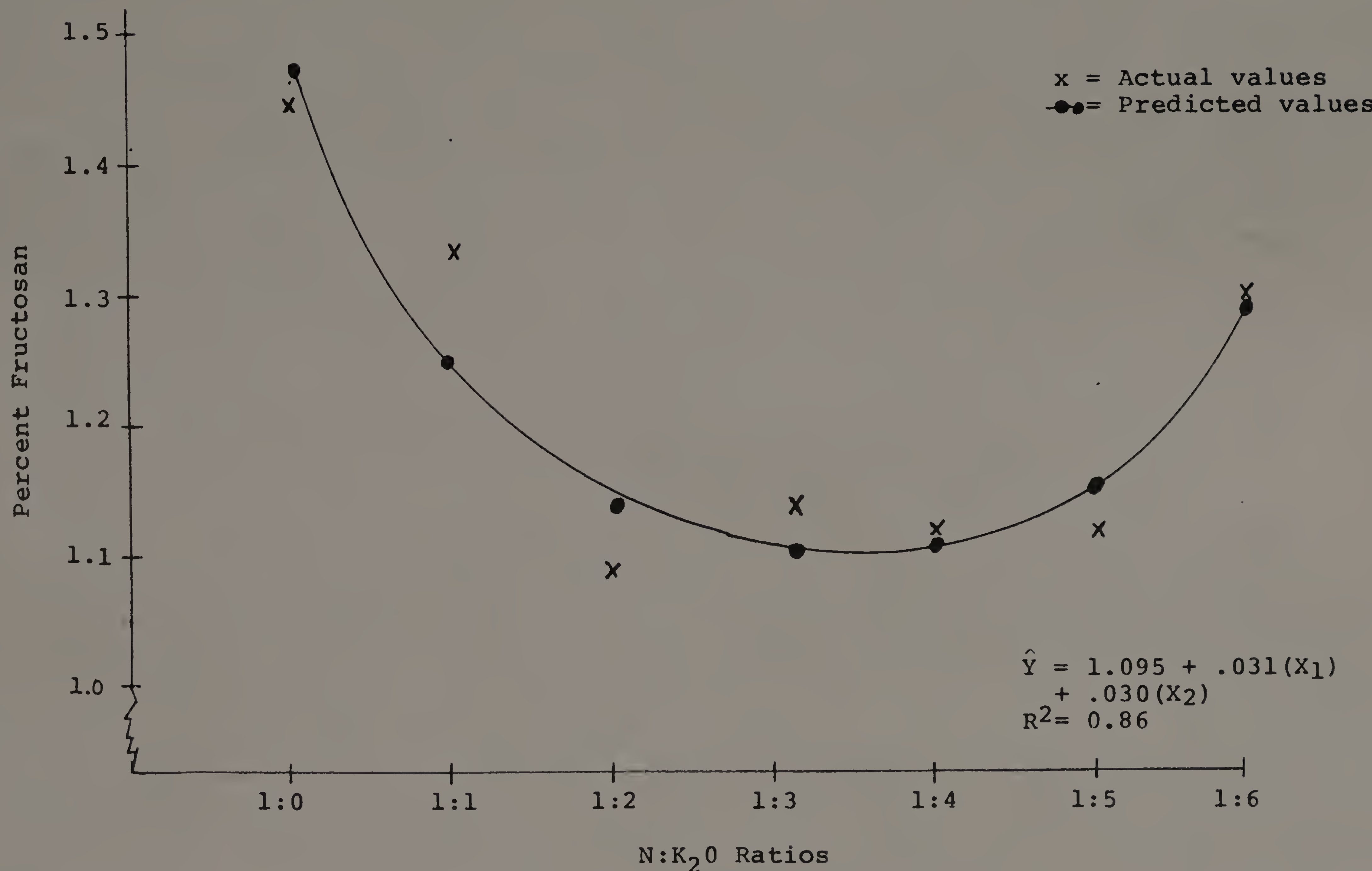
1 Data average of four replications/treatment.

2 1 equals worst quality, 9 equals best quality.

n.s. No significant trend.

** Significant trend at 1%.

FIGURE 2
N:$K_2$0 RATIOS AND % FRUCTOSAN CONTENT
IN PENNCROSS CREEPING BENTGRASS



Grass which received the 1:5 and 1:6 ratios wilted sooner than those that received the 1:3 and 1:4 but later than the 1:0, 1:1, and 1:2 ratios (Table 5, Figure 3).

Turfgrass quality. Turfgrass quality was best for turf that received the 1:3 and 1:4 ratios, and worst for the turfgrass which received the 1:0, 1:5, and 1:6 ratios. These results showed a highly significant quadratic trend (Table 5, Figure 4).

Turfgrass quality was shown to be negatively correlated to the calcium content in the plant tissue (Appendix B).

FIGURE 3

$N:K_2O$ RATIOS AND DAYS TO WILT OF PENNCROSS CREEPING BENTGRASS

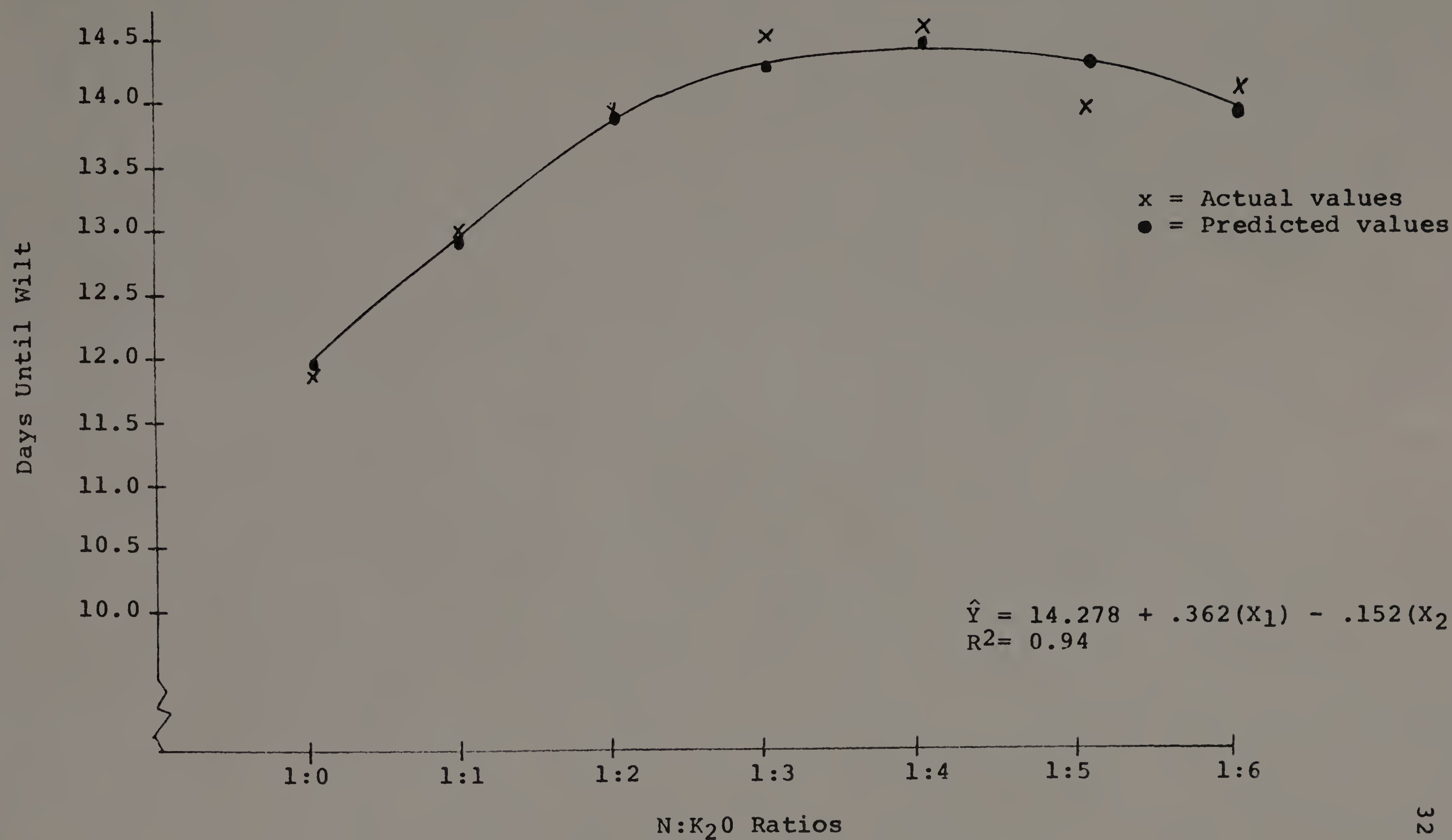
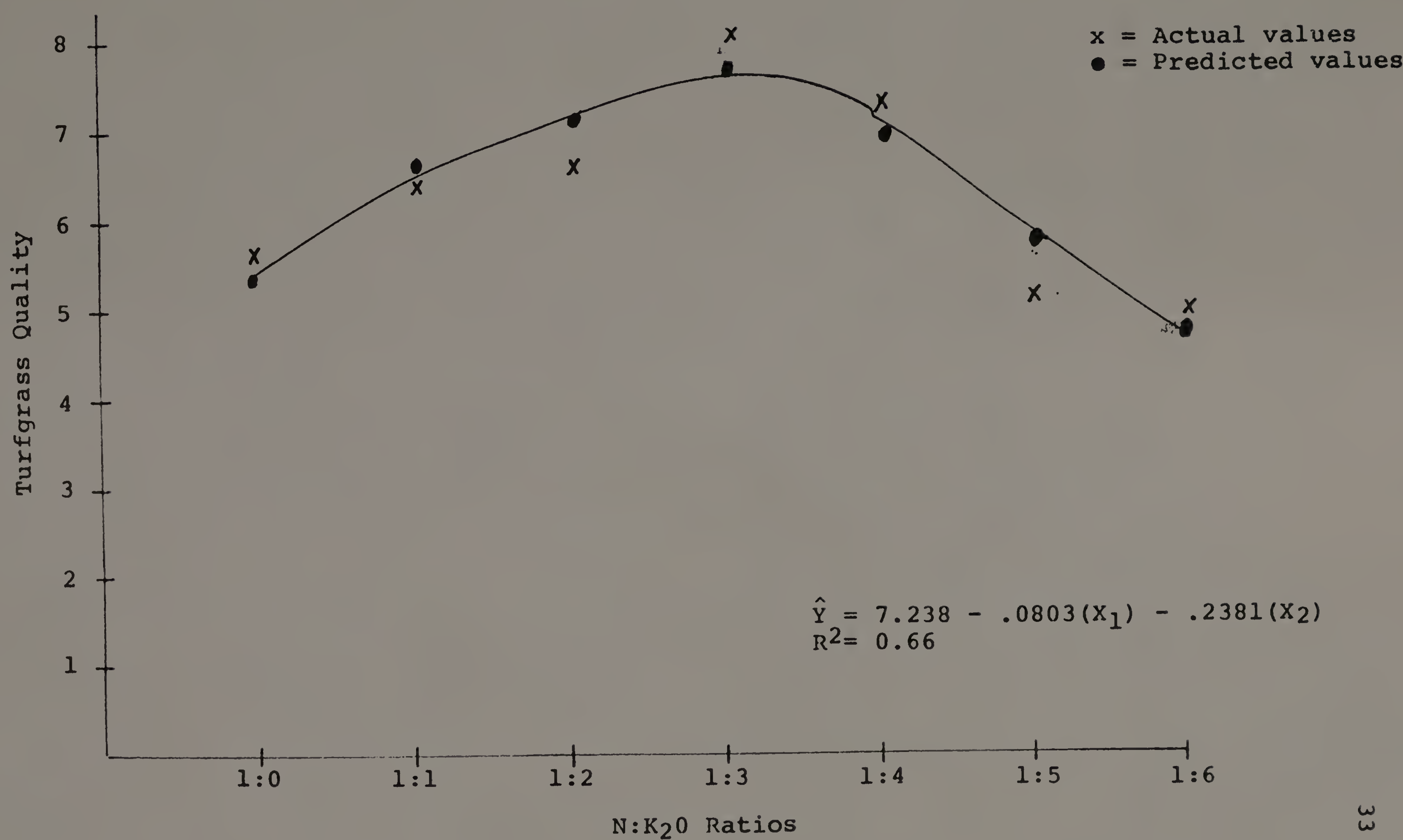


FIGURE 4
$N:K_2O$ RATIOS AND QUALITY
OF PENNCROSS CREEPING BENTGRASS



EXPERIMENT III

FIELD TRIAL 1980

Field studies were initiated in the spring of 1980 to determine the effects of different $N:K_2O$ ratios of fertilization on the wilting and turfgrass quality of Penncross creeping bentgrass, *Agostis palustris L.*

Materials and Methods

Growing the turf. The experiment was conducted on a $107m^2$ three year old stand of Penncross creeping bentgrass. The experimental area was divided into four blocks each containing eight separate $3.35m^2$ plots. The soil consisted of a 100% pure sand (Appendix A), with a pH of 6.0. The potassium content of the soil was low as determined by the Morgan Method (38). Turf at the onset of the experiment was sparse. Density was improved after the green was cored, overseeded, and topdressed, at a later date turf was verdicut and again overseeded. The experimental area was topdressed at bi-weekly intervals with pure sand for the duration of the study. The topdressing material was low in potassium.

Turf was cut every other day to a height of 0.64 cm. and clippings were removed. Water was applied as needed with an oscillating sprinkler, which provided for good uniform coverage over the entire experimental area. All applications of water were monitered by rain gauges.

Treatments. A completed randomized block design with four replications of each treatment was used. Treatments consisted of eight different N:K_2O fertilizer ratios (Table 6) applied every nine to ten days, totaling nine applications. All fertilizer was mixed in water and applied with a sprayer. Micro-nutrients were applied three times during the growing season at the rate of 60ml/93m^2 (using Chipco Microgreen) per application. N was applied in the form of urea and K_2O as muriate of potash.

Evapotranspiration rate determination. After the seventh fertilizer application, one turfgrass plug (diameter 5.1 cm., depth 9.5 cm.) was removed from each plot to determine the evapotranspiration rates for each different N:K_2O ratio treatment. Hot paraffin was brushed over the soil of each plug, leaving only the turf canopy exposed. Plugs were brought to the lab and saturated with water, and then placed in the growth chamber (35°C/18°C, D/N) to compensate for any wound responses before being weighed. After three hours plugs were removed from the growth chamber, weighed and again placed back into the chamber. Forty-eight hours later plugs were once again weighed and evapotranspiration rates were recorded in ml water lost/$cm.^2$.

Turfgrass quality determination. Turfgrass quality in each

TABLE 6

EXPERIMENT III

NITROGEN TO POTASSIUM RATIOS AND RATES APPLIED TO PENNCROSS CREEPING BENTGRASS EVERY TEN DAYS

$N:K_2O$ Ratios	Rates in Grams per $93m^2$	
	N	K_2O
1:0	56.8	0
3:1	56.8	19.0
2:1	56.8	28.6
3:2	56.8	37.7
1:1	56.8	56.8
1:2	56.8	113.5
1:3	56.8	170.3
1:4	56.8	227.0

plot was evaluated after the last fertilizer treatments were applied. The quality rating system used was the same as described in Experiment II.

Time until wilt. One turfgrass plug from each plot (diameter 10.8 cm., depth 14.5 cm.) was removed and placed in a pot. Pots were then brought to the lab and placed in the growth chamber (21°C/18°C, D/N) for a two week acclimation period before being subjected to wilt studies. After the two week acclimation period in the growth chamber, pots were removed and placed in water for 24 hours and then allowed to drain to achieve "field capacity." The growing turf was then placed back into the growth chamber and watering practices were stopped. Growth chamber temperatures were maintained at 35°C/18°C, D/N. Relative humidity was kept between 75%-85%, lighting duration was 16/8 (D/N) and intensity was 5.5 milliwatts cm^2. Time until wilt occurred for each treatment was recorded in days until wilt using the equation from Experiment II.

Fresh and dry weights. When the turf in each pot wilted, fresh and dry weights of the vegetative growth were obtained using the same methods outlined in Experiment II.

Nutrient and fructosan determination. Analysis of the tissue for total nitrogen, phosphorus, potassium, calcium, magnesium, and fructosan was determined by using the procedures described in Experiment II.

Results

The N:K_2O ratios didn't significantly effect the percent N, P, Ca, Mg, and fructosan in the plant tissue (Table 7). However, the percent potassium in the plant tissue increased significantly as the rate of applied K_2O was increased (Table 7, Figure 5).

No significant trends were found in evapotranspiration rates, turfgrass quality, time until wilt, fresh and dry weights with respect to the N:K_2O ratios (Table 8).

Calcium in the plant tissue was positively correlated with phosphorus, magnesium, and time until wilt. A negative correlation was found between calcium and turfgrass quality (Appendix C). The percent nitrogen in the plant tissue showed a negative correlation with time until wilt, and both, fresh and dry weights of the turfgrass stand. Time until wilt was positively correlated with fresh and dry weights (Appendix C).

TABLE 7

EXPERIMENT III

N:$K_2$0 RATIOS, PERCENT NUTRIENTS AND FRUCTOSAN IN TISSUE IN PENNCROSS CREEPING BENTGRASS[1]

N:$K_2$0 Ratios	Percentage in Tissue					
	N	P	K	Ca	Mg	Fructosan
1:0	1.44	0.36	0.98	0.68	0.32	1.02
3:1	1.38	0.26	0.92	0.53	0.26	1.11
2:1	1.64	0.35	0.94	0.70	0.31	1.25
3:2	1.44	0.30	0.89	0.67	0.35	1.16
1:1	1.57	0.31	1.00	0.73	0.32	0.92
1:2	1.51	0.33	0.95	0.68	0.27	0.96
1:3	1.40	0.27	1.06	0.68	0.29	1.33
1:4	1.35	0.31	1.33	0.69	0.27	1.44
Trend	n.s.	n.s.	linear**	n.s.	n.s.	n.s.
$S_{\bar{x}}$	.103	.023	.103	.070	.026	.174

1 Data average of four replications/treatment.

n.s. No significant trend.

** Significant trend at 1%.

FIGURE 5

$N:K_2O$ RATIOS AND THE PERCENT POTASSIUM IN PENNCROSS CREEPING BENTGRASS TISSUE

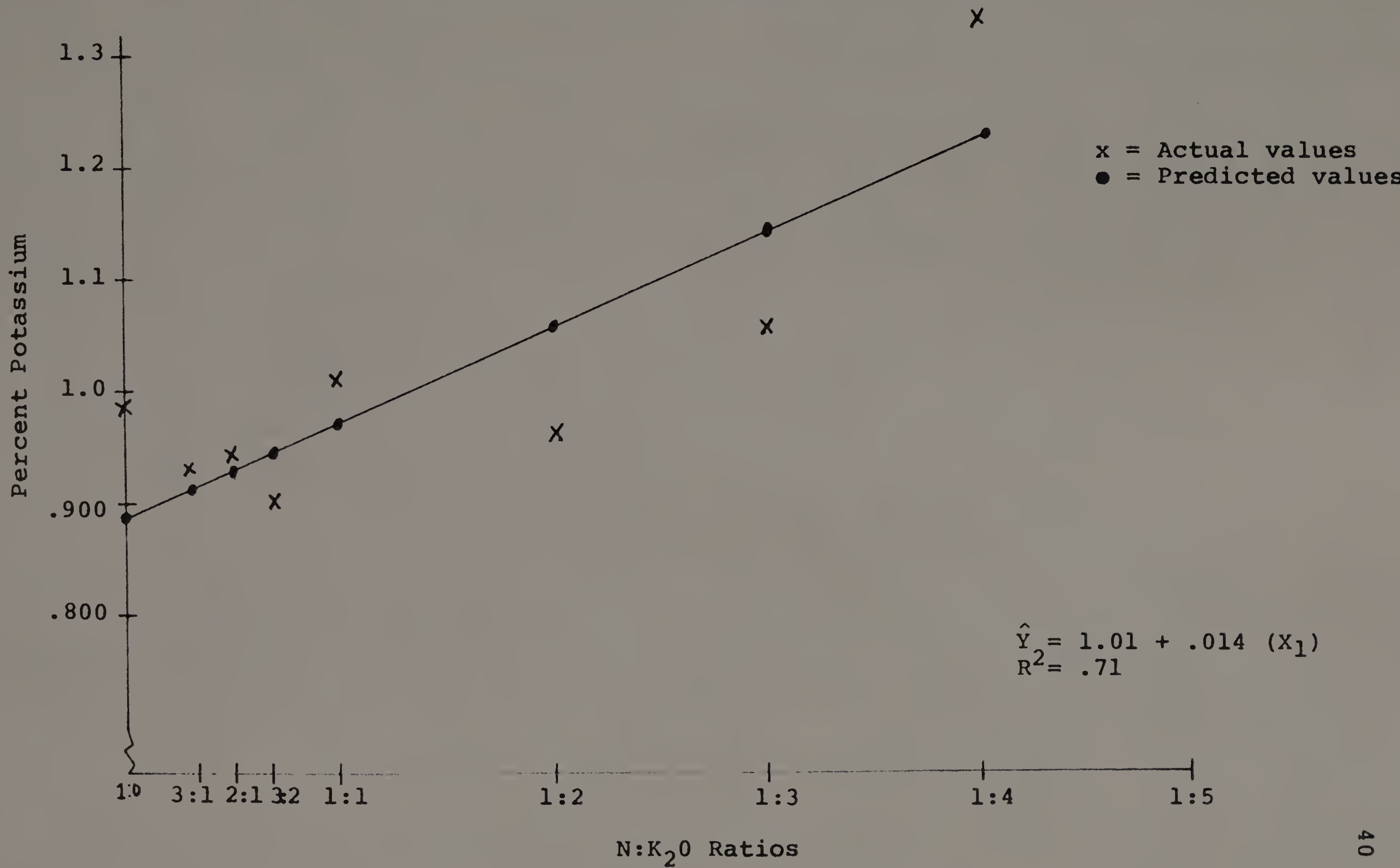


TABLE 8

EXPERIMENT III

$N:K_2O$ RATIOS EVAPOTRANSPIRATION RATES, TURFGRASS QUALITY, DAYS TO WILT AND FRESH AND DRY WEIGHTS OF PENNCROSS CREEPING BENTGRASS[1]

$N:K_2O$ Ratios	Evapotrans. ml/cm^2 (48 Hrs.)	Turf-grass[2] Quality	Days to Wilt	Fresh wt. Grams	Dry wt. Grams
1:0	0.92	6.4	7.7	2.90	2.12
3:1	0.86	6.4	7.8	3.68	2.46
2:1	0.89	6.0	7.1	2.21	1.71
3:2	0.90	6.0	8.2	3.23	2.25
1:1	0.89	6.0	7.5	3.70	2.53
1:2	0.93	5.9	7.1	3.28	2.14
1:3	0.88	6.1	8.3	3.54	2.50
1:4	0.91	5.6	8.0	3.09	2.30
Trend	n.s.	n.s.	n.s.	n.s.	n.s.
$S_{\bar{x}}$	.034	.703	.377	.355	.201

1 Data average of four replications/treatment.

2 1 equals worst quality, 9 equals best quality.

n.s. No significant trend.

EXPERIMENT IV

FIELD TRIAL 1981

Materials and Methods

Growing the turf. Field studies in 1981 were performed on the same turf plots as the previous year (Experiment III). The pH for all plots was 5.5$\pm$ 0.3. Prior to the first treatment the entire experimental area was cored, verticut, and topdressed. Plots were mowed every other day to a height of 0.64 cm. and clippings were removed. Water was applied once a week (when needed) with an oscillating sprinkler which provided uniform coverage. Dursban was applied twice (June 3, July 10) during the growing season to control cut worm. Fungicides were applied every three weeks throughout June and July as a preventative measure. Fertilizer treatments were initiated on May 4th.

Treatments. A complete randomized block design with four replications of each treatment was used. Fertilizer ratios applied were the same as those for Experiment III. However, the rate of applied nitrogen for each plot was increased to 113gr/93m^2 per application from 56.7gr/93m^2, this in turn raised the amount of K_2O applied per application (Table 9). Treatments were applied every 9 to 10 days for a total of nine applications. All fertilizer was mixed in water and applied with a sprayer. Urea was the source of nitrogen

TABLE 9

EXPERIMENT IV

$N:K_2O$ RATIOS AND RATES APPLIED TO PENNCROSS CREEPING BENTGRASS EVERY TEN DAYS

$N:K_2O$ Ratios	Rates Grams Per $93m^2$	
	N	K_2O
1:0	113.4	0
3:1	113.4	36.3
2:1	113.4	56.7
3:2	113.4	72.3
1:1	113.4	113.4
1:2	113.4	226.8
1:3	113.4	340.2
1:4	113.4	453.6

and muriate of potash for K_2O.

<u>Evapotranspiration rate determination</u>. After the eighth fertilizer application, one turfgrass plug (diameter 5.1 cm., depth 9.5 cm.) was removed from each plot to determine the evapotranspiration rates. This was accomplished by using the methods outlined in Experiment III. However, in this study evapotranspiration rates were measured over three different time periods, 24 hours, 48 hours, and 72 hours.

<u>Stomatal densities</u>. After the final fertilizer applications were made, three intact turf plants were removed by random from each experimental plot. Stomatal counts were made on the third leaf from the top of each plant on both the abaxial and adaxial leaf blade surfaces. Counts were made by taking leaf impressions using the method developed by Rice, Glenn, and Quisenberry (49). Stomatal counts were made from the mid-portion of the leaf blade at a 430 magnification. Four counts were made per leaf on both the abaxial and adaxial leaf surfaces. The actual area of the microscopic field was .108mm^2, with counts being converted to density/mm^2.

<u>Turfgrass quality</u>. Turfgrass quality ratings were performed by three evaluators using the system described in Experiment II.

<u>Time until wilt</u>. Wilt studies began after the last fertilizer applications were watered into the soil. Water was

kept off plots until all the turfgrass wilted. During periods of precipitation the entire experimental area was completely covered with a polyethylene tarp. Time until wilt occurred was recorded in days by using the equation given in Experiment II.

Volumetric water content of soil at wilt. After wilting occurred in each plot, soil samples (vol. 140cc) were taken just below the thatch layer and weighed. The soil was then oven dried at 105°C for 24 hours and reweighed. The difference in wet weight and oven dried weight equaled the mass or volume of water in the soil at wilt. The volumetric water content (θ) of the soil at wilt was found by dividing the volume of soil water (V_w) at wilt by the total volume of the soil (V_t) or $\theta = \frac{V_w}{V_t}$ (31).

Root lengths and tissue samples. Turfgrass plugs (diameter 10.8 cm., depth 14.5 cm.) were removed from each plot at the time of wilt. Root length measurement, including the thatch layer, were taken and recorded.

The vegetation growth of the turfgrass plugs was removed below the crowns at the soil surface using a razor blade. Plant tissue samples were then oven dried at 70°C for 48 hours. Dried tissue was ground through a 40 mesh screen using a Wiley Mill for nutrient and fructosan determination.

Nutrient and fructosan determination. Analysis of the tissue for total nitrogen, phosphorus, potassium, calcium, magnesium, and fructosan was determined by using the methods outlined in Experiment II.

Soil samples. After all plots had wilted, soil samples were taken to determine the pH, potassium concentration, and salt concentration of the soil for each experimental plot. Soil potassium was determined by emission spectrophotometry (28). Salt concentrations were found by saturating 25 grams of soils in 50 mls. of distilled water for thirty minutes and then measuring the electrical conductivity of the filtrate in millimhos per centimeter.

Results

Nitrogen content. The nitrogen content of the plant tissue followed a significant quadratic trend in regard to the different $N:K_2O$ ratios applied to the turf plots. The percent nitrogen in the turf plant tissue decreased from the 1:0 ratio to the 1:2 ratio, and then increased to the 1:4 ratio where the highest amounts of tissue nitrogen were found (Table 10, Figure 6).

The percent nitrogen recovered in the plant tissue correlated positively with the percent potassium, and the percent phosphorus found in the plant tissue (Appendix D).

Phosphorus and fructosan content. Increased K_2O fertilization did not significantly effect the percentage of phosphorus

TABLE 10

EXPERIMENT IV

$N:K_2O$ RATIOS, NUTRIENT, AND FRUCTOSAN CONTENT OF PENNCROSS CREEPING BENTGRASS TISSUE[1]

$N:K_2O$ Ratios	Percentage in Tissue N	P	K	Ca	Mg	Fructosan
1:0	1.76	0.26	1.14	0.73	0.28	11.80
3:1	1.71	0.26	1.43	0.61	0.23	10.00
2:1	1.71	0.26	1.44	0.63	0.22	10.85
3:2	1.68	0.26	1.46	0.60	0.22	9.80
1:1	1.69	0.22	1.49	0.61	0.19	11.45
1:2	1.64	0.27	1.82	0.60	0.18	9.82
1:3	1.91	0.26	2.19	0.58	0.18	10.25
1:4	2.00	0.28	2.30	0.53	0.15	9.38
Trend	Quad.*	n.s.	lin.**	cubic*	cubic*	n.s.
$S_{\bar{x}}$	.077	.181	.110	.028	.012	.930

[1] Data average of four replications/treatment.

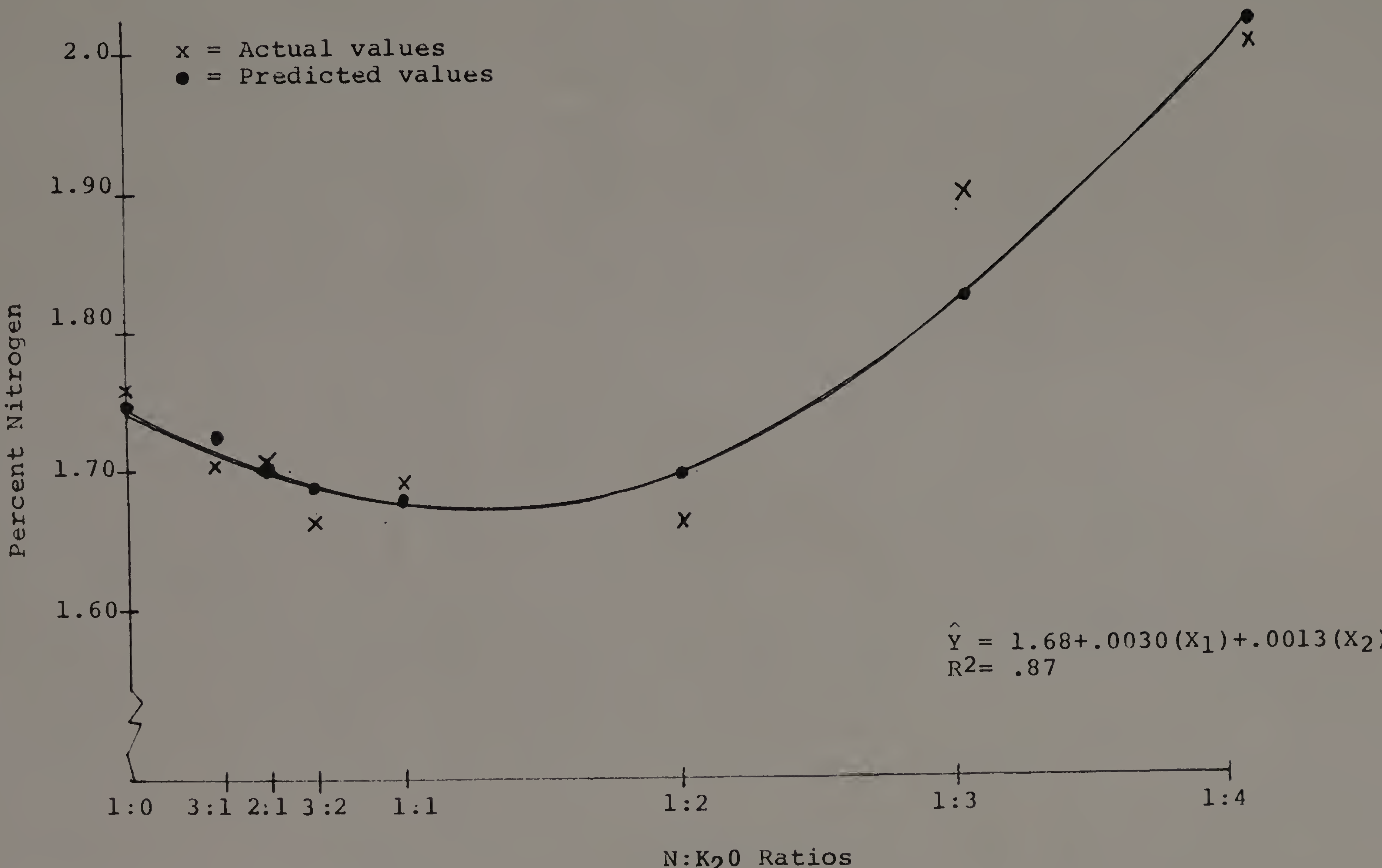
n.s. No significant trend.

* Significant trend at 5%

** Significant trend at 1%.

FIGURE 6

$N:K_2O$ RATIOS AND THE PERCENT NITROGEN IN PENNCROSS CREEPING BENTGRASS TISSUE



and fructosan found in the plant tissue (Table 10).

Potassium content. A significant linear trend was observed between the amount of K_2O applied and the percentage of potassium recovered in the plant tissue (Table 10, Figure 7).

Tissue potassium levels were negatively correlated to magnesium and calcium (Appendix D).

Calcium and magnesium content. Regression analysis revealed that the percentages of magnesium and calcium in the plant tissue followed significant cubic trends in relation to all N:K_2O ratios used (Table 10). The highest percentages of calcium and magnesium were found in turf that had not received K_2O fertilization. Sharp decreases in the amounts of Ca and Mg existed between the ratios of 1:0 and 1:1. The percentage of calcium and magnesium remained almost unchanged between the 1:1 and 1:3 ratios. At the 1:3 ratio sharp decreases in the percentages of calcium and magnesium were observed (Figures 8, 9).

Both, calcium and magnesium were positively correlated with one another (Appendix D).

Evapotranspiration rates. The rate of water loss from the turf canopy over three separate time periods, 24 hours, 48 hours, and 72 hours was not significantly effected by any of the N:K_2O ratios applied (Table 11).

Stomatal densities. No significant differences were seen in

FIGURE 7
$N:K_2O$ RATIOS AND THE PERCENT POTASSIUM
IN PENNCROSS CREEPING BENTGRASS TISSUE

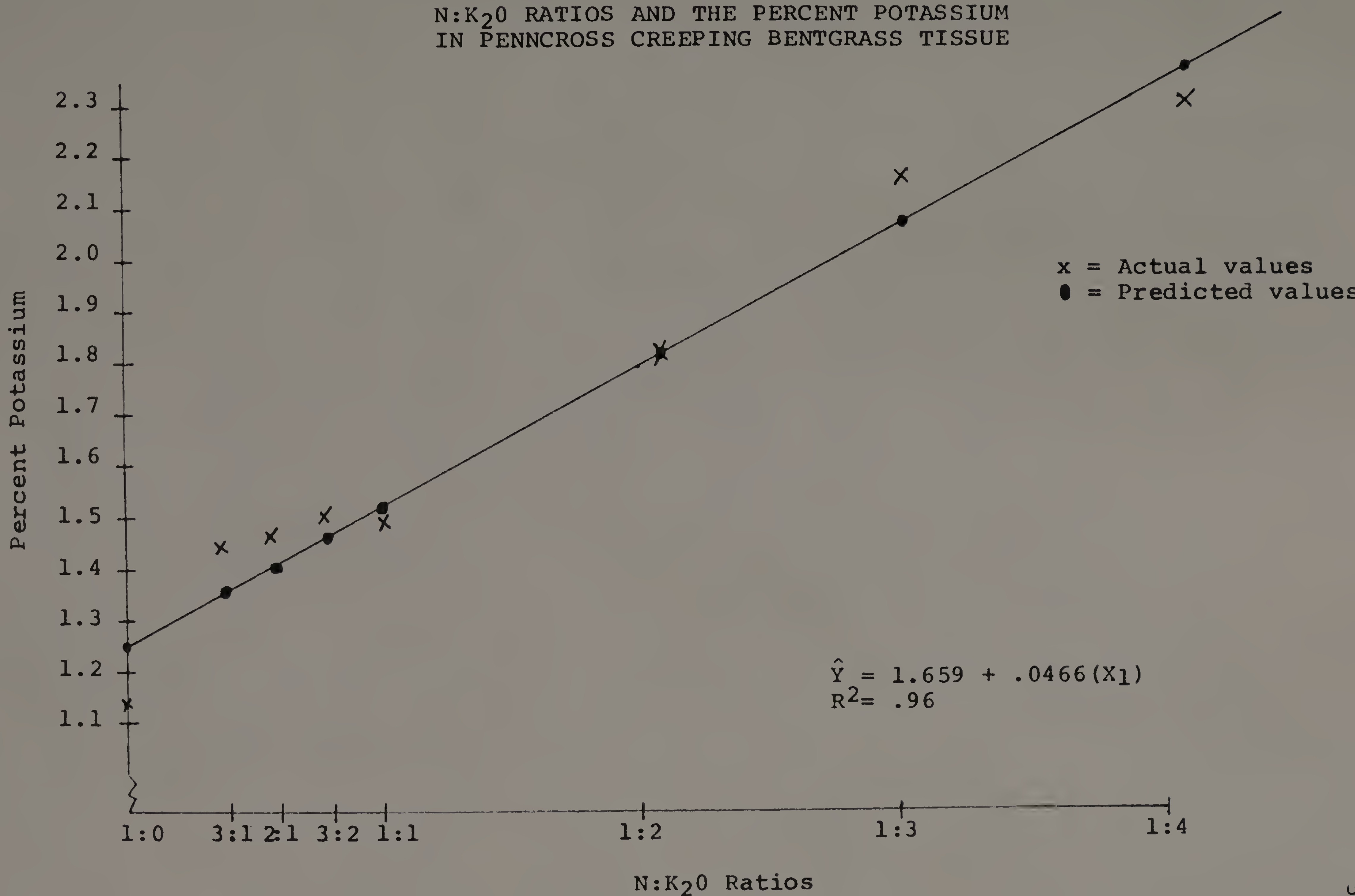


FIGURE 8
$N:K_2O$ RATIOS AND THE PERCENT CALCIUM IN PENNCROSS CREEPING BENTGRASS TISSUE

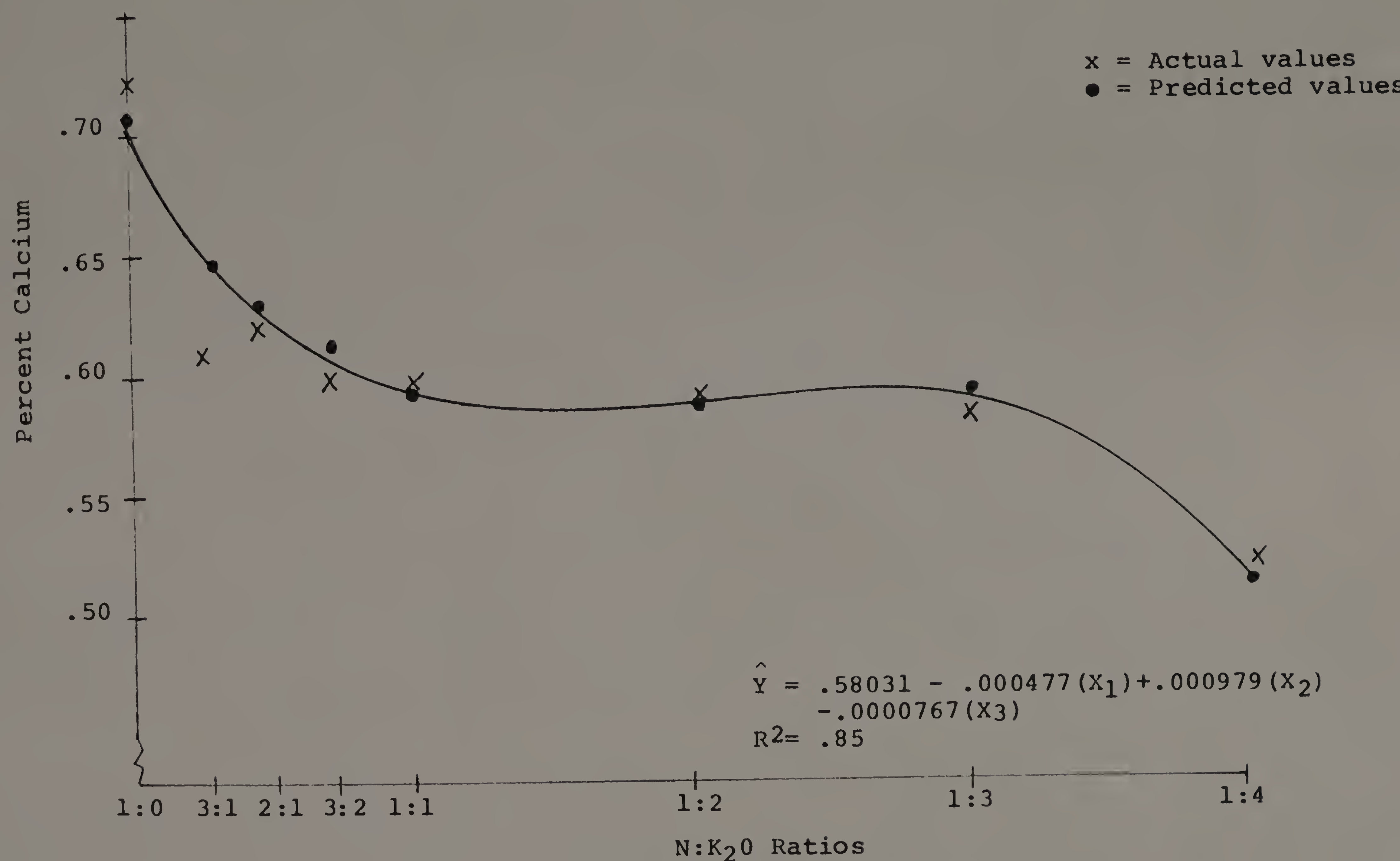


FIGURE 9

$N:K_2O$ RATIOS AND THE PERCENT MAGNESIUM IN PENNCROSS CREEPING BENTGRASS TISSUE

$\hat{Y} = .18292 - .002436(X_1) + .000592(X_2) - 0.0000367(X_3)$

$R^2 = .98$

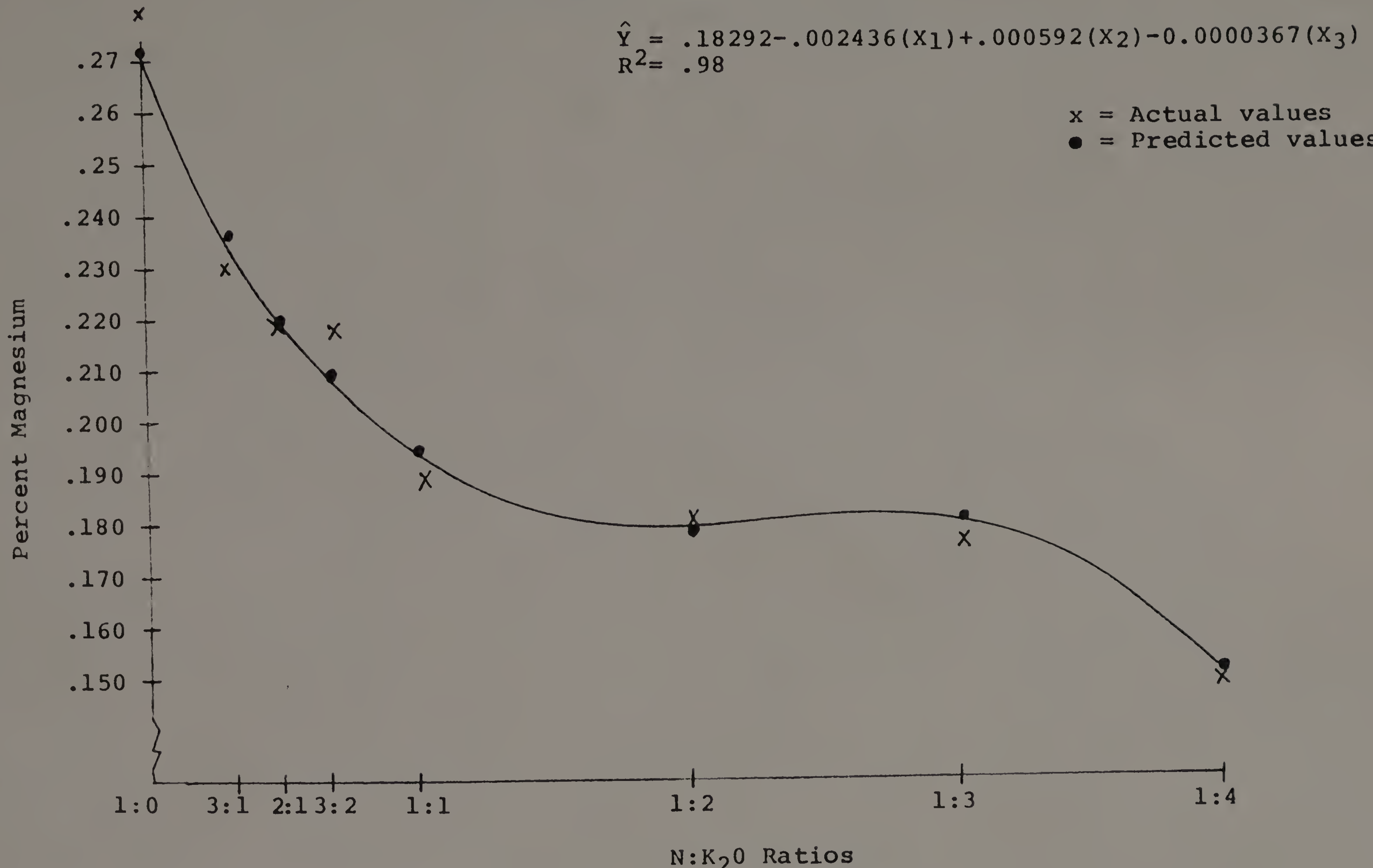


TABLE II

EXPERIMENT IV

N:K_2O RATIOS, EVAPOTRANSPIRATION RATES, STOMATAL DENSITIES, TURFGRASS QUALITY, DAYS TO WILT, ROOT LENGTH, AND THE VOLUMETRIC WATER CONTENT OF THE SOIL AT WILT FOR PENNCROSS CREEPING BENTGRASS[1]

N:K_2O Ratios	Evapotranspiration ml/cm^2 after 24 hrs.	48 hrs.	72 hrs.	Stomatal Densities per mm^2 Adaxial	Abaxial	Turfgrass[2] Quality	Root Length cm.	Days to Wilt	Volumetric Soil Water Content at Wilt
1:0	0.61	1.20	1.72	205.3	144.6	8.2	6.44	12.4	6.3
3:1	0.63	1.24	1.82	217.6	127.7	7.7	6.56	14.1	4.7
2:1	0.64	1.20	1.70	212.3	123.6	8.2	6.62	13.2	8.6
3:2	0.80	1.35	1.92	214.8	129.5	7.2	6.56	13.1	6.4
1:1	0.61	1.20	1.74	211.5	129.8	7.2	7.38	13.4	6.5
1:2	0.64	1.26	1.82	204.5	125.7	7.1	7.94	13.4	6.3
1:3	0.63	1.19	1.72	202.6	120.0	6.4	7.88	13.9	4.7
1:4	0.68	1.32	1.92	202.5	114.0	6.0	7.04	13.9	4.8
Trend	n.s.	n.s.	n.s.	n.s.	linear*	linear**	n.s.	n.s.	n.s.
$S_{\bar{x}}$	.036	.044	.063	8.65	6.91	.252	.670	.521	1.09

1 Data average of four replications/treatment.

2 1 equals worst quality, 9 equals best quality.

n.s. No significant trend.

* Significant trend at 5%.

** Significant trend at 1%.

the number of stomates on the adaxial surface of the leaf in regards to increased K_2O fertilization. However, increased K_2O fertilization yielded a significant linear decrease in the stomatal densities on the abaxial surface of the leaf blade (Table 11, Figure 10).

Stomatal densities on the abaxial leaf surface were negatively correlated to the potassium tissue content, but, positively correlated to the calcium and magnesium content (Appendix D).

Turfgrass quality. Turfgrass quality was positively correlated to the percent magnesium and calcium in the plant tissue, and negatively correlated to the percent potassium recovered in the plant tissue (Appendix D).

The quality of the turfgrass stand decreased linearly as the levels of applied potassium were increased from the 1:0 to the 1:4 ratio (Table 11, Figure 11).

Root length. No significant trends or correlations were found with regards to root length and the $N:K_2O$ ratios studied (Table 11).

Days to wilt. Under drought conditions increasing levels of K_2O fertilization from the 1:0 to the 1:4 ratio yielded no significant trends in prolonging the time until wilt.

However, it was observed that plots which had not received K_2O, onset of wilt occurred sooner than plots that received K_2O (Table 11).

FIGURE 10
$N:K_2O$ RATIOS AND STOMATAL DENSITIES
OF THE ABAXIAL LEAF SURFACE

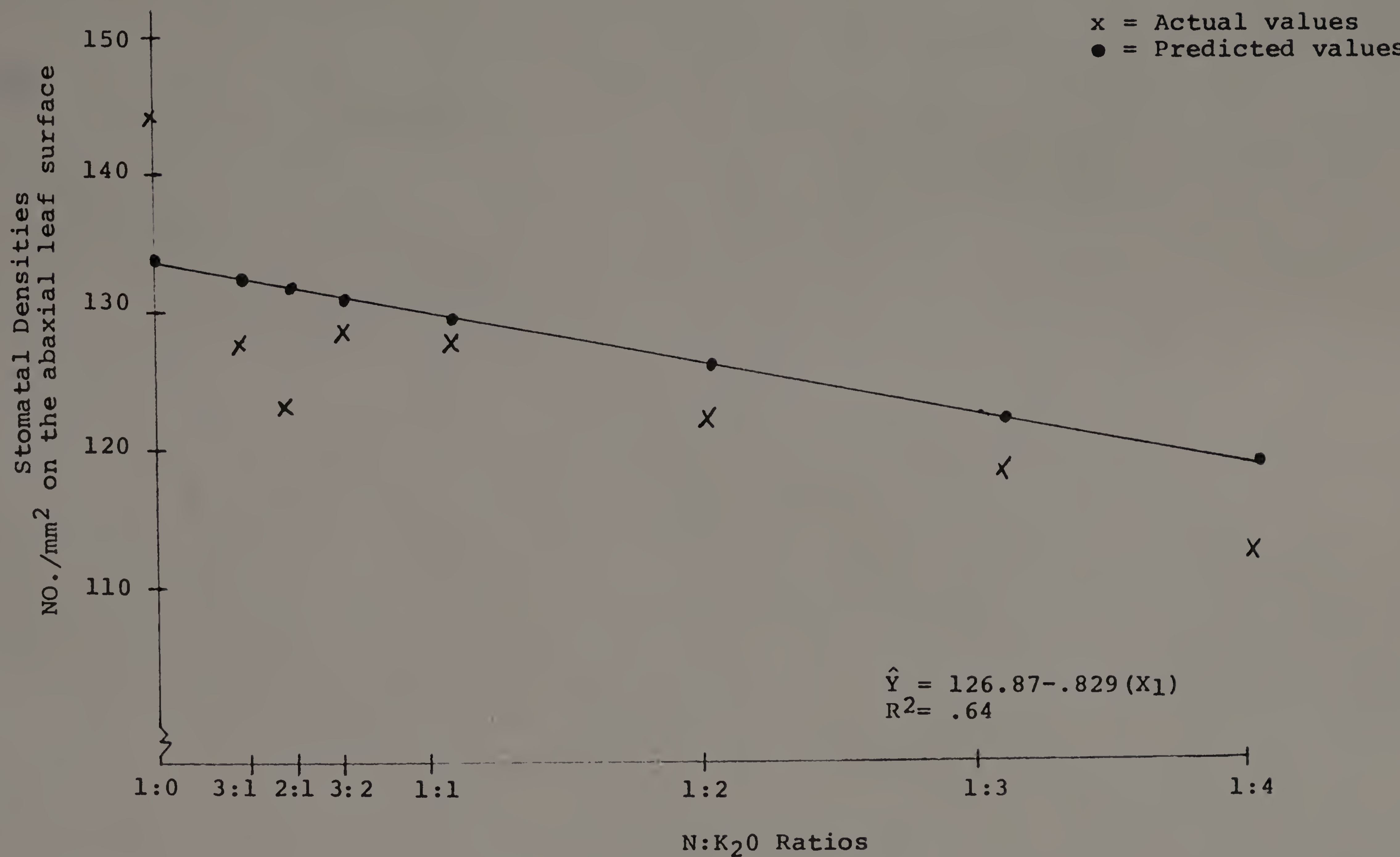
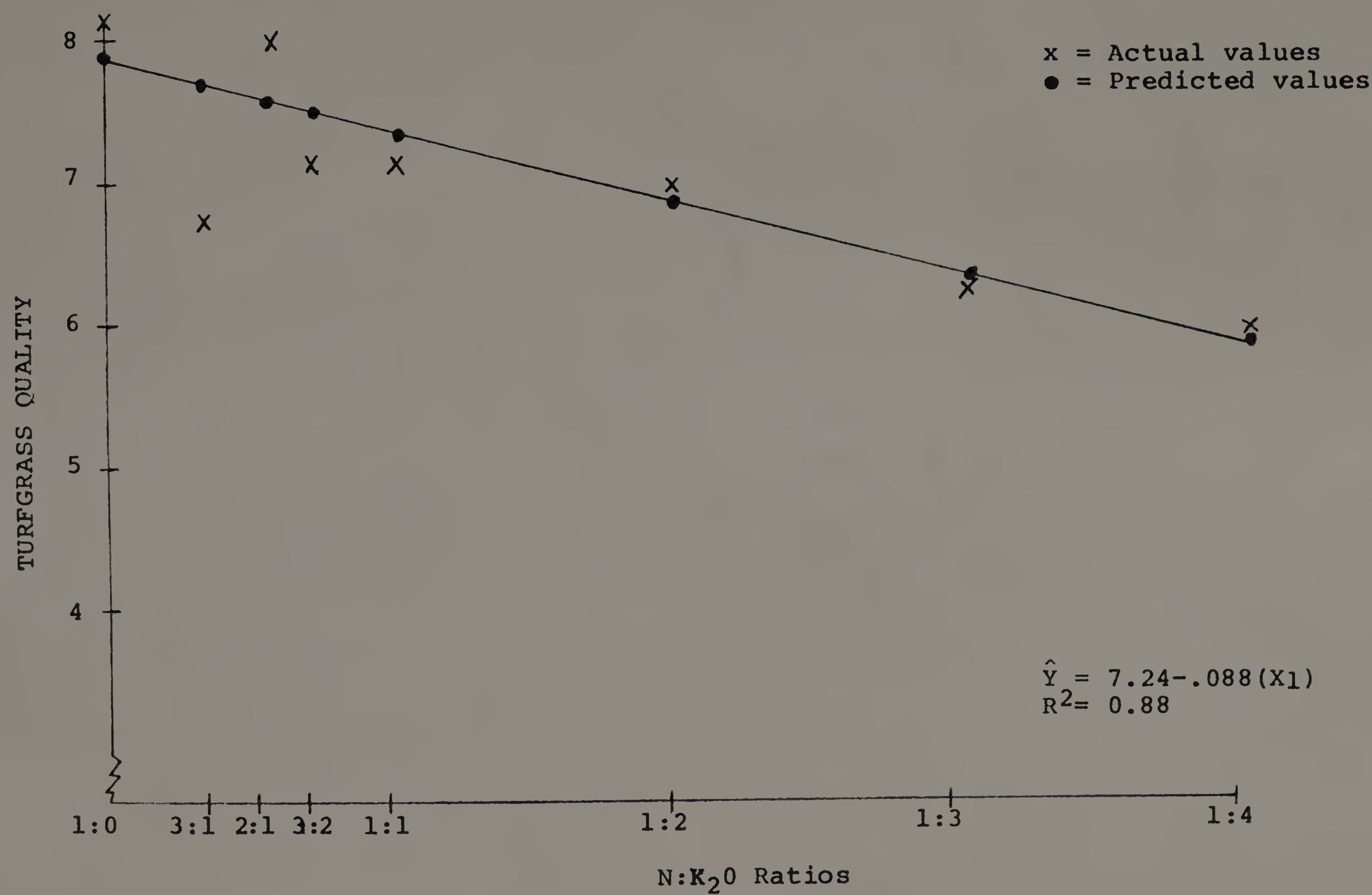


FIGURE 11
$N:K_2O$ RATIOS AND THE QUALITY OF PENNCROSS CREEPING BENTGRASS



Time until wilting occurred was positively correlated to the percent of nitrogen in the plant tissue (Appendix D).

Volumetric soil water content. No significant trends were found among the different N:K_2O ratios and the volumetric water content of the soil when wilting occurred.

Evapotranspiration rates at 72 hours, time until wilt, the percent nitrogen, and the percent potassium in the plant tissue were all negatively correlated to the volumetric water content at wilt. A negative correlation existed between the volumetric soil water content and the concentrations of potassium and salt present in the soil at the termination of the study (Appendix D).

Soil pH, soil potassium, and soil salt concentration. Upon termination of the study, soil samples were taken from each plot, and the pH, concentration of salt, and concentration of soil potassium were determined (Table 12).

With increasing amounts of N:K_2O, from the 1:0 to the 1:4 ratio, the pH of the soil dropped linearly (Figure 12).

Soil pH was positively correlated to the turfgrass quality (Appendix D).

The amounts of potassium and salt determined in the soil increased linearly from the 1:0 ratio to the 1:4 fertilizer ratio (Figures 13 and 14).

Turfgrass quality was negatively correlated to both, soil potassium and soil salt.

A negative correlation existed between soil potassium and the percent calcium and magnesium in the plant tissue, whereas a positive correlation was found with the percent nitrogen in the plant tissue and soil potassium and soil salt (Appendix D).

TABLE 12

EXPERIMENT IV

$N:K_2O$ RATIOS, SOIL pH, SALT CONCENTRATION, AND PPM POTASSIUM FOUND IN THE SOIL AT TERMINATION[1]

K_2O Ratios	Soil pH	Salt Concentration millimhos/centimeter	Soil K ppm
1:0	5.0	0.056	33.5
3:1	4.9	0.063	38.0
2:1	5.0	0.064	40.0
3:2	5.2	0.060	46.0
1:1	5.0	0.063	76.2
1:2	5.0	0.071	85.2
1:3	4.6	0.080	113.5
1:4	4.6	0.084	145.5
Trend	linear**	linear**	linear**
$S_{\bar{x}}$	.152	.005	7.03

1 Data average of four replications/treatment.

** Significant trend at 1%.

FIGURE 12

$N:K_2O$ RATIOS AND THE pH OF THE SOIL

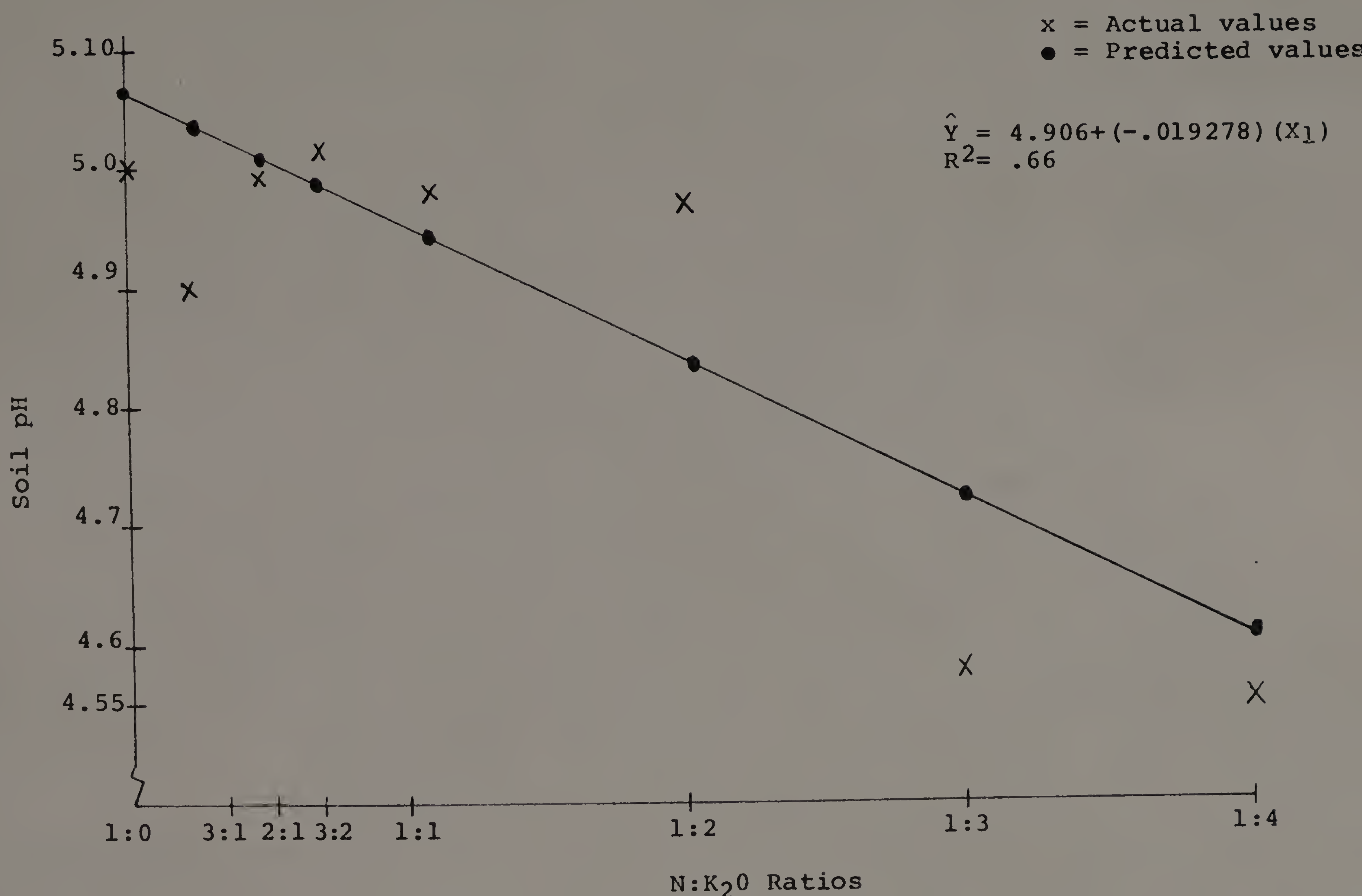


FIGURE 13
$N:K_2O$ RATIOS AND THE SOIL POTASSIUM PPM

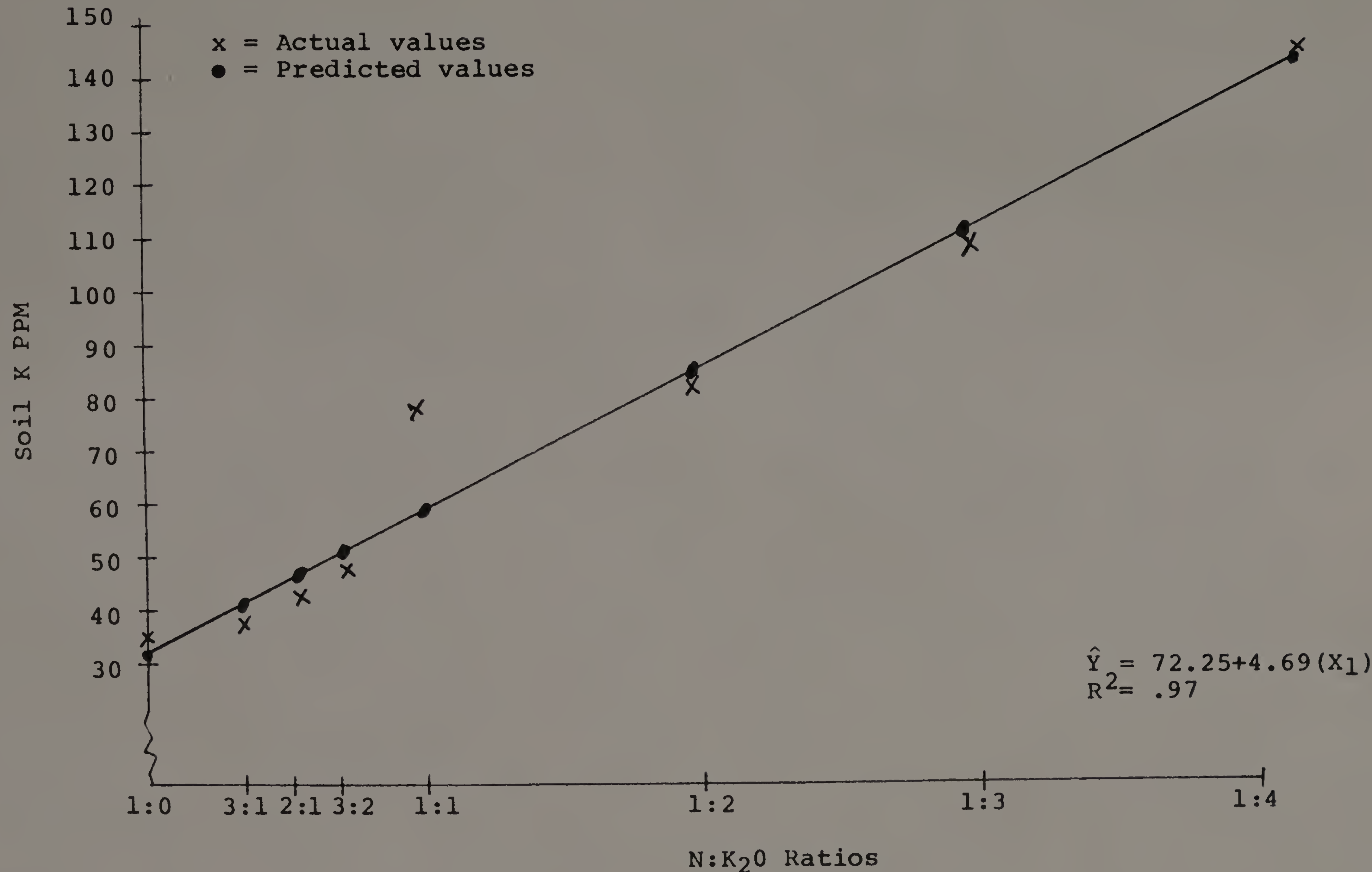
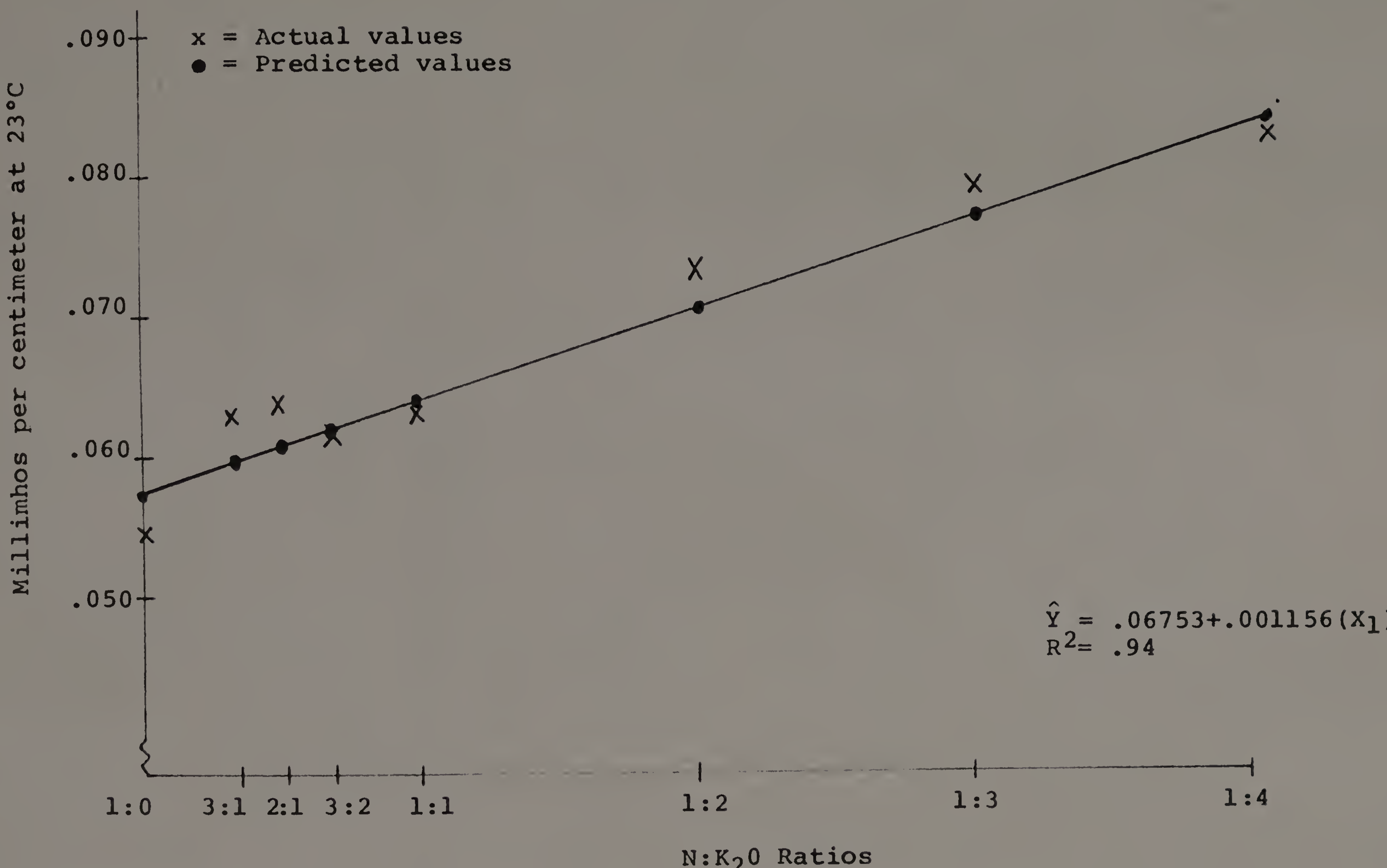


FIGURE 14
$N:K_2O$ RATIOS AND SALT CONCENTRATIONS MEASURED BY ELECTRICAL CONDUCTIVITY



DISCUSSION

CONTROLLED ENVIRONMENT STUDIES

Pilot studies. It appears that when Penncross creeping bentgrass is growing on a sand:peat mix (80:20), which is allowed to drain, wilting will not occur when the media is watered to saturation nightly, and day time temperatures are maintained at 35°C. Wilt was observed only when moisture levels in the growing media reached the wilting point.

Plants growing at 35°C wilted sooner than plants growing at 24°C. Two possible reasons for these results could be: a) with higher air temperatures, an increase in water loss occurred from the soil due to higher evapotranspiration rates; b) with lower air temperatures, 24°C plants had longer root systems, and were able to extract water from greater depths.

Greenhouse study. Applications of potassium fertilizer to a soil has been shown (16,32,62) to cause decreases in the amount of calcium and magnesium in the tissue of grasses. Greenhouse study results were not in agreement with the above. Calcium was found to be positively correlated to the amount of potassium recovered in the plant tissue. This suggests that even with high levels of applied K_2O (1:6) ion uptake for calcium was not restricted. With increased K_2O fertilization there were no significant trends in the amount of nitrogen and phosphorus found in the plant tissue. The amount of potassium in the plant tissue increased linearly as the level of K_2O applied went from the 1:0 to the 1:6 ratio. Maintaining good turfgrass quality (density, uniformity, and color) is probably the most important aim a turf manager tries to achieve. Greenhouse tests appeared to indicate the optimum $N:K_2O$ fertilization ratio for best quality Penncross creeping bentgrass should be the 1:3. Christens _et al_. (15) showed similar results, as the potassium level increased to the 1:3 ratio turf quality improved. Waddington _et al_. (62) noted that turf plots which had not received potassium fertilizer were darker green than plots which had received potassium. However, color is but one factor of quality.

Pots of turf that had been fertilized with the 1:5 and 1:6 ratios formed brown patches. The poor turf quality was not due to restricted root growth. Roots observed for each treatment were equal in length, white, and appeared healthy. A valid explanation for discoloration cannot be given.

Turf which received the 1:3 and 1:4 ratios appeared to be the most drought tolerant. Perhaps potassium levels within the plant tissue permitted better stomatal control, which in turn, may have reduced transpiration. If this occurred the plant water use rate would decrease and the time until wilting could be prolonged. K_2O fertilization increased the potassium ions within the plant which could have raised the plant osmotic pressure and thereby increasing drought tolerance. Iljin (33) stated that plants growing in dryer climates had higher osmotic pressures, than plants growing in milder climates. He further stated that increased osmotic pressures within the plant would allow better soil water movement to plant roots, and to areas within the plant where water is deficient. In addition investigators (6,14,40,48) have noted less severe wilting of turf grasses with increased levels of potassium fertilization.

Potassium fertilization significantly affected the carbohydrate content of the turfgrass. The lowest amount of carbohydrates were found in the plants where the 1:2, 1:3, and 1:4 N:K_2O ratios were applied. This suggests that turf that received these fertilizer ratios may have been more actively growing than turf receiving the 1:0, 1:1, 1:5 and 1:6 ratios. It has been shown by researchers (47,63) that potassium fertilization has led to an increase in the foliear growth of Penncross creeping bentgrass and Kentucky bluegrass. In contrast, Zanoni (71) found potassium fertilization produced no differences in the carbohydrate content of creeping bentgrass.

DISCUSSION

FIELD STUDIES 1980 AND 1981

Field study 1980. The 1980 field study results showed that as the level of applied potassium was increased from the 1:0 to the 1:4 ratio a highly significant increase in the amount of potassium recovered in the plant tissue occurred. However, no significant differences for any of the other nutrients investigated was noted (N, P, Ca, Mg, fructosan). The relative small amounts of nitrogen and K_2O applied to the turf throughout the growing season may have accounted for the lack of effect on the other elements and carbohydrate levels.

Field study 1981. The 1981 field study indicated that increases in potassium fertilizer decreased the calcium and magnesium in the plant tissue. Sharp drops in the levels of Ca and Mg existed between the 1:0 and 1:1 ratios and again between the 1:3 and 1:4 ratios. Such sharp drops possibly indicate that calcium and magnesium uptake is inhibited within a range of certain $N:K_2O$ ratios. Inhibition occurred between the 1:0 and 1:1 ratio, and again at the 1:3 ratio (Figures 8 and 9). Other researchers (16, 32,62) observed that increases in potassium fertilization decreased the calcium and magnesium content recovered in plant tissue.

Increased K_2O fertilization produced no significant changes in the phosphorus content of the plant tissue. This was not the case for nitrogen, where a significant quadratic trend was observed. The highest amounts of nitrogen were found in plants from the treatment plots receiving the lowest (1:0) and the highest (1:3 and 1:4 ratios). Plants which contained the least amount of tissue nitrogen were those that received the 3:2, 1:1, and 1:2 $N:K_2O$ ratios. Both the 1:3 and 1:4 ratios produced plants which contained more tissue nitrogen than any of the other ratios studied, including the 1:0. Waddington et al. (62) observed that potassium fertilization led to reduction in the nitrogen content of Penncross creeping bentgrass. But, the rates of potassium they used did not exceed the amount of nitrogen applied. Perhaps the increase in nitrogen found in the plants that received the 1:3 and 1:4 ratios may have been due to decreased growth which permitted an increase in nitrogen accumulation in the plant.

No significant changes in the carbohydrate content of the turf, as related to the $N:K_2O$ ratios, were found. This may indicate that there were no differences in foliar growth among treatments. If a difference did occur, one would expect topgrowth growing at a faster rate to be lower in carbohydrates. Zanoni (71) observed similar results. He showed that potassium fertilization had no effect on the carbohydrate levels of Penncross creeping bentgrass.

Turf that received the 1:0 $N:K_2O$ ratio was darker green in color than plots which received the higher $N:K_2O$ ratios. Chlorosis occurred in plots that received the 1:3 and 1:4 ratios. Yet, the plants treated with either of these ratios contained the greater percent of nitrogen in their tissue. It appears that the chlorosis was not due to a nitrogen deficiency. The discoloration of the turf, with increasing levels of potassium, was not due to high salt concentrations in the soil. The salinity tolerance of creeping bentgrass (as measured by electrical conductivity) should be between 8 and 16 millimhos/centimeters (6). The salt concentration of the soil for the 1:4 ratio, at the conclusion of the field study was only 0.08 millimhos/ centimeters (Table 11).

The chlorosis that occurred could be attributed to a magnesium deficiency in the plant tissue, as the $N:K_2O$ ratios increased. Madison (40) reported that the percent Mg on a dry weight basis of bentgrass, should be between 0.25 and 0.75%, which is higher than the percentages found in the 1:3 and 1:4 treated stands (Table 10). Hewitt and Smith (30) stated that at least 10% of the total leaf magnesium is incorporated in chlorophyll. They also noted that if a deficiency of magnesium exists chlorosis will occur.

The possibility of potassium effecting stomatal densities on grass blades was investigated. The results showed that increases in K_2O fertilization did not significantly effect stomatal densities on the adaxial leaf surface. However, significant linear decreases in stomatal densities on the abaxial leaf surface were found with increases in $N:K_2O$ ratios from the 1:0 to 1:4. Meusal (44) working with Poa and Agrostis species observed that plants with higher stomatal densities wilted first under drought conditions.

Transpiration rates were measured every 24 hours, during a 72 hour period, and no significant trends were found related to any of the fertilizer ratios or time periods. These results differ from observations of other investigators (14,48), who stated that the transpiration rates are enhanced by low potassium.

Under drought conditions as the $N:K_2O$ ratios increased, no significant trends existed in prolonging time until wilt occurred. However, turf plots that received potassium did not wilt as quickly as turf that did not receive potassium (1:0). This is in accordance with other researchers (48, 14,3,40,6) who found similar results.

The water content of the soil at the time of wilt for each plot was determined on a percent or volumetric basis. It is hypothesized that increased K_2O fertilization may lead to an increase in the concentration of potassium ions within the plant. This would allow for an increase in the water extracting power of the turf resulting in less moisture in the soil at the time of wilting. Iljin (33) stated that plants with higher osmotic pressures extract more water from the growing media. However, no significant differences in the volumetric water content of the soil were observed when wilting occurred.

No significant trends in root lengths were noted as related to the $N:K_2O$ ratios. These results can be attributed to the condition of the sand media. It was highly compacted and the root growth was inhibited from extending beyond aerification holes.

At the conclusion of the field study, soil tests were conducted to determine the pH, salt concentration, and potassium concentration. Linear increases in the amount of soil potassium and the concentration of salt were observed as ratios of $N:K_2O$ increased from the 1:0 and 1:4. Increases in the concentration of salt were no doubt due to the increases of applied KCL to the soil.

Soil pH was found to slightly decrease linearly as the amount of potassium fertilization was increased. A valid explanation cannot be given. Brady (10) has stated that KCL should not effect soil pH.

DISCUSSION

A COMPARISON BETWEEN CONTROLLED ENVIRONMENT STUDIES AND FIELD STUDIES

Results of experiments performed in controlled environment studies may not be the same compared to those conducted in the field. A few variables which could account for differences in the results obtained between controlled environment studies and field studies are: a) different light intensities; b) different CO_2 concentrations; c) different seed sources; d) differences in turf maturity and; e) differences in the physical and biological characteristics of the growing media. Another important possibility for the differences in the results between studies could be related to nutrient rates. Terman and Mortvedt (7) found that nutrient rates adequate for corn in small greenhouse pot studies are much higher than rates equivalent to normal rates recommended for crops grown under field conditions.

In the experiments investigated calcium levels in the plant tissue increased with increasing K_2O in the growth chamber studies. While in the field experiments the percentage of calcium decreased as the level of K_2O was increased. No significant differences were found in the magnesium content in the turfgrass tissue in controlled environment studies, but in field studies the percent magnesium was found to decrease as the rate of applied K_2O was increased.

Fructosan levels exhibited a significant quadratic trend in growth chamber studies, but in the field experiments the levels of carbohydrates was not significantly affected.

Turfgrass quality for plants in the field decreased with increasing amounts of K_2O. The opposite was observed for turf growing in controlled environment studies.

SUMMARY AND CONCLUSIONS

The primary cause for wilting of Penncross creeping bentgrass at 35°C in soils which drain freely appears to be attributed to the depletion of soil water. High temperatures (35°C) increased the rate of water loss from the soil, thus decreasing the time until wilt occurred. It was also noted that high temperature caused a reduction of root growth.

Increased K_2O fertilization to field plots led to a decrease in the calcium and magnesium content of the turfgrass tissue. Turfgrass quality decreased in field plots as the rate of potassium fertilization increased. Increasing $N:K_2O$ ratios showed no significant effects on evapotranspiration rates, root lengths and soil water use rates of Penncross creeping bentgrass.

Stomatal densities were found to decrease significantly as the ratios of $N:K_2O$ increased on the abaxial leaf surface, while no significant differences were observed on the adaxial leaf surfaces.

No significant trends were seen for prolonging time until wilt occurred on field plots as the rate of $N:K_2O$ was increased. However, potassium fertilization (3:1-1:4) versus no potassium (1:0) was found to approach the level of significance (between 5-10%) in regards to increasing the time until wilting occurred. This would indicate that the higher rates of potassium applied were not important in increasing the time until wilt. The ratio of 3:1 would probably be the best because this did give the optimum drought tolerance and good quality Penncross creeping bentgrass stand.

Results obtained in controlled environment studies cannot be assumed to be the same which are found in field experiments.

More field research is needed to determine the optimum frequencies in which potassium fertilizers should be applied to Penncross creeping bentgrass to increase drought tolerance and at the same time produce the best quality turfgrass stand.

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APPENDIX A

PARTICLE SIZE ANALYSIS OF SANDS USED FOR SOIL MIXES

Sieve Sizes mm	Pilot Study & Experiment 2* Percent	Experiment 3 & 4 Percent
2.00	4	0
2.00 - 1.00	10.8	0.1
1.00 - 0.50	26.2	0.6
0.50 - 0.25	37.0	1.3
0.25 - 0.10	17.6	43.8
0.10 - 0.05	1.0	53.0

* Mixed with peat to make a mixture of 80%:20% sand:peat (v/v).

APPENDIX B

CORRELATION MATRIX GREENHOUSE STUDY

	Percent K	Quality Rate	Time to Wilt	Fresh wt.	Dry wt.
Percent K	1.0000				
Quality Rate	-0.1431	1.0000			
Time to Wilt	0.6479**	0.2182	1.0000		
Fresh wt.	0.0794	0.3401	0.2889	1.0000	
Dry wt.	-0.0531	0.4569*	0.2255	0.8988**	1.0000
Percent N	0.1119	-0.2387	-0.0672	-0.6352**	-0.7600**
Percent Fruc.	-0.2184	-0.2538	-0.4621*	-0.1669	-0.2512
Percent P	0.0652	-0.3719	-0.1091	-0.7576	-0.8454**
Percent Mg	-0.1218	-0.3390	-0.2074	-0.4322*	-0.5723**
Percent Ca	0.4353*	-0.3857*	0.2639	-0.3665*	-0.5552**

APPENDIX B

CORRELATION MATRIX GREENHOUSE STUDY (CONTINUED)

	Percent N	Percent Fruc.	Percent P	Percent Mg	Percent Ca
Percent K					
Quality Rate					
Time to Wilt					
Fresh wt.					
Dry wt.					
Percent N	1.0000				
Percent Fruc.	-0.0415	1.0000			
Percent P	0.7491**	0.1130	1.0000		
Percent Mg	0.6048**	0.1446	0.5196**	1.0000	
Percent Ca	0.6670**	0.0059	0.6067**	0.6996**	1.0000

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

APPENDIX C

CORRELATION MATRIX FIELD STUDY 1980

	Evapo-trans.	Quality	Time to Wilt	Fresh wt.	Dry wt.	Percent N
Evapotrans.	1.0000					
Quality	0.3095	1.0000				
Time to Wilt	0.0060	-0.1329	1.0000			
Fresh wt.	-0.0126	0.2369	0.4387*	1.0000		
Dry wt.	-0.1393	0.1827	0.4018*	0.9180**	1.0000	
Percent N	-0.2442	0.0328	-0.4311*	-0.3839*	-0.3544*	1.0000
Percent K	0.0828	0.1460	0.0893	0.0642	0.1465	0.2686
Percent P	0.1743	0.0311	-0.1744	-0.2361	-0.3551*	0.1885
Percent Mg	-0.0651	-0.0498	0.2724	0.0770	0.0695	0.1083
Percent Ca	-0.1021	-0.3957*	0.3592*	-0.0571	-0.0616	-0.0117
Percent Fruc.	-0.1909	-0.1412	0.1414	-0.2033	-0.0750	0.1549

APPENDIX C

CORRELATION MATRIX FIELD STUDY 1980 (CONTINUED)

	Percent K	Percent P	Percent Mg	Percent Ca	Percent Fruc.
Evapotrans.					
Quality					
Time to Wilt					
Fresh wt.					
Dry wt.					
Percent N					
Percent K	1.0000				
Percent P	0.1097	1.0000			
Percent Mg	-0.0777	0.4168*	1.0000		
Percent Ca	0.1795	0.4297*	0.6269**	1.0000	
Percent Fruc.	0.2877	-0.1411	-0.0547	-0.0773	1.0000

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

APPENDIX D
CORRELATION MATRIX FIELD STUDY 1981

	Quality	Evapo. 24 hrs.	Evapo. 48 hrs.	Evapo. 72 hrs.	Stomates Adaxial	Stomates Abaxial
Quality	1.0000					
Evapo. 24 hrs.	0.1077	1.0000				
Evapo. 48 hrs.	0.0407	0.7443**	1.0000			
Evapo. 72 hrs.	-0.0288	0.6342**	0.9286**	1.0000		
Stomates Adaxial	-0.0298	-0.1211	-0.1199	-0.0914	1.0000	
Stomates Abaxial	0.3154	-0.3314	-0.3090	-0.3121	0.4550*	1.0000
Root Length	0.1171	-0.0668	-0.1428	-0.1517	-0.1275	0.1641
Time to Wilt	0.1115	0.1953	0.1870	0.2178	-0.0377	-0.2379
Percent N	-0.1605	0.0830	0.0665	0.0781	-0.0807	-0.2534
Percent K	-0.6789**	-0.0209	-0.0725	0.0172	-0.1322	-0.5263**
Percent P	0.1063	0.2769	0.2705	0.2238	-0.1644	-0.3113
Percent Mg	0.7438**	0.0209	-0.0854	-0.1119	0.0943	0.4468*
Percent Ca	0.6520**	-0.0578	-0.2020	-0.2458	0.0456	0.3513*
Percent Fruc.	0.0569	-0.0585	-0.1893	-0.2436	0.2545	0.0241
pH	0.4044*	0.5686**	0.5162**	0.3974*	-0.0378	0.1055
Soil K	-0.7517**	-0.0758	0.0426	0.1455	-0.2156	-0.3921
Salt	-0.4546**	-0.0826	0.0171	0.1360	-0.0726	-0.3422
Soil θ	0.3531	-0.0875	-0.3386	-0.4596*	-0.0047	0.1489

APPENDIX D

CORRELATION MATRIX FIELD STUDY 1981 (CONTINUED)

	Root Length	Time to Wilt	Percent N	Percent K	Percent P	Percent Mg
Quality						
Evapo. 24 hrs.						
Evapo. 48 hrs.						
Evapo. 72 hrs.						
Stomates Adaxial						
Stomates Abaxial						
Root Length	1.0000					
Time to Wilt	0.3471	1.0000				
Percent N	0.3334	0.4323*	1.0000			
Percent K	0.2068	0.2682	0.5311**	1.0000		
Percent P	0.2417	0.2637	0.4994**	0.2494	1.0000	
Percent Mg	0.0482	-0.0439	-0.1127	-0.6080**	0.0394	1.0000
Percent Ca	0.0266	-0.0126	-0.0768	-0.4091*	0.0479	0.7021**
Percent Fruc.	-0.1536	-0.1057	0.0252	-0.0938	-0.1722	-0.0852
pH	-0.0348	0.1458	-0.1509	-0.4181*	0.2047	0.3556*
Soil K	0.1616	0.2128	0.5188**	0.8410**	0.1179	-0.6928**
Salt	0.2621	0.4667**	0.4898**	0.6877**	0.2268	-0.3374
Soil θ	-0.0536	-0.4236*	-0.3774*	-0.3506*	0.0541	0.0985

APPENDIX D

CORRELATION MATRIX FIELD STUDY 1981 (CONTINUED)

	Percent Ca	Percent Fruc.	pH	Soil K	Salt	Soil θ
Quality						
Evapo. 24 hrs.						
Evapo. 48 hrs.						
Evapo. 72 hrs.						
Stomates daxial						
Stomates Abaxial						
Root Length						
Time to Wilt						
Percent N						
Percent K						
Percent P						
Percent Mg						
Percent Ca	1.0000					
Percent Fruc.	0.1361	1.0000				
pH	0.1865	0.0245	1.0000			
Soil K	-0.5919**	-0.1417	-0.2820	1.0000		
Salt	-0.4225*	-0.2296	-0.2065	0.7081**	1.0000	
Soil θ	0.2409	0.0897	0.0236	-0.4501*	-0.4327*	1.0000

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.