Winter 1976

EFFECT OF NITROGEN - POTASSIUM RATIOS AND NITROGEN SOURCE ON NUTRIENT UPTAKE AND ROOT AND SHOOT GROWTH OF MERION KENTUCKY BLUEGRASS AND PENNCROSS CREEPING BENTGRASS

WILLIAM EDWARD KNOOP

77-10,260

KNOOP, William Edward, 1936-
EFFECT OF N-K RATIOS AND N SOURCE ON NUTRIENT UPTAKE AND ROOT AND SHOOT GROWTH OF MERION KENTUCKY BLUEGRASS AND PENNCROSS CREEPING BENTGRASS.

University of New Hampshire, Ph.D., 1976
Agriculture, plant culture

Xerox University Microfilms, Ann Arbor, Michigan 48106

EFFECT OF N-K RATIOS AND N SOURCE ON NUTRIENT UPTAKE AND ROOT AND SHOOT GROWTH OF MERION KENTUCKY BLUEGRASS AND PENNCROSS CREEPING BENTGRASS

by

WILLIAM EDWARD KNOOP

B.S., Iowa State University, 1965

M.S.A., University of Florida, 1969

A THESIS

Submitted to the University of New Hampshire

In Partial Fulfillment of

The Requirements for the Degree of

Doctor of Philosophy

Graduate School

Department of Plant Science

December, 1976

This thesis has been examined and approved.

Thesis director, George O. Estes, Assoc. Prof. of Plant Science

Lincoln C. Peirce, Prof. of Plant Science

G. Thomas Fisher, Assoc. Prof. of Entomology

Nobel K. Peterson, Assoc. Prof. of Soil and Water Science

Douglas G. Routley, Prof. of Plant Science

William E. MacHardy, Asst. Prof. of Plant Pathology

ACKNOWLEDGEMENTS

The writer wishes to express sincere appreciation and gratitude to Dr. George O. Estes, Associate Professor, Department of Plant Science, University of New Hampshire, for his guidance and encouragement throughout this study.

Appreciation is also extended to: Drs. G. T. Fisher, R. D. Harter, L. C. Peirce, A. E. Rich and D. G. Routley for their assistance, Mr. Lucien Duval, Golf Course Superintendent, Manchester Country Club, for the use of his nursery for the field part of this study, Mr. Dominic Morales and Mr. Steve Robley for their assistance in the greenhouse, and my wife, Elaine, for her patience and encouragement.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

EFFECT OF N-K RATIOS AND N SOURCE ON NUTRIENT UPTAKE AND ROOT AND SHOOT GROWTH OF MERION KENTUCKY BLUEGRASS

by

WILLIAM EDWARD KNOOP

The shoot and root growth and chemical composition of Merion Kentucky bluegrass (*Poa pratensis* L. var. Merion) were studied in the greenhouse under nine different N-K treatments using solution culture techniques. Significant differences existed with respect to dry weight of foliage and roots and chemical composition of foliage. The highest foliar weights resulted from the 60 ppm N-60 ppm K treatment and the highest root weight resulted from the 10 ppm N-60 ppm K treatment.

Significant differences were observed in the accumulation of N, P, K, Ca, Mg, Cu, Fe, Mn and Zn in the foliage.

The chemical composition of Penncross creeping bentgrass (*Agrostis palustris* Huds. var. Penncross) was studied in the field under six fertilizer treatments over two growing seasons. Significant differences were observed in the foliar levels of N. The application of fertilizers containing higher levels of slowly soluble N resulted in fairly uniform levels of N in the foliage during both growing seasons. Foliar levels of N in plants supplied with fertilizers lower in slowly soluble N decreased during both seasons. There were few treatment differences in foliar levels of P, K, Ca, Mg, Cu, Fe, Mn and Zn with the exception of the 6-3-0 which did produce higher foliar levels of Cu, Fe, Mn and Zn.

A general increase in all foliar levels of P in the second year of the study suggested that application rates for that element were excessive.

INTRODUCTION

The turfgrass industry plays an important part in agriculture by providing an essential ingredient for the maintenance and modification of functional and aesthetic environments. Turf is recognized for its function in creating beauty within the landscape. The true value of turf is difficult to estimate because of problems in assigning monetary values to aesthetics.

Each year millions of dollars are spent on the establishment and maintenance of turfgrasses. Basic to turfgrass maintenance is the provision of mineral nutrients necessary for the support of root and shoot growth rates that will enable the turfgrass plant to withstand the heavy use associated with todays recreational functions. In the past few years fertilizer costs have increased at a rapid rate. We are also becoming more aware of the potential pollution problems associated with excessive fertilizer use.

Turfgrass nutrition research should be concerned with determining nutritional programs that will supply the plant with optimum levels of nutrients. The objectives of this study are twofold. The first part is concerned with the effect of various ratios of nitrogen to potassium on the balance between root and shoot growth. The second part is concerned with an evaluation of the tissue levels of selected nutrients which result from the application of five commercially available fertilizers applied at the manufacturers recommended rate of application.

REVIEW OF LITERATURE

EFFECT OF N AND K ON THE GROWTH OF TURFGRASS

At low N levels in the growing medium carbohydrates are primarily used for root growth; at higher N levels, the carbohydrates are used to form amino acids needed for the increased protein demands of high shoot growth rates (3, 25). With excessively high N levels, turfgrass may experience impaired root growth along with increased thatch, increased disease incidence, reduced rhizome or stolon growth, reduced winter hardiness and increased tendency to wilt (3, 14, 23, 25).

Madison (25) indicates that K exerts a regulatory effect on the use of N in protein production. Beard (3) has reported increased root growth of turfgrasses in general at higher K levels. He suggests that plants with high K levels have increased leaf turgor pressure, reduced incidence of disease and increased wear tolerance (3). Smaller root systems have been observed by Liebhardt (22) in plants that are deficient in K. He attributes this to the development of K deficiencies in the lower leaves which supply photosynthate to the root system. Teel (37) points out that there is increased utilization of amino acids in protein synthesis at high K levels.

EFFECT OF N:K RATIOS ON TOP GROWTH

Pellett and Roberts (32) in a solution culture study found the highest growth rates of Kentucky bluegrass resulted when the nutrient solution contained 102 ppm N and 63 ppm K compared to either 11 ppm N or 11 ppm K. Griffith *et al*. (15) obtained the highest yield of orchardgrass with an application of 300 pounds of n/acre and either 166 or 332 pounds of K per acre. No difference in yield was reported between the two rates of K as long as the N rate was 300 pounds per acre. In another study of orchardgrass, Kresge and Younts (19) found that the highest yield resulted from an application rate of 200 pounds N and 83 pounds K per acre. They indicated that a 2.4:1 ratio of N to K produced the best foliar growth rate regardless of N rate. The same workers (18), in a study of bluegrass as a forage crop noted the highest yield resulted from an application of 160 pounds N and 166 pounds K per acre. MeLeod (24), in a study of pasture grasses obtained the highest yield with 200 pounds N and 100 pounds K per acre. These studies indicate the presence of a relationship between N and K application rates and the amount of foliar growth. Soil was the growth medium in most of these studies and, because of the complex interactions between plant nutrients and the clay fraction of the soil, it is difficult to attribute the growth effects entirely to applied N or K. Pellett and Roberts (32) used combinations of only two levels of N (102 and 11 ppm) and two levels of K (63 and 10 ppm). Their study did not include treatments that would provide the plant with equal concentrations of N and K at the higher rates. In a solution culture study of bermudagrass and bahiagrass, the deletion of N from the nutrient solution had a greater effect in reducing the yield of either grass than did the deletion of either P or K (17).

EFFECT OF N:K RATIOS ON ROOT GROWTH

The root growth of turfgrasses is more important than in most economic crops because of its relationship to wear and drought tolerance (3). Shallow rooted turfgrass will not survive the same traffic intensity as will deeper rooted turfgrasses, and deeper rooted turfgrasses have a greater part of the soil profile from which to obtain water and nutrients.

Wright (43), in a root study of blue panicgrass grown on a Gila sandy loam, reported that plants receiving applications of 525 pounds N and 350 pounds K per acre had greater root weights than plants receiving 875 pounds of N and either 0 or 350 pounds of K per acre.

In a nutrient solution study of perennial ryegrass Adams et al. (1) found that the roots of the plants receiving N-K at a ratio of 5:1 had the lowest length and weight while plants receiving N-K at a 1:2 ratio had the greatest root length and weight.

EFFECT OF N:K RATIOS ON SHOOT/ROOT RATIOS

Using shoot/root ratios of perennial ryegrass as an indicator of nutrition response Vose (39) found that the ratio increased with increasing levels of N regardless of the K level of the nutrient solution. The highest shoot/root ratio resulted when plants were maintained on a nutrient solution containing 126 ppm N and 90 ppm K. In another nutrient solution study Monore et al. (30) found that Kentucky bluegrass plants receiving 130 ppm N and 200 ppm K had the greatest dry weight of clippings while those receiving 65 ppm N and 100 ppm K had the greatest dry weight of roots. Lawton and Tesar (21) obtained the highest top weight and root weight from bromegrass plots, grown in a Hillsdale sandy loam that received 320 pounds of N and 484 pounds of K per acre. McLean (27), using a one-fifth concentration of Hoagland solution, found that oat plants receiving lower levels of N produced the greatest root weight; plants receiving the higher levels of N had the greatest top weights.

Although, as noted, several studies have been concerned with the effect of N-K ratios on foliar growth or on root growth, few studies (21, 27, 30, 39) have been concerned with the effect of N-K ratios on the ratio of shoot-root growth. Monroe et al. (30) did study these effects, but they did not include any N levels lower than 65 ppm nor any K levels lower than 100 ppm.

NUTRIENT INTERACTIONS

Nutritional studies, in general, have indicated that the presence or absence and the concentration of a nutrient ion has an effect on the uptake of other nutrient ions.

Nitrogen vs. Phosphorus

Nitrogen has been reported to decrease, have no effect on, or increase the uptake of phosphorus. Eheart and Ellett (9) in a study of pasture grasses found that as applied N was increased, tissue P decreased. Fagan and Watkins (11) studying pasture grasses also found a decrease of tissue P in plants receiving N compared with plants receiving no fertilization. Evans *et al*. (10) reported that the rate of N application had little effect on P content of Coastal bermudagrass when applied at 0, 150 and 600 pounds of N per acre per year, but P content of Pensacola bahiagrass decreased with increasing rates of N. Walker and Pesek (41), working with Kentucky bluegrass, found that the P content was high when a fertilizer containing P was used, and was still higher in the absence of N. Burton and De Van (6) reported no significant differences in P content of bermudagrass at N levels from 0 to 400 pounds per acre. The P content of carpetgrass, as reported by Blaser and Stokes (4), was higher in samples taken from an unfertilized plot than from plots receiving only N or those receiving both N and K.

Nitrogen vs. Potassium

Workers have reported varied interactions between N and K in the growth of grasses. Washko (42), in a nutrient solution study varying K from

5 to 320 ppm, found little difference in percentage of N in bromegrass as a result of applied K. Ramage et al. (34) determined that the level of N had little effect on the K content of orchardgrass, but in reed canarygrass, fertilization with N from 50 to 400 pounds per acre produced a decrease in K. Fagan and Watkins (11) found that pasture grasses given only N fertilizer contained smaller amounts of K than unfertilized grass. Blaser and Stokes (4) also found that N fertilization of carpetgrass depressed the absorption of K. Variation among species in the N:K interaction is further illustrated by the fact that the K content of bermudagrass changed little under different levels of N fertilization according to Burton and De Van (6). Walker and Pesek (41) noted the same lack of difference in K content under different N levels in Kentucky bluegrass. Evans et al. (10) reported that K content of Coastal bermudagrass was higher when 150 pounds N per acre was applied than when no fertilizer was applied. As the N rate was increased to 600 pounds of N per acre, the K content of the leaves dropped. Monroe et al. (30) noted the highest tissue levels of N in Kentucky bluegrass occurred in a nutrient solution study when no K was supplied. The highest K levels in tissue in the same study resulted from the addition of 130 ppm N and 200 ppm K to the nutrient solution.

In a nutrient solution study supplying annual ryegrass with both the NH_4 and NO_3 forms of N, nutrient solution, Nielsen and Cunningham (31) found that neither form significantly influenced the uptake of K.

Turfgrasses require higher levels of N and K than of any other essential nutrients. It is apparent than an interaction between N and K does exist in many grass species. To evaluate the nutrient requirements for Merion Kentucky bluegrass it is essential to determine the relationship between N and K and the effect of that relationship on growth and the levels of other nutrients.

Phosphorus vs. Potassium

Washko (42) found that K depressed P levels in bromegrass tissue. Fagan and Watkins (11) also reported that a reciprocal relationship existed between K and P levels. Walker and Pesek (41) in work with Kentucky bluegrass, and Blaser and Stokes (4) with carpetgrass reported the same interaction between P and K.

Other workers (8, 12) have reported that increased levels of K in the plant may reduce foliar growth rates and rates of respiration, both processes requiring relatively large amounts of P.

Calcium and Magnesium

Burton and De Vane (6) found no significant differences in Ca content of bermudagrass at N (NH_4NO_3) application rates from 0 to 400 pounds per acre per year. Conversely, Eheart and Ellett (9) found that as N levels increased from 0 to 150 pounds per acre the percentage of Ca decreased in pasture grass. Washko (42) reported that as K was raised from 5 to 320 ppm in the nutrient solution the percentage of Ca in bromegrass tissue decreased. Fagan and Watkins (11) found the highest percentage of Ca in tissue of pasture grass when P was the only nutrient added to plots although the addition of only N or only K did increase the percentage of Ca in the grass.

Prince (33), in a study of annual ryegrass grown on a Cecil sandy loan soil, found that both the Ca and Mg content of the foliage decreased as the N (NH_4NO_3) application rates increased from 30 to 90 pounds N per acre; as K rates increased from 40 to 120 pounds K_20 per acre Ca and Mg levels in foliage were also reduced. Knoop (17) found that the removal of N from the nutrient solution had no effect on the Ca and Mg levels of either bermudagrass or bahiagrass, but tissue levels of Ca and Mg increased when K was removed from a complete nutrient solution. The interaction of K, Ca and Mg was also shown in a study by Vicinte-Chandler et al. (38) with pangolograss grown in Fajardo clay, in which both Ca and Mg levels in tissue decreased as the application rate of K was increased from 0 to 1600 pounds per acre per year. In a soil study of Coastal bermudagrass, Landua et al. (20) found the tissue levels of Mg decreased with increasing applied levels of K. In a study of Penncross creeping bentgrass grown in a Hagerstown silt loam, Waddington et al. (40) also reported a decrease in both Ca and Mg as K rates were increased.

Most turfgrass studies have not considered the relationship between shoot and root growth as affected by nutritional levels. Those that have, have not investigated this relationship at low N and K levels. This study proposed to do that as well as evaluate the influence of N and K on the uptake of other selected nutrient ions.

EFFECT OF N SOURCE ON CHEMICAL COMPOSITION

A turfgrass plant requires more N than any of the other essential plant nutrients (3). University turfgrass specialists and fertilizer companies have made recommendations that range from 2 to 8 pounds of N per 1000 square feet per year. These recommendations usually suggest that the N source to be a combination of soluble and slowly soluble sources. According to Davis (7), N sources may be classified as either soluble (those that are quickly soluble in water) or slowly soluble (those that require some microbiological and/or soil chemical action before the N is converted to a usable form).

Soluble N sources include urea, $(NH_4)_2SO_4$, NH_4NO_3 and $Ca(NO_3)_2$. They have a low dependency on temperature for availability but have a high leaching potential. Also, although they produce a rapid initial plant response the plants become more sensitive to foliar burn. In comparison the slowly soluble sources such as the natural organics and urea formaldehyde produce a slower initial growth response, have a lower foliar burn potential, are somewhat dependent on temperature for availability and are less likely to leach. Many workers (3, 16, 18, 26, 31, 35, 40) have reported higher tissue levels of N in plants receiving N from a soluble source than in plants supplied N from a slowly soluble source. Gilbert et al. (13) and Kresge and Younts (18) indicated an increase in the yield of bluegrass fertilized with a soluble N source compared with a slowly soluble N source. However, yield does not represent the plant characteristic of major importance in turf management. Uniform growth, stand density and, to a lesser degree, color are very important. The most intensely managed turf is the golf course putting green. The turfgrass manager is interested in a nutritional program that will furnish the plant with a uniform supply of nutrients and thus produce a uniform growth during the season. Moberg et al. (29) suggests that uniform growth can be obtained on turfgrass using frequent light applications of soluble N or fewer, heavy applications of slowly soluble N.

In a study using combinations of soluble and slowly soluble N sources, Boeker and von Boberfeld (5) found no significant difference in root depth or weight in their two-year study of turfgrass mixtures on a sandy loam soil.

There are a number of commercial fertilizers available for use on turfgrass. The ratios of N-P-K vary with nearly every material as do their recommended rates of application. The field part of this study was designed basically to determine what effect several commercial fertilizers may have on the levels of selected essential plant nutrients in foliage over two growing seasons.

MATERIALS AND METHODS

Nutrient studies were conducted with two commercially important turfgrasses to evaluate plant response and tissue nutrient composition. To investigate the N requirements of Merion Kentucky bluegrass (Poa pratensis L. var. Merion), a hydroponic experiment was conducted in the Plant Science research greenhouse, Durham, N.H., in 1972. A field study to determine changes in growth and elemental concentration in tissue of Penncross creeping bentgrass (Agrostis palustris Huds. var. Penncross) was conducted in an established nursery in 1972 and 1973 at the Manchester Country Club, Manchester, N.H.

GREENHOUSE STUDY

A 3 x 3 factorial experiment in a randomized block design with four replications was established to test the effects of three levels of N and three levels of K on the growth and chemical composition of Merion Kentucky bluegrass.

Solution culture techniques similar to those used by Pellett and Roberts (32) were used. Each culture unit consisted of a glazed two-gallon crock and a black plexiglass lid used to support 102 cm^2 of sod. Levels of the N-K treatments were: 10, 60 and 110 ppm N and 10, 60 and 110 ppm K (Table 1). Solutions were aerated with air stones receiving a constant, rate-controlled supply of air.

Merion Kentucky bluegrass was established by seed on January 31, 1972 at a rate of 1.9 kg per 100 m^2 and grown on a complete nutrient solution including 60 ppm N and 60 ppm K until June 13, when differential treatments were applied (Table 2). Ammonium nitrate was chosen as the N source and

Table 1. Hydroponic culture treatments and nutrient sources for the greenhouse study. Values represent nutrient level as ppm elemental form

NUTRIENT SOURCE	NUTRIENT	TREATMENT 1	2	3	4	5	6	7	8	9
NH_4NO_3	N	10	10	10	60	60	60	110	110	110
KOH	K	10	60	110	10	60	110	10	60	110

Table 2. Nutrient composition of the hydroponic solution employed in the greenhouse study. Concentration (ppm) represents the level of element in the final growth medium

NUTRIENT SOURCE	NUTRIENT	CONCENTRATION, PPM
H_2PO_4	P	23.0
$CaSO_4 \cdot 2H_2O$	Ca	95.0
$MgSO_4 \cdot 7H_2O$	Mg	22.0
H_3BO_3	B	0.1
HCl	Cl	2.0
$CuSO_4 \cdot 5H_2O$	Cu	0.1
Sequestrene (6% Fe)	Fe	4.0
$MnSO_4 \cdot H_2O$	Mn	0.24
MoO_3	Mo	0.01
$Na_2SO_4 \cdot 10H_2O$	Na	9.0
$ZnSO_4 \cdot 7H_2O$	Zn	0.1

potassium hydroxide as the K source so that the N and K levels in the nutrient solution could be independently varied without affecting the concentration of any other nutrient. The pH levels of the nutrient solutions ranged from 4.0 in solutions containing low levels of KOH to 6.0 in solutions containing high levels of KOH. No attempt was made to adjust the pH of the solutions. There was no evidence of any precipitate in any of the crocks during the experiment. Solutions were changed biweekly until the final harvest on August 22. Distilled water was added to keep the solution levels constant throughout the experiment.

Grass was clipped initially and weekly at a height of 5.1 cm. using a clipping frame (Figure 1). Harvested samples were dried at 80° C and dry weights of each treatment recorded weekly from June 20 to August 8. The final harvest was made on August 22.

Tissue from the harvests of June 20, July 11 and August 22 was analyzed spectrophotographically for P, K, Ca, Mg, Cu, Fe, Mn and Zn using the services of the Ohio Plant Analysis Laboratory, Wooster, Ohio. Nitrogen was determined by the micro-Kjeldahl procedure.

Data on yield and chemical composition were analyzed by Duncan's multiple range test as outlined by Steel and Torrie (36).

FIELD STUDY

In this two-year study under field conditions, six different fertilizer treatments with three replications were arranged in a randomized block design using a five-year-old Penncross creeping bentgrass (*Agrostis palustris* Huds. var. Penncross) nursery located at Manchester Country Club, Manchester, N.H. The nursery had always been maintained at putting green

Figure 1. Harvesting techniques for greenhouse hydroponic study using clipping frame.

height (0.48) and was uniform in fertility, soil type and pH at the onset of this study. The pH of the soil was approximately 6.5. The normal fertilizer program consisted of a 12-2-8 fertilizer applied at a rate of 2.59 kilograms of N per are per year (6 pounds N/1000 sq ft/year). During the establishment of the nursery and throughout this study, water was applied as needed through an irrigation system.

The six fertilizer treatments used as sources of nutrients in this study are given in Table 3. The percentage of water-insoluble nitrogen (W.I.N.) contained in the various fertilizers ranged from 15.5% in the 31-5-3 to 3.5% in the 10-3-6. The release of nitrogen from water-insoluble sources may be dependent on soil moisture, temperature and soil microbial activity. Generally, nitrogen sources high in water-insoluble nitrogen release nitrogen over a longer period of time and allow higher application rates with less tendency to burn. In 1972 all fertilizer treatments were applied on May 22, June 19, August 2 and August 28; in 1973 applications were made on June 5 and August 28. Table 4 gives the fertilizer treatments and rates of application. With the exception of 19-6-13, application rates were constant whenever a product was applied during a given growing season. Application rates were based on the manufacturers' recommendations. The 19-6-13 fertilizer was applied at two different rates; 19-6-13H indicates the higher rate and 19-6-13L indicates the lower rate.

Samples of tissues from the June 5, June 19, July 3, July 17, July 31, August 14, August 28, September 11 and September 25 harvests of 1972 and the June 19, July 3, July 17, August 14, August 28, September 11 and September 25 harvests of 1973 were dried at 80°C and analyzed for N using the micro-Kjeldahl procedure.

Table 3. Nutrient content of fertilizers used for respective treatments of the field study

TREATMENT	NUTRIENT CONTENT, %			
	TOTAL N	WATER INSOLUBLE N	P_2O_5	K_2O
1	19	14.0	6	13
2	19	14.0	6	13
3	6	5.5	3	0
4	12	3.6	2	8
5	10	3.0	3	6
6	31	15.5	5	3

Table 4. Fertilizer grade, application dates and broadcast rates of fertilizers used in the field study. Values represent the rate of application in kg N/a

FERTILIZER	1972				1973	
	5/22	6/19	8/2	8/28	6/5	8/28
19-6-13H	2.78	0.0	0.0	0.0	2.78	0.0
13-6-13L	1.95	0.0	0.0	0.0	1.95	0.0
6-3-0	0.49	0.49	0.49	0.49	0.98	0.98
12-2-8	0.98	0.0	0.0	0.98	0.98	0.98
10-3-6	0.98	0.0	0.0	0.98	0.98	0.98
31-5-3	1.76	0.0	0.0	1.76	1.76	1.76

Samples of tissue from the June 5, July 17, August 28 and September 25 harvests of 1972 and the June 19, July 17, August 28 and September 25 harvests of 1973 were dried at 80° C and analyzed spectrophotographically for P, K, Ca, Mg, Cu, Fe, Mn and Zn by the Ohio Plant Analysis Laboratory, Wooster, Ohio.

Data were statistically analyzed by Duncan's multiple range test as outlined by Steel and Torrie (36).

RESULTS AND DISCUSSION

GREENHOUSE STUDY

Dry Weight of Foliage

Because all turfgrass had been maintained on a uniform nutrient solution, there was no significant statistical difference in the dry weights of foliage prior to the initiation of treatments; the range of weights from 3.25 to 4.75 grams. The various N-K treatments were commenced on June 13 and periodic harvests were made through August 22. The dry weight of the turfgrass foliage on nine harvest dates as influenced by N-K treatments is shown in Table 5 and Figures 2, 3 and 4.

At the time of the first harvest, on June 20, all the treatments providing 110 ppm N, regardless of K level, and the 60 ppm N-60 ppm K treatment had significantly higher yields compared to all other treatments. All treatments providing 10 ppm N, regardless of K level, had the lowest yields during the study. No increase in growth occurred beyond 60 ppm N. Plants receiving 60 ppm N-60 ppm K had the highest yield at the final harvest compared to both the 60 ppm N-10 ppm K and the 60 ppm N-110 ppm K treatments. When the nutrient solution contained was 110 ppm N, the highest yield generally occurred when the K level was 60 ppm. There was no significant difference in yield at the final harvest between the 60 ppm N-60 ppm K and the 110 ppm N-60 ppm K treatments. The highest total yields for all nine harvests resulted from the 60 ppm N-60 ppm K and the 110 ppm N-60 ppm K treatments. These results are consistent with those of other studies (1, 15, 19, 24, 32) in which highest yields were obtained after providing the

Table 5. Dry weight of turf foliage on nine harvest dates as influenced by N-K treatments. Values represent mean weight in grams of four replications

Treatment--ppm		Harvest Dates									Total
N	K	6/20	6/27	7/4	7/11	7/18	7/25	8/1	8/8	8/22	All Harvest
10	10	2.28d	1.03e	1.28e	1.88d	1.05e	0.95d	1.65d	1.50e	1.83d	13.45
10	60	2.55bc	1.40d	1.45e	1.98d	1.75c	0.83d	1.83cd	1.68d	1.80d	15.27
10	110	2.25d	1.20e	1.43e	2.00d	1.30d	0.98d	1.90c	1.68d	2.33d	15.07
60	10	2.50c	1.53cd	2.03bc	2.95b	2.03b	1.85ab	2.35b	1.98c	4.05c	21.27
60	60	2.75ab	2.15b	2.18b	3.45a	2.38a	2.03a	2.65a	2.33b	6.33a	26.25
60	110	2.43cd	2.23ab	2.03bc	3.60a	2.45a	2.03a	2.35b	1.68d	4.30c	23.10
110	10	2.75ab	1.78c	1.70d	2.60c	2.25a	1.70bc	2.35b	2.35b	4.38c	21.86
110	60	2.85a	2.05b	2.38a	3.38a	2.25a	2.00ab	2.68a	2.68a	6.38a	26.65
110	110	2.88a	1.98cd	1.98cd	3.50a	2.28a	1.43c	2.55ab	2.73a	5.25b	24.58

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test

Figure 2. Foliar growth response of Merion Kentucky bluegrass (*Poa pratensis* L. var. Merion) to 10 ppm N and (from left to right) 10, 60 and 110 ppm K in nutrient solution under greenhouse conditions.

Figure 3. Foliar growth response to Merion Kentucky bluegrass (*Poa pratensis* L. var. Merion) to 60 ppm N and (from left to right) 10, 60 and 110 ppm K in nutrient solution under greenhouse conditions.

Figure 4. Foliar growth response of Merion Kentucky bluegrass (*Poa pratensis* L. var. Merion) to 110 ppm N and (from left to right) 10, 60 and 110 ppm K in nutrient solution under greenhouse conditions

plant with an N level approximately twice that of K, and those (15, 18) who reported that equal amounts of N and K produced the highest yields.

These data suggest that there is a ratio between N and K application rates at which the highest foliar growth rate occurs. Increasing N application rates above this level will not necessarily result in increased yield. The results also suggest it may be possible to reduce N application rates, as long as K application rates are optimum, without any reduction in yield.

Consideration should be given to the amount of wear a turfgrass area receives when determining N and K application rates. Foliar growth rates, with respect to density of blades, must be high enough to protect the growing point of the plant from damage. According to Beard (3), when excessively high N applications are used to produce high growth rates there is a reduction in root, rhizome or stolon growth, winter hardiness is reduced, the tendency to wilt is increased and the plant is more susceptible to disease.

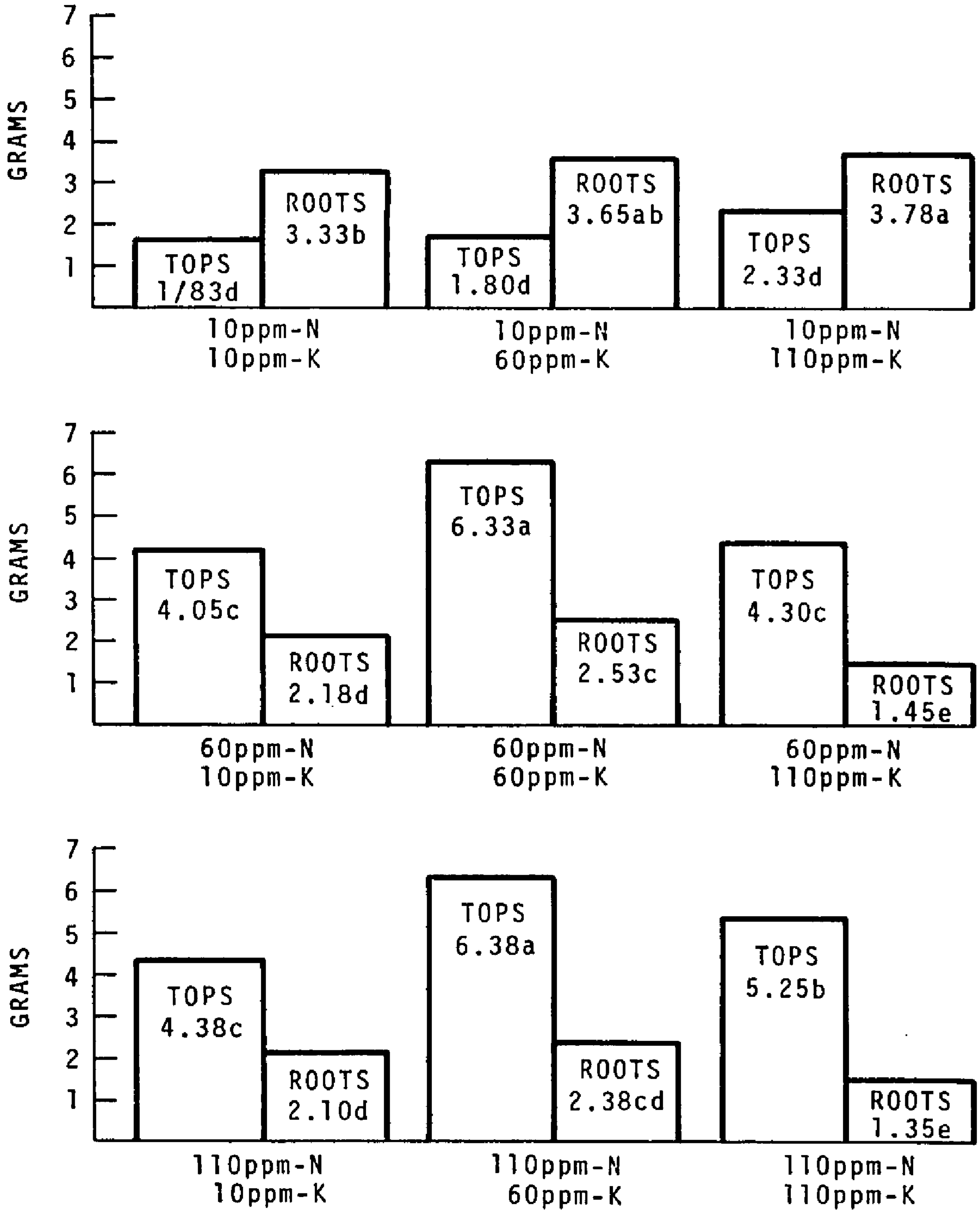
These results suggest that it may be possible to maintain high growth rates by balancing N and K application rates without the deleterious effects associated with excessively high N application rates. For example, the 60 ppm N-60 ppm K treatment produced the highest foliar growth rate without the reduction in root weight associated with treatments receiving 110 ppm N.

Dry Weight of Roots

The effects of N-K treatments on the dry weight of roots are shown in Figure 5. All treatments receiving 10 ppm N, regardless of K level, had significantly higher root weights. There was no difference in root weights

Figure 5. Dry weight of turf tissue harvested on August 22 as influenced by N-K hydroponic treatments under greenhouse conditions

Means within a given column having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.


GRAMS
7
6
5
4
3
2
1
TOPS
1/83d
ROOTS
3.33b
TOPS
1.80d
ROOTS
3.65ab
TOPS
2.33d
ROOTS
3.78a
10ppm-N
10ppm-K
10ppm-N
60ppm-K
10ppm-N
110ppm-K
GRAMS
TOPS
4.05c
ROOTS
2.18d
TOPS
6.33a
ROOTS
2.53c
TOPS
4.30c
ROOTS
1.45e
60ppm-N
10ppm-K
60ppm-N
60ppm-K
60ppm-N
110ppm-K
GRAMS
TOPS
4.38c
ROOTS
2.10d
TOPS
6.38a
ROOTS
2.38cd
TOPS
5.25b
ROOTS
1.35e
110ppm-N
10ppm-K
110ppm-N
60ppm-K
110ppm-N
110ppm-K

between plants receiving either 60 ppm N or 110 ppm N at the same K levels. Generally with increasing N concentration and constant K levels in the nutrient solution, foliage weight increased and root weights decreased or remained the same (Figure 5).

According to Beard (3), when high foliar growth rates are produced by excessive N applications, carbohydrates are used primarily for foliar growth with very little being available for root growth. This may cause a reduction of the plant's total root surface area and thus restrict water and nutrient uptake. Higher water and nutrient application rates may be necessary to compensate for the plant's reduced contact with the soil solution.

In this study the highest root weights occurred with N-K ratio of 1:6 or 1:11. The lowest N-K ratio treatment reported in a nutrient solution study of perennial ryegrass is by Adams *et al*. (1). They indicated that a N-K ratio of 1:2 produced the highest root weight. Wright (43), in a study of blue panicgrass using soil as a growth medium, reported that a N-K treatment ratio of approximately 1:0.6 produced the greatest root weight. Considering the complex interactions possible between soils and the nutrient elements and the variability of soil nutrient levels, variation between nutrient solution and soil nutrition studies should be expected.

Shoot-Root Ratio

The highest ratio of foliage to root weight resulted from the 110 ppm N-110 ppm K treatment (Table 6). The ratio of foliage growth to root growth increased with increasing levels of N at all K levels. These results are consistent with those reported by Vose (39), Monroe *et al*. (30) and McLean (27).

Table 6. Ratio of shoot-root weights on dry matter basis of Merion Kentucky bluegrass (*Poa pratensis* L. var. Merion) harvested on August 22 as influenced by various levels of N and K in hydroponic culture

Treatment--ppm		
N	K	Shoot/Root
10	10	1:1.82
10	60	1:2.03
10	110	1:1.62
60	10	1:0.54
60	60	1:0.40
60	110	1:0.34
110	10	1:0.48
110	60	1:0.37
110	110	1:0.26

The increase of 50 ppm N in the nutrient solution resulted in a change in the shoot-root ratio from 1:2.03 (10 ppm N-60 ppm K) to 1:0.40 (60 ppm N-60 ppm K). McLean (27) and Vose (39) have reported that in nutrient solution as N levels increase in relationship to K levels the amount of top growth increases and the amount of root growth decreases.

Monroe *et al*. (30) found that a reduction in the concentration of the nutrient solution from 130 ppm N-200 ppm K to 65 ppm N-100 ppm K resulted in more root growth. The results of this study and the study by Monroe *et al*. (30) would indicate that the concentrations of N and K as well as the ratio between N and K may interact to affect the shoot-root ratio. Studies using soil as a growth medium need to be developed to test this N-K relationship.

The change in shoot-root ratio as a result of varying N-K ratios may be one of the more significant results of this study. More and more high turfgrass use areas are being constructed using 100% sand, thus creating a situation which closely simulates hydroponic conditions in terms of nutrient availability. In this system there is need to provide maximum root growth while still maintaining a foliar growth rate able to withstand high traffic. It is evident from this study that the N-K ratio can have an important effect on turfgrass grown under hydroponic conditions.

ELEMENTAL COMPOSITION OF FOLIAGE

Effect of Treatment on Foliar Levels of N and K

Results show that while the ratio of N to K in solution culture ranged from 1:1 to 1:11 the N to K ratio in the foliage growing in such media ranged from 1:0.5 to 1:0.1. In general the K content of the foliage increased relative to N content as the K concentration of the nutrient solution increased regardless of the substrate N concentration (Tables 7, 8, 9 and 10). When plants were grown at 10, 60 and 110 ppm K changes in total uptake of K were most dramatic at the higher levels of N in the growing medium.

According to Beard (3) turfgrasses utilize NO_3^- in preference to NH_4^+. Gauch (12) suggested that plants requiring large amounts of NO_3^- require amounts of K over the amount required for K-related functions in the plants. This may account for the higher levels of K found in this study at the higher nutrient solution levels of N (Table 9).

The concentration of K in the nutrient solution had no effect on the level of N in the foliage. This is in agreement with the results of Washko (42).

In general, the results of this study did not indicate any antagonistic relationship between the uptake of N and K. This is important when considering the increased use of soluble N and K sources in turfgrass nutrition programs. If these two nutrients were highly antagonistic it would be difficult to use them in combination.

Effect of Treatment on P Uptake

When the nutrient solution contained either 60 or 110 ppm N, the concentration of K had no effect on the P level of the foliage. At the 10 ppm N concentration, an increase of K to 60 or 110 ppm depressed P levels in the foliage. This is in agreement with several workers (4, 41, 42) that have reported that K may have a depressing effect on P uptake.

Table 7. Elemental composition of turf foliage harvested on June 20 as influenced by N-K treatments. Values represent nutrient concentration as a mean of four replications

TREATMENT (PPM)		NUTRIENT ELEMENT								
		%					PPM			
N	K	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
10	10	4.14b	1.04 N/S	2.92c	0.41ab	0.45ab	24 N/S	169a	63cd	55 N/S
10	60	3.90b	1.01	3.59a	0.49a	0.38bc	26	162ab	163a	58
10	110	4.14b	0.97	3.64a	0.46a	0.36c	22	140b	120b	63
60	10	5.31a	1.03	2.99c	0.30c	0.50a	23	158ab	39d	56
60	60	5.24a	0.97	3.65a	0.38bc	0.35c	23	142ab	61cd	67
60	110	5.35a	0.97	3.74a	0.39ab	0.35c	25	154ab	112b	53
110	10	5.28a	1.07	3.15bc	0.36bc	0.51a	26	165ab	45d	54
110	60	5.38a	1.00	3.47ab	0.33bc	0.35c	22	161ab	62cd	50
110	110	5.44a	0.94	3.53a	0.38bc	0.33c	22	163ab	93bc	49

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 8. Elemental composition of turf foliage harvested on July 11 as influenced by N-K treatments. Values represent nutrient concentration as a mean of four replications

TREATMENT (PPM)		NUTRIENT ELEMENT								
		%					PPM			
N	K	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
10	10	3.64b	0.84abc	2.96bc	0.44ab	0.48b	24b	157 N/S	110bcd	46b
10	60	3.48b	0.69c	3.18b	0.45ab	0.38b	21b	148	186ab	45b
10	110	3.51b	0.80bc	3.40ab	0.52a	0.41b	22b	138	188a	50ab
60	10	5.01a	0.99ab	2.43c	0.33b	0.64a	27b	171	37d	50ab
60	60	5.13a	0.96ab	3.48ab	0.39b	0.40b	23b	154	73cd	62a
60	110	4.96a	0.95ab	3.93a	0.47a	0.39b	25b	170	144abc	50ab
110	10	5.11a	1.01a	2.49c	0.34b	0.61a	32a	184	40d	47ab
110	60	4.94a	1.00ab	3.49ab	0.38b	0.37b	23b	162	82cd	45b
110	110	5.40a	0.90ab	3.23b	0.39b	0.40b	22b	180	93cd	51ab

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 9. Elemental composition of turf foliage harvested on August 22 as influenced by N-K treatments. Values represent nutrient concentration as a mean of four replications

TREATMENT (PPM)		NUTRIENT ELEMENT								
		%					PPM			
N	K	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
10	10	3.36c	0.80a	2.64bc	0.39bc	0.49b	23abc	177bc	68bcd	47ab
10	60	3.21c	0.64c	2.98ab	0.44b	0.38b	19c	130c	198a	43ab
10	110	3.36c	0.67bc	3.02ab	0.54a	0.44b	20c	169bc	215a	42ab
60	10	4.57b	0.79a	2.13d	0.28d	0.64a	26ab	240a	37d	51ab
60	60	4.65ab	0.88a	3.38a	0.36cd	0.44b	22bc	202ab	52cd	56a
60	110	4.68ab	0.82a	3.49a	0.45b	0.38b	22bc	180b	103b	49ab
110	10	4.80ab	0.85a	2.34cd	0.28d	0.53a	28a	212ab	33d	44ab
110	60	5.08a	0.82a	3.50a	0.35cd	0.39b	21bc	203ab	64bcd	44ab
110	110	4.76ab	0.77ab	3.37a	0.35cd	0.40b	24ab	215ab	76bc	38b

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 10. Ratio of N to K concentration in foliage on three harvest dates

TREATMENT (PPM) N	K	June 20	July 11	August 22
10	10	1:0.70	1:0.82	1:0.79
10	60	1:0.92	1:0.91	1:0.93
10	110	1:0.88	1:0.97	1:0.90
60	10	1:0.56	1:0.48	1:0.46
60	60	1:0.69	1:0.68	1:0.73
60	110	1:0.70	1:0.79	1:0.75
110	10	1:0.60	1:0.49	1:0.48
110	60	1:0.65	1:0.71	1:0.69
110	110	1:0.65	1:0.60	1:0.71

Generally N had little effect on P foliage levels. Evans *et al.* (10) and Burton and DeVane have also found that N levels did not significantly affect foliage P levels.

There were no visual symptoms of P deficiency present even in the foliage of the plants containing the lower levels of P. This would indicate that none of the various ratios of N to K in the nutrient solution had a pronounced effect in reducing P uptake.

Effect of Treatment on Ca Uptake

The foliage levels of Ca (1) decreased as the N concentration increased and (2) increased as the K concentration increased. Other workers (9, 33, 42) have generally reported that foliage levels of Ca decreased as the N or K concentration increased. According to Gauch (12) Ca uptake may be diminished at pH 4 and 5 as compared to uptake at higher pH levels. The pH level of the nutrient solution ranged from 4.0 in those solutions containing low concentrations of K and high concentrations of N to 6.0 in those containing high levels of K and low levels of N. The uptake of Ca in this study may be related to the pH of the nutrient solution. Consideration should be given to a study designed to test the effect of pH on the uptake of ions such as Ca because of the increased use of soluble nutrient sources.

Effect of Treatment on Mg Uptake

The concentration of N in the nutrient solution had little effect on the foliage levels of Mg; however, the foliage levels of Mg were reduced as the K concentration increased. These results are in agreement with others (17, 20, 28, 33, 38, 40) which have reported this same relationship between K and Mg.

Effect of Treatment on Cu, Fe, Mn and Zn Uptake

Foliar levels of Fe increased and Mn decreased as the N concentration increased in the nutrient solution. As the concentration of K increased in the nutrient solution foliar levels of Mn increased. The various treatments had no effect on foliar levels of Cu and Zn.

Effect of Treatment on Cation Concentrations

According to Gauch (12) the sum of the cations (K, Ca and Mg) per 100 g of dry plant material tends to be a constant for a given species of plant so that if there is a decreased uptake of one of the cations, one or more of the others tend to increase. The milliequivalent (meqs) weights of the cations K, Ca and Mg present in the foliage on the three harvest dates as a result of the various treatments are shown in Tables 11, 12 and 13. Generally as the N concentration increased in the nutrient solution the total meqs of absorbed cations decreased; for a given level of substrate N, the total meqs of absorbed cations increased with elevated levels of substrate K.

It is apparent that variance of the N-K ratio supplied to the plant may cause the content of cations to vary. It may be possible that if one cation is supplied in excess a shift may occur in the plant's requirements for the other cations. This relationship has particular importance if the concentration of any cation is in low supply.

In evaluating the data several factors should be considered. Two of the major soil problems affecting the management of turfgrasses are poor drainage and high salt levels. Grower response to these problems has been to increase the amount of sand used in the construction of golf greens, tees and athletic fields. Many of these facilities are 100% sand and thus have

Table 11. Milliequivalents of selected cations per 100 grams dry weight of foliage harvested on June 20

TREATMENT (PPM)		Cations			
N	K	K	Ca	Mg	Total
10	10	74.69	20.46	37.00	132.15
10	60	91.83	24.45	31.25	147.53
10	110	93.10	22.95	29.60	145.65
60	10	76.48	14.97	41.12	132.57
60	60	93.36	18.96	28.78	141.10
60	110	95.66	19.46	28.78	143.90
110	10	80.57	17.96	41.94	140.47
110	60	88.76	16.47	28.78	148.66
110	110	90.29	18.96	27.14	136.39

Table 12. Milliequivalents of selected cations per 100 grams dry weight of foliage harvested on July 11

TREATMENT (PPM)		Cations			
N	K	K	Ca	Mg	Total
10	10	75.71	21.96	39.47	137.14
10	60	81.37	22.46	31.25	135.05
10	110	86.97	25.95	33.72	146.64
60	10	62.15	16.47	50.99	129.61
60	60	89.01	19.46	32.89	141.36
60	110	100.52	23.45	32.07	156.04
110	10	63.69	16.97	50.16	130.82
110	60	89.27	18.96	30.43	138.66
110	110	82.62	19.46	32.89	134.97

Table 13. Milliequivalents of selected cations per 100 grams dry weightof foliage harvested on August 22

TREATMENT (PPM)		Cations			
N	K	K	Ca	Mg	Total
10	10	67.53	19.46	40.30	127.29
10	60	76.22	21.96	31.25	129.43
10	110	77.25	26.95	36.18	140.38
60	10	54.48	13.97	52.63	121.08
60	60	86.45	17.96	36.18	140.59
60	110	89.27	24.46	31.25	144.98
110	10	59.85	13.97	43.59	117.41
110	60	89.52	17.47	32.07	139.06
110	110	86.20	17.47	32.89	136.56

little if any cation exchange or buffering capacity. This means that the results of solution culture studies do illustrate relationships which may be relevant to field conditions.

Growth rates are replacing color as the prime criteria for evaluating nutrition programs. Highly used turfgrass areas will require higher growth rates than those areas that receive little use. Turfgrass managers are interested in nutrition programs that will produce growth rates in relationship to the intensity of wear to which the plant is subjected.

Excessively high growth rates are expensive since they are usually maintained by applications of N, currently the most expensive fertilizer element. Many golf course and park budgets have been reduced, and a turfgrass manager must be highly selective in developing his fertilizer program.

The effect of increasing the N supply at all levels of K was to reduce the amount of root growth and increase the amount of top growth. The various N-K treatments used in the hydroponic study produced great shifts in the relative growth of tops and roots (Figure 6). Foliage weights approximately four times the weight of roots were obtained with 110 ppm N-110 ppm K. In contrast, foliage weights that were approximately one-half the weight of the roots resulted from the 10 ppm N-60 ppm K treatment.

Criteria have not been established to identify the optimum ratio of shoot-root growth which likely differs among species. In addition, such criteria must consider the amount of traffic associated with the use of turfgrass. In this study the highest foliage growth rate resulted from the 60 ppm N-60 K treatment. It should be noted that the 110 ppm N-60 ppm K treatment produced the same foliage and root growth rates. There was no significant advantage in increasing the N concentration of the substrate

Figure 6. Shoot and root growth response of turf plants to 10 ppm N-60 ppm K and 110 ppm N-110 ppm K hydroponic treatments under greenhouse conditions

when the K level was 60 ppm. If root growth is of prime consideration, the best root growth rates were a result of treatments supplying 10 ppm N with the highest root rate resulting from the 10 ppm N-60 ppm K treatment.

This study suggests an interrelationship between N and K that affects the turfgrass plant's ratio of shoot-root growth. Turfgrasses grown on heavily trafficked areas will require high foliar growth rates and the N-K nutritional program should be adjusted accordingly.

Nitrogen is an expensive nutrient and should not be applied at rates any higher than are dictated by the use of the area. Over application not only may produce unnecessarily high foliar growth rates but may, in sandy soils, be considered a potential pollutant source.

It is very difficult to compare the N-K treatment ratios used in this study with "normal" soil levels of NO_3^- and K. Soil tests for turfgrass usually do not include a NO_3^- determination. Beard (3) states that the variable results from nitrate analysis have not given satisfactory information for use in nitrogen fertilization. Soil levels of soluble or exchangeable K have also been widely variable.

There is a wide variety of N-K ratios commercially available in fertilizers. They may run anywhere from 10:1 to 2:1. In a hydroponic system the ratio of nutrients supplied to the plant can be carefully controlled. While some turfgrasses are grown under near hydroponic conditions, such as 100% sand, most are grown using soil as a medium. Studies should be developed to investigate the effect soils may have in moderating the applied N-K ratio.

FIELD STUDY

The major objective of this study was to observe seasonal variation in N uptake as influenced by the water insoluble nitrogen (W.I.N.) content of five commercially available fertilizers (Table 3).

Nitrogen Levels

The effects of six fertilizer treatments on the N concentration in foliage of nursery-grown Penncross creeping bentgrass are shown in Figures 7 and 8[1]. Generally the N levels in foliage resulting from the application of 19-6-13H and 19-6-13L were fairly consistent throughout both growing seasons; little difference in levels of foliar N resulted from the two rates (2.78 and 1.95 kg N/a) of application. This would indicate that there was no advantage in applying this material at the higher rate.

Three fertilizers (6-3-0, 12-2-8 and 10-3-6) were applied at the rate of 1.95 kg N/a/year. The N levels in the foliage resulting from these fertilizers were nearly the same for the two-year period of this study. This would suggest that choice among these three fertilizers for use in a turfgrass nutrition program should be primarily based on economics. It should be noted that the 6-3-0 fertilizer was applied four times during the 1972 season at a rate of 0.49 kg N/a; in 1973 two applications were made at 0.98 kg N/a per application. These data do not indicate any large degree of variation in N levels of the foliage during either year. Approximately 92% of the N in the 6-3-0 is in a slowly available form, and, as Beard (3) suggests, fertilizers containing high levels of slowly available N may be

[1]Refer to Appendix, Tables 14 through 22 for statistical analysis.

Figure 7. Levels of N in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by 19-6-13H, 19-6-13L and 6-3-0 fertilizer treatments under field conditions

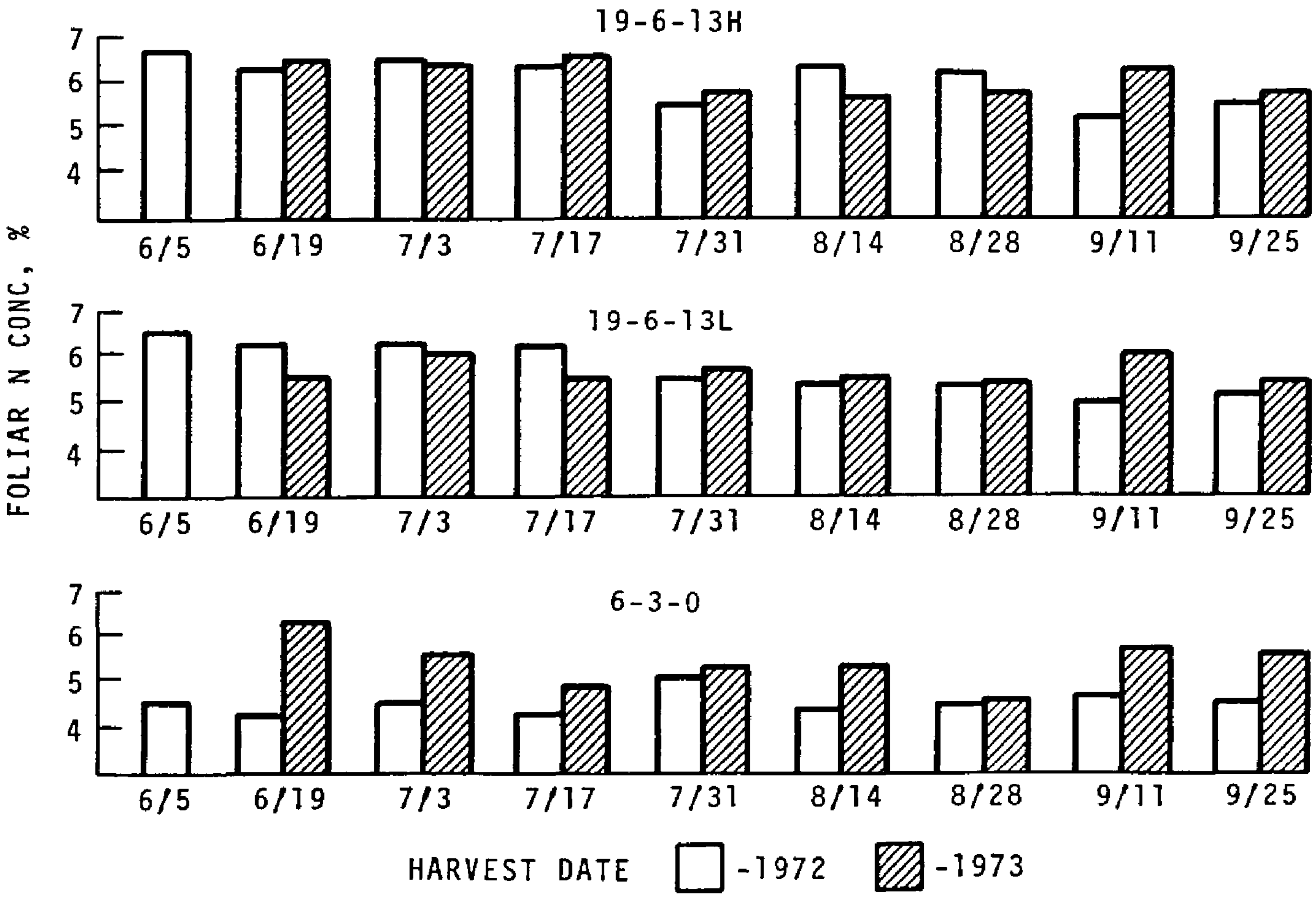
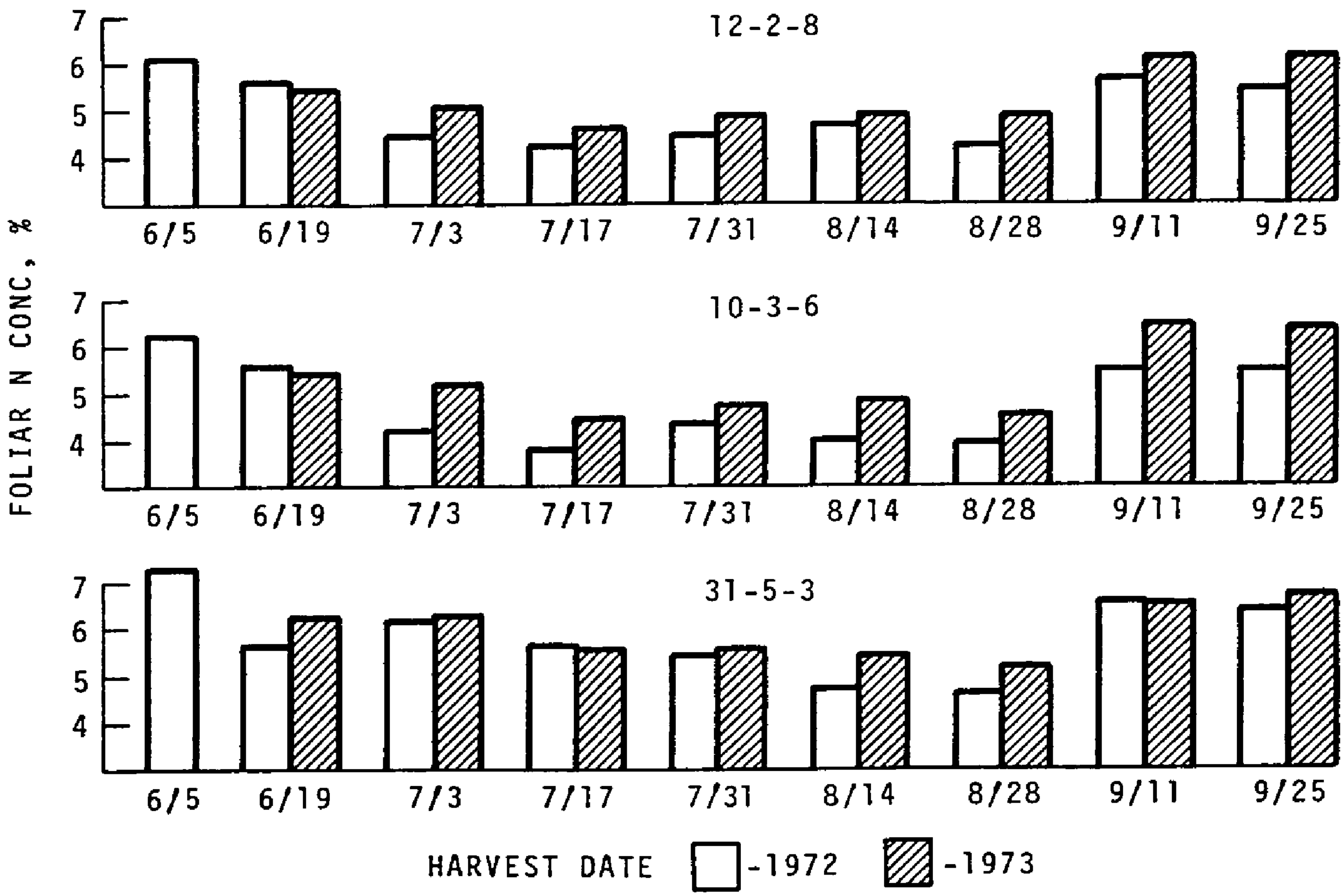

FOLIAR N CONC, %
19-6-13H
19-6-13L
6-3-0
7
6
5
4
6/5
6/19
7/3
7/17
7/31
8/14
8/28
9/11
9/25
HARVEST DATE
-1972
-1973

Figure 8. Levels of N in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by 12-2-8, 10-3-6 and 31-5-3 fertilizer treatments under field conditions


12-2-8
10-3-6
31-5-3
FOLIAR N CONC, %
7
6
5
4
6/5
6/19
7/3
7/17
7/31
8/14
8/28
9/11
9/25
HARVEST DATE
-1972
-1973

applied less frequently at higher rates than soluble N sources with the same results. These results would seem to agree with this statement. Turfgrass managers may reduce their application costs by using N sources that contain high levels of slowly soluble N.

The 31-5-3 fertilizer was applied at a rate of 3.52 kg N/a/year. The resulting N levels in the foliage were among the highest during the two-year study of any of the fertilizer treatments. This fertilizer was applied at the highest rate and 50% of its N was in a slowly soluble form. The 19-6-13L fertilizer, containing 74% slowly soluble N, was applied at a rate of 1.95 kg N/a/year and resulted in N foliage levels as high, if not higher at times than the 31-5-3. This would suggest that a great deal of the N supplied by the 31-5-3 may not have been utilized by the plant.

During the course of this study there were no visual differences in the color or the density among any of the plots. All fertilizers used in this study produced an acceptable putting surface. Beard (3) suggests that N levels in foliage are typically in the 3 to 6% range. According to Madison (25) foliar levels over 5% should be considered excessive. A total of 102 N determinations are reported in this study and approximately 70% are above the 5% Madison suggests as excessive. As the N levels resulting from the application of 19-6-13H and 19-6-13L were over 5% N, 88% of the 31-5-3 were over 5% N, 47% of the 12-2-8 and the 10-3-6 were over 5% and 41% of the N levels resulting from the 6-3-0 were over 5%. While it is reasonable to expect high N levels in foliage shortly after a N fertilizer is applied, these results would suggest that at least two of these materials (19-6-13 and 31-5-3) were applied at higher N rates than were necessary.

The approximate percentages of N in a slowly soluble form for each of the five fertilizers were as follows: 6-3-0, 92%; 19-6-13, 74%; 31-5-3, 50%; and both the 12-2-8 and 10-3-6 contained 30% N in slowly soluble form. Workers (3, 16, 18, 26, 31, 35, 40) have reported higher tissue levels of N resulting from soluble N sources than from slowly soluble sources based on the same rates of application. Turfgrass managers are interested in fertilizers that will produce a fairly rapid N response, which is a characteristic of a slowly soluble N source. Two fertilizers (19-6-13 and 6-3-0) containing the highest levels (74% and 92%, respectively) of slowly soluble N produced fairly uniform levels of N throughout the two growing seasons (Figure 7).

A slow decline of foliage N levels was noted as a result of the two fertilizers (12-2-8 and 10-3-6) that contained a lower amount (30%) of slowly soluble N. A similar decline was noted in the foliage N levels resulting from the 31-5-3 fertilizer (50% N in a slowly soluble form).

The lowest N level in foliage (3.82%) during the course of the study resulted from the 10-3-6 fertilizer harvested on July 17, 1972. Even though it was low as compared to the other foliage N levels, it was still within the 3 to 6% range suggested by Beard (3).

This study indicates that the application of those fertilizers higher in slowly available N did result in fairly uniform foliar levels of N throughout the study and that even though they contained high percentages of slowly soluble N, they contained enough soluble N to produce a fairly rapid response in N foliage levels shortly after application.

Phosphorus Levels

The foliage P levels for the two years of this study are shown in Figures 9 and 10. Madison (25) indicates that a P foliage level of 0.34% will produce an adequate growth response in Penncross creeping bentgrass. All foliar levels of P reported in this study were considerably above the value suggested by Madison, suggesting that the level of P contained in the five fertilizers was in excess of the P needs of the plant. It should be noted that while foliar P levels could be considered excessive in 1972 they were even higher in 1973, suggesting a build up of P in the soil.

These high foliar P levels illustrate the point that many times when commercially available N-P-K fertilizers are used the rate of P and K application is determined by the N rate of application and may supply P and/or K at higher or lower rates than are necessary.

Potassium Levels

Foliar levels of K (Figure 11) did not vary greatly during this study. Madison (25) found that Pennlu creeping bentgrass contained 1.40% K. All K values determined in this study were above the K value reported by Madison. The fertilizers used in this study ranged in their K content from 0 (6-3-0) to 13% (19-6-13) yet the foliage K levels were not highly different and apparently did not nearly approach a critically low level. The soil level of K apparently was high enough throughout the study to provide the plant with an adequate supply. Soil levels of K were not monitored during this study. In retrospect this information may have proved to be of value in evaluating the foliar K levels.

Figure 9. Levels of P in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by 19-6-13H, 19-6-13L, 6-3-0 and 12-2-8 fertilizer treatments under field conditions

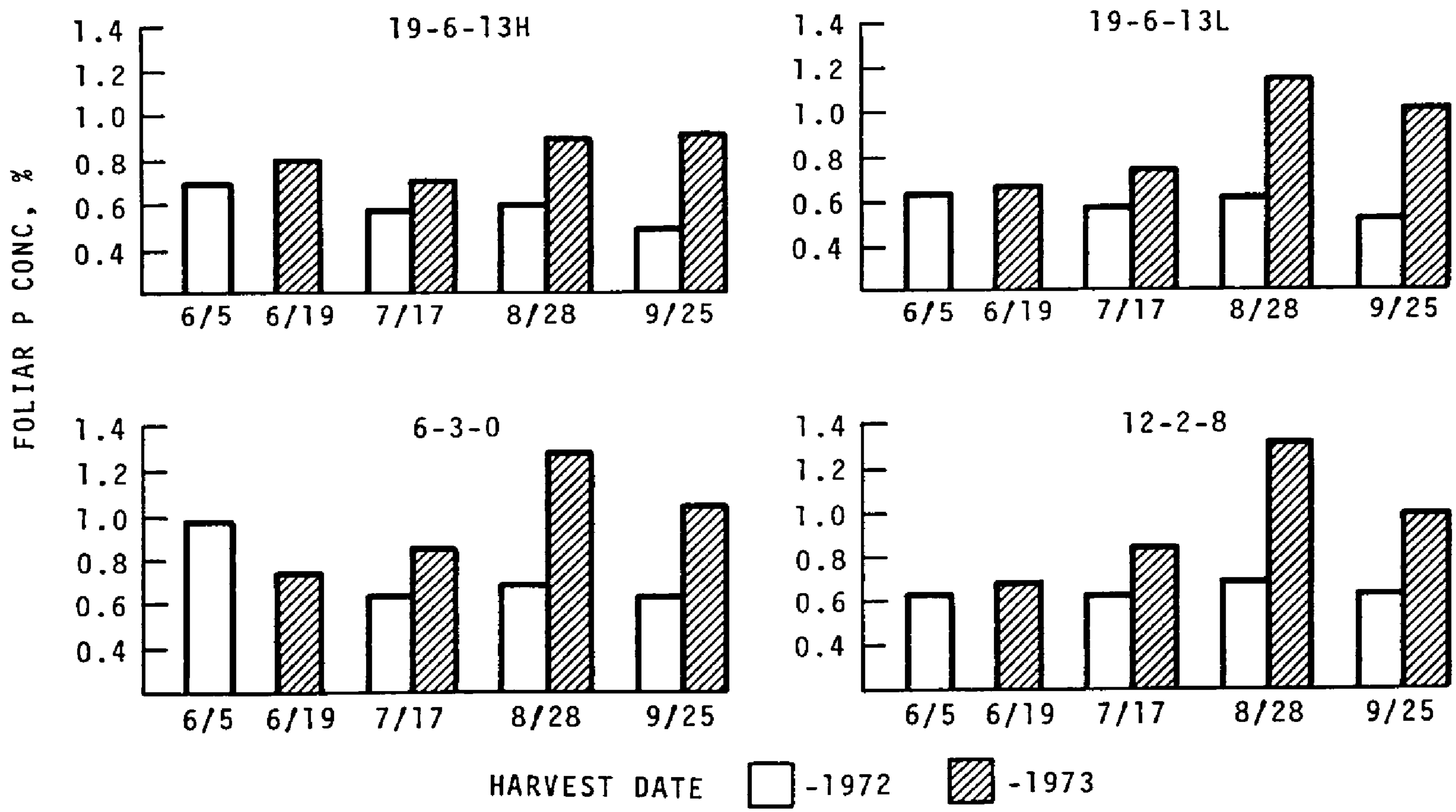
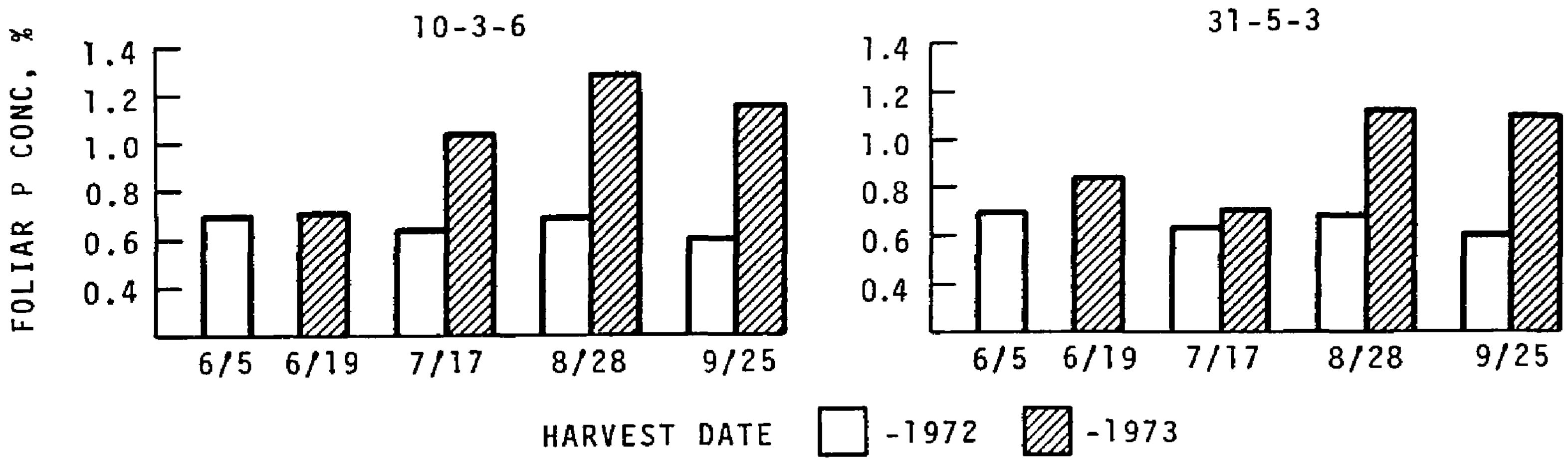
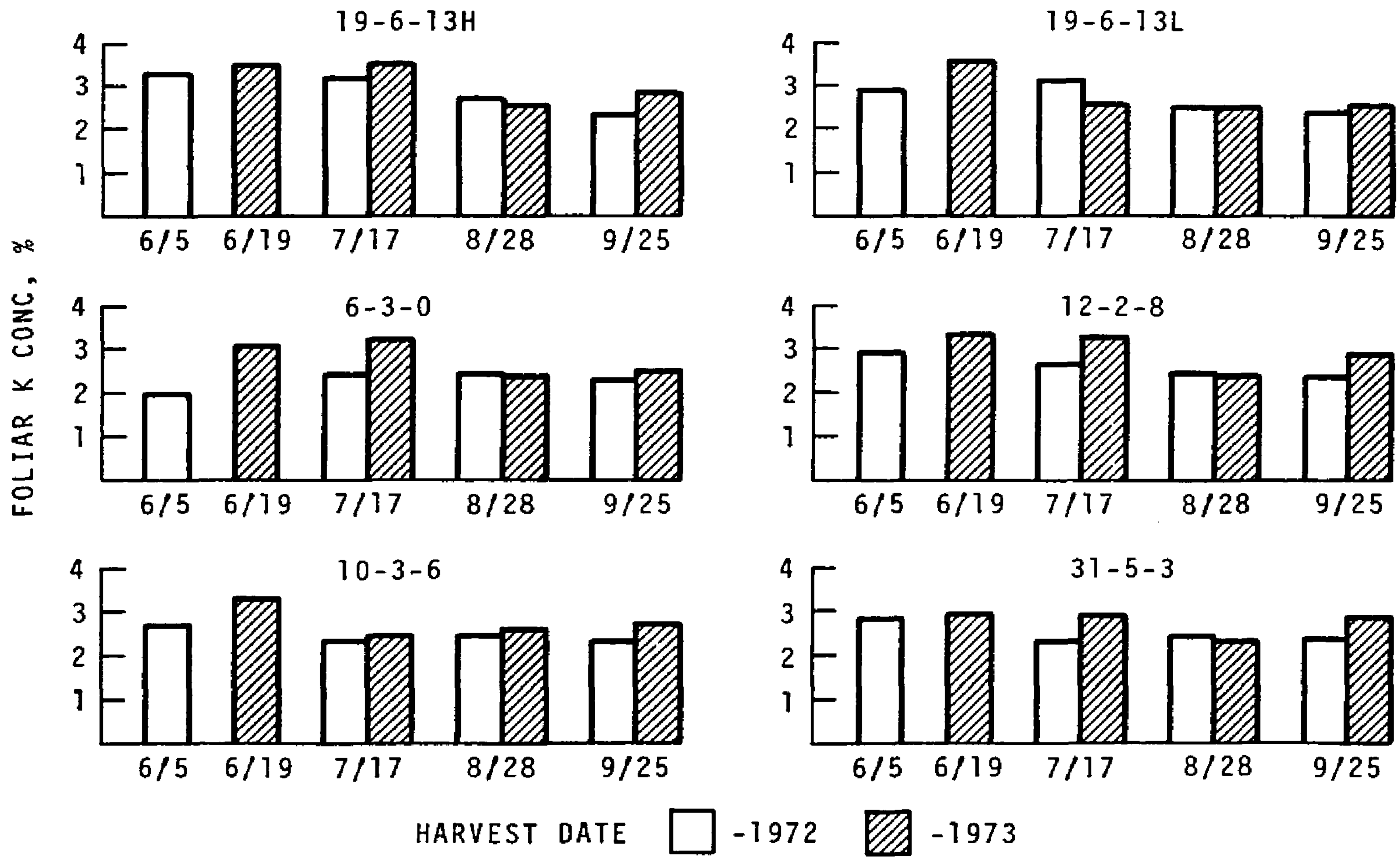

19-6-13H
19-6-13L
6-3-0
12-2-8
FOLIAR P CONC, %
1.4
1.2
1.0
0.8
0.6
0.4
6/5
6/19
7/17
8/28
9/25
HARVEST DATE
-1972
-1973

Figure 10. Levels of P in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by 10-3-6 and 31-5-3 fertilizer treatments under field conditions



FOLIAR P CONC, %
10-3-6
31-5-3
1.4
1.2
1.0
0.8
0.6
0.4
6/5
6/19
7/17
8/28
9/25
HARVEST DATE
-1972
-1973

Figure 11. Levels of K in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by fertilizer treatments under field conditions


19-6-13H
19-6-13L
6-3-0
12-2-8
10-3-6
31-5-3
FOLIAR K CONC, %
4
3
2
1
6/5
6/19
7/17
8/28
9/25
HARVEST DATE
-1972
-1973

Calcium, Magnesium, Copper, Iron, Manganese and Zinc Levels

Generally the levels of these elements did not vary greatly in response to the various fertilizer treatments (Figures 12, 13, 14, 15, 16 and 17). According to Beard (3) the 6-3-0 fertilizer used in this study contains Cu, Fe and Zn. Because 6-3-0 is a sewage product the amount of these minor elements varies and the producer does not guarantee their levels. The presence of these elements in 6-3-0 would explain the significant differences found in the foliage.

The foliage levels of the nutrients, other than N, analyzed in this study show little treatment effect. The N levels generally reflect the characteristics that have been attributed to either soluble or slowly soluble N sources (3, 7). It is evident that fertilizers high in W.I.N. are capable of providing the plant with a fairly uniform supply of N over an extended period. In order to maintain a uniform level of N over a growing season the turfgrass manager will be required to make more frequent applications of fertilizers that are low in W.I.N.

Many turfgrass managers rely on the fertilizer producers' recommended rates of application. This study suggests that these rates may, at times, provide the plant with nutrients far in excess of its needs. The study further suggests that when complete fertilizers (containing N, P and K) are used, as long as the application rates are based on the level of one of the nutrients, the other two nutrients may be supplied at excessively high or excessively low levels.

Data from this study show a seasonal tendency for P levels in foliage to increase and for K levels to decrease.

Figure 12. Levels of Ca in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by fertilizer treatments under field conditions

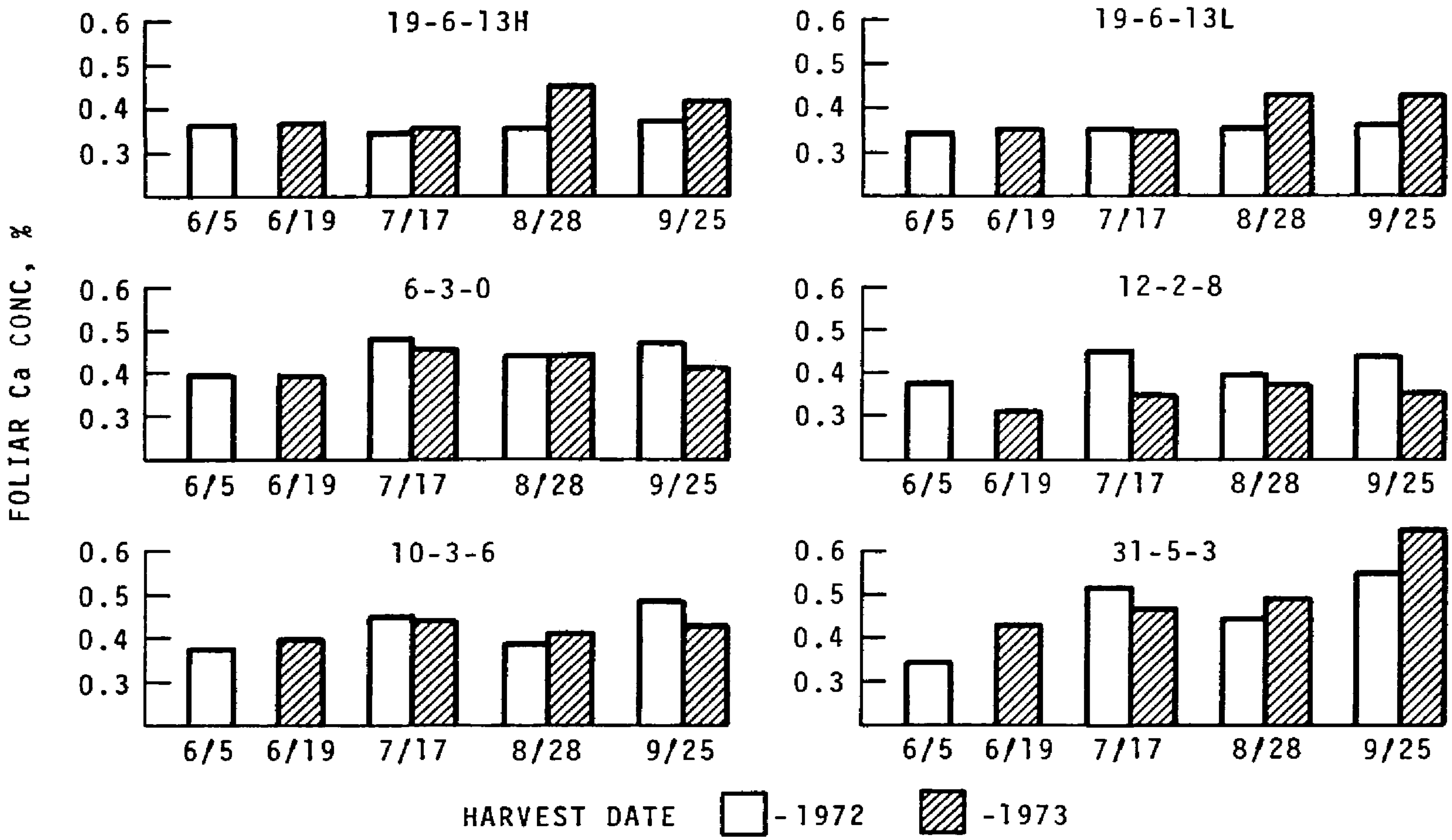

FOLIAR Ca CONC, %
19-6-13H
19-6-13L
6-3-0
12-2-8
10-3-6
31-5-3
0.6
0.5
0.4
0.3
6/5 6/19 7/17 8/28 9/25
HARVEST DATE
-1972
-1973

Figure 13. Levels of Mg in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by fertilizer treatments under field conditions

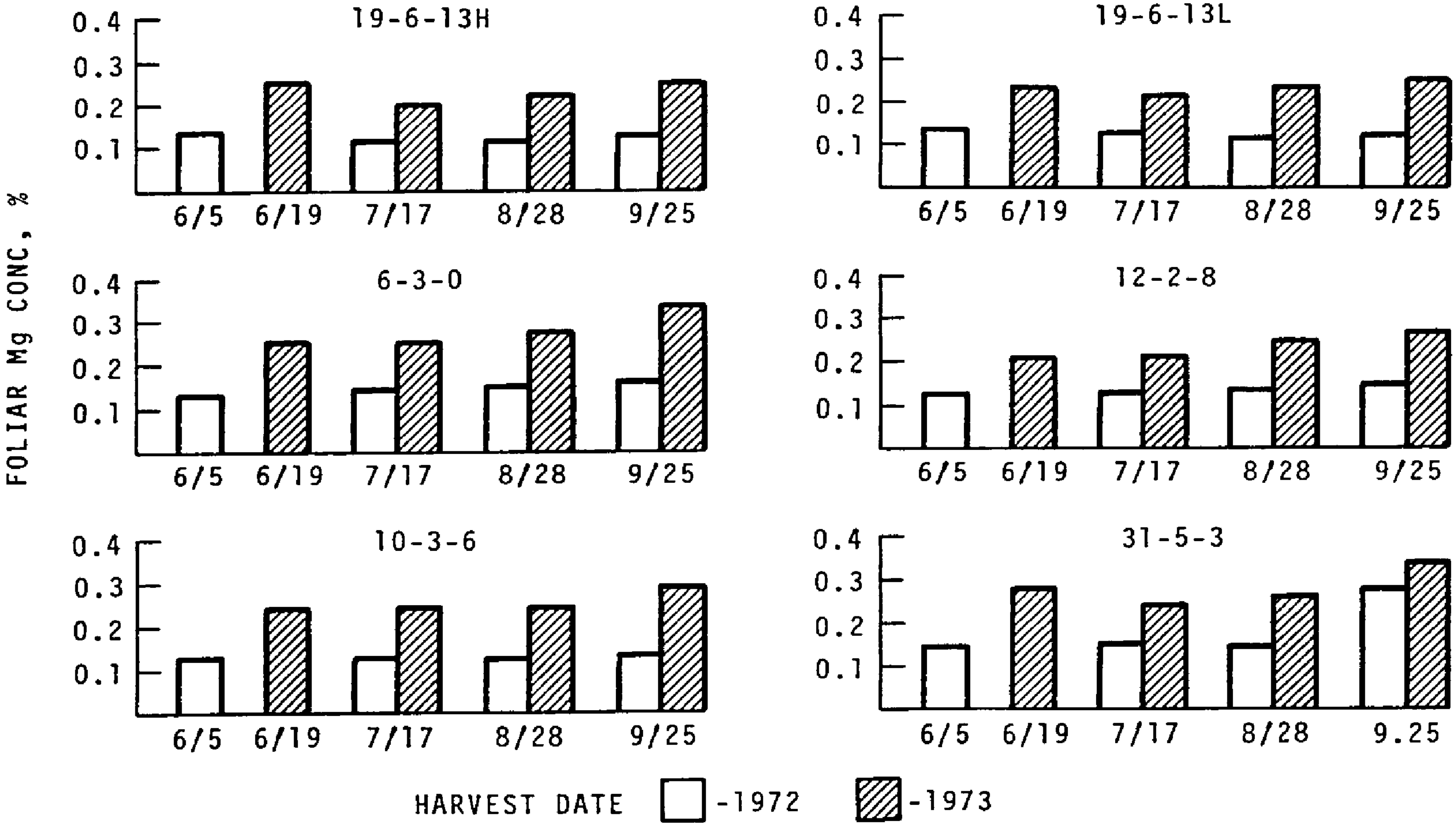
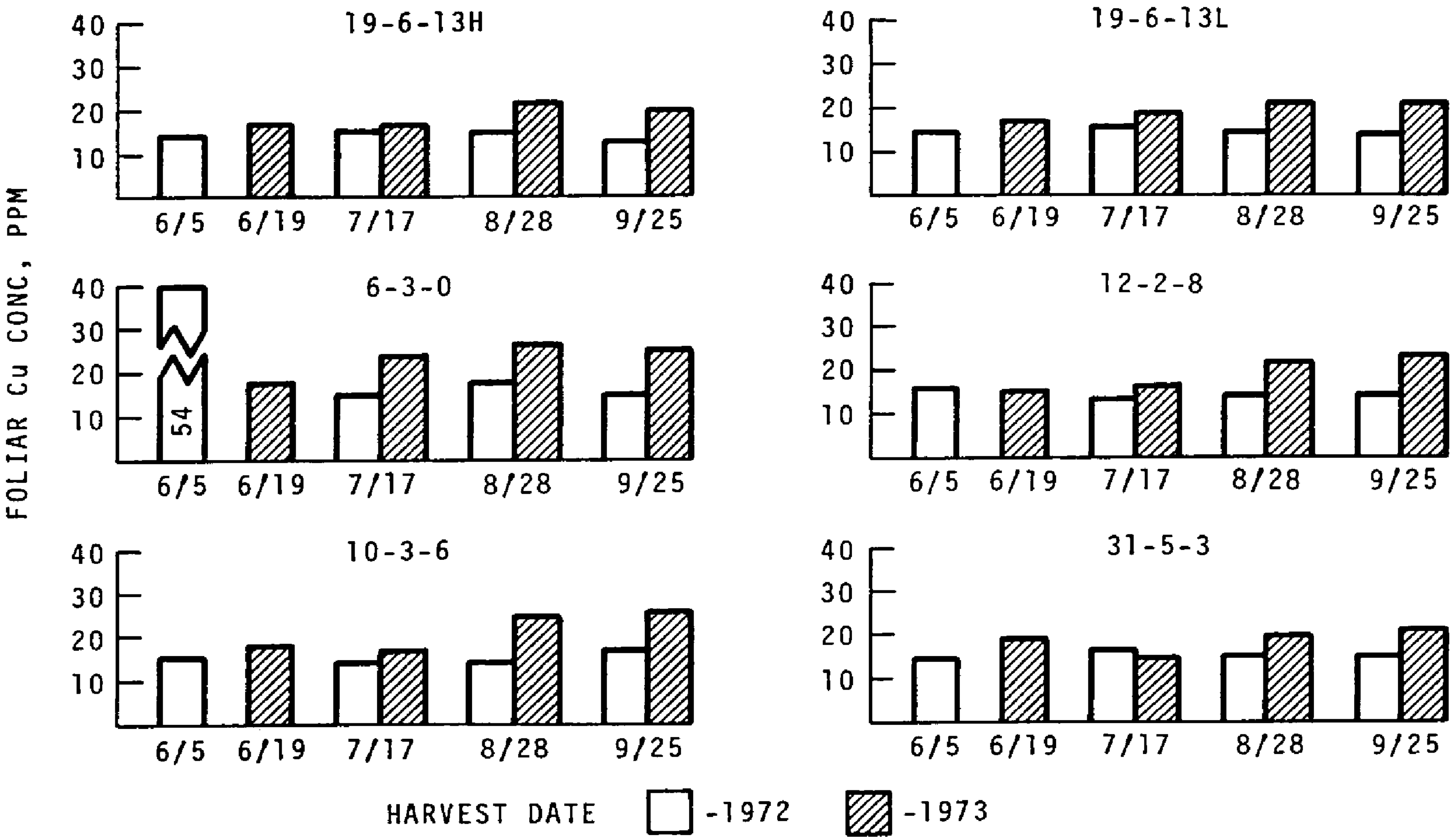

FOLIAR Mg CONC, %
19-6-13H
19-6-13L
6-3-0
12-2-8
10-3-6
31-5-3
0.4
0.3
0.2
0.1
6/5
6/19
7/17
8/28
9/25
9.25
HARVEST DATE
-1972
-1973

Figure 14. Levels of Cu in foliage of Penncross creeping betngrass during 1972 and 1973 as influenced by fertilizer treatments under field conditions



FOLIAR Cu CONC, PPM
19-6-13H
19-6-13L
6-3-0
12-2-8
10-3-6
31-5-3
54
6/5
6/19
7/17
8/28
9/25
HARVEST DATE
-1972
-1973

Figure 15. Levels of Fe in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by fertilizer treatments under field conditions

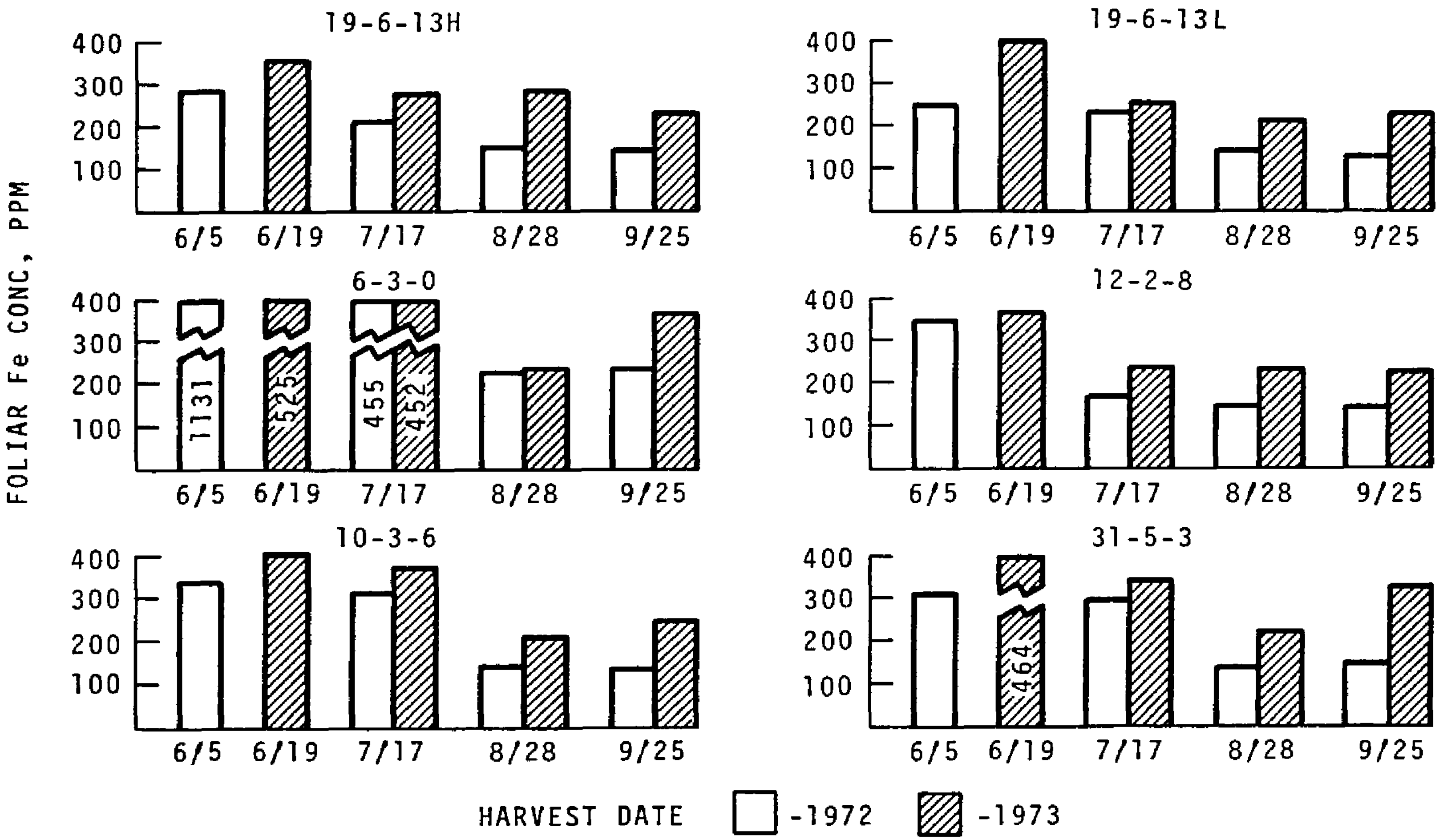

19-6-13H
19-6-13L
6-3-0
12-2-8
10-3-6
31-5-3
400
300
200
100
6/5
6/19
7/17
8/28
9/25
1131
525
455
452
464
FOLIAR Fe CONC, PPM
HARVEST DATE
-1972
-1973

Figure 16. Levels of Mn in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by fertilizer treatments under field conditions

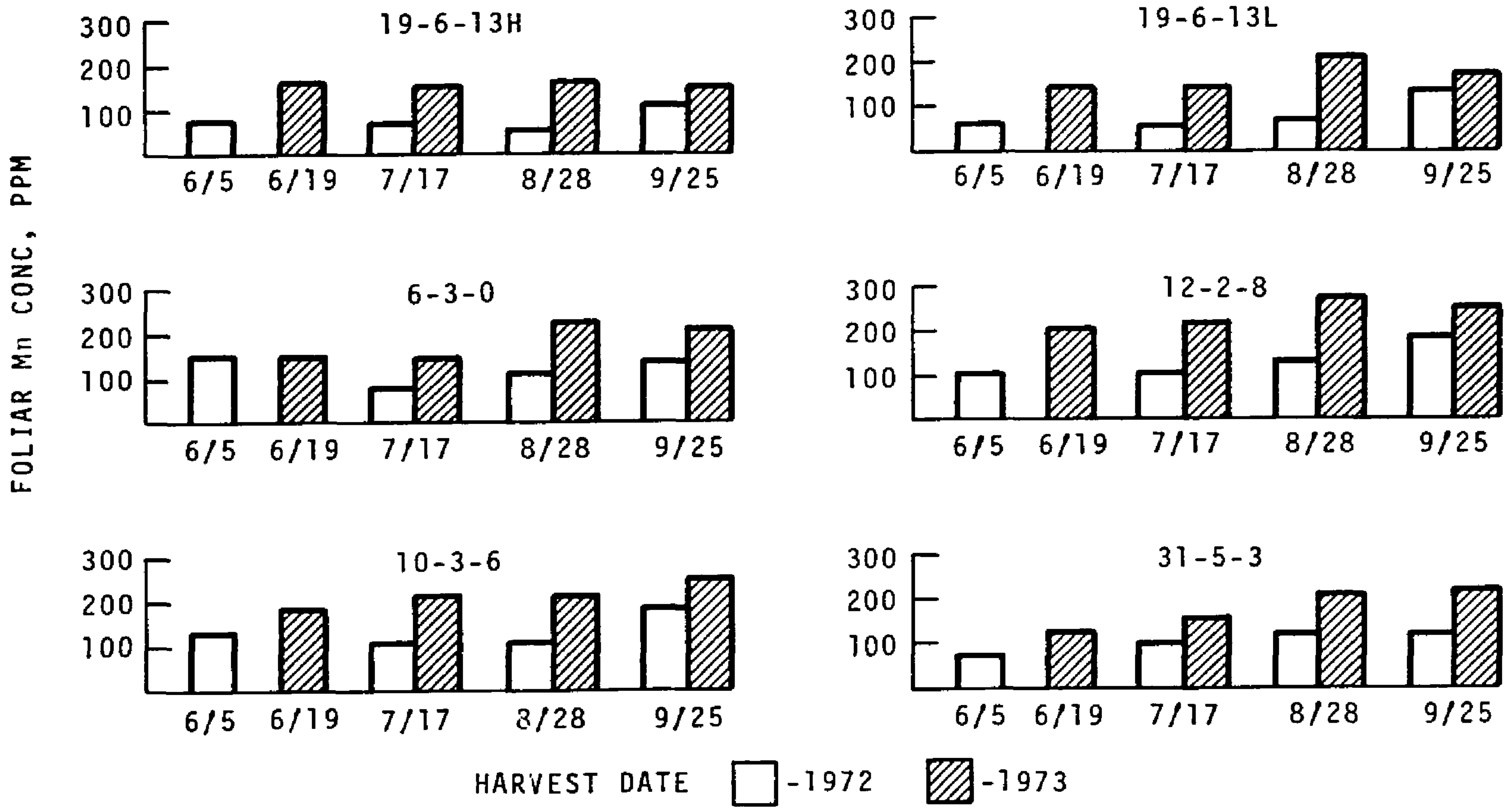
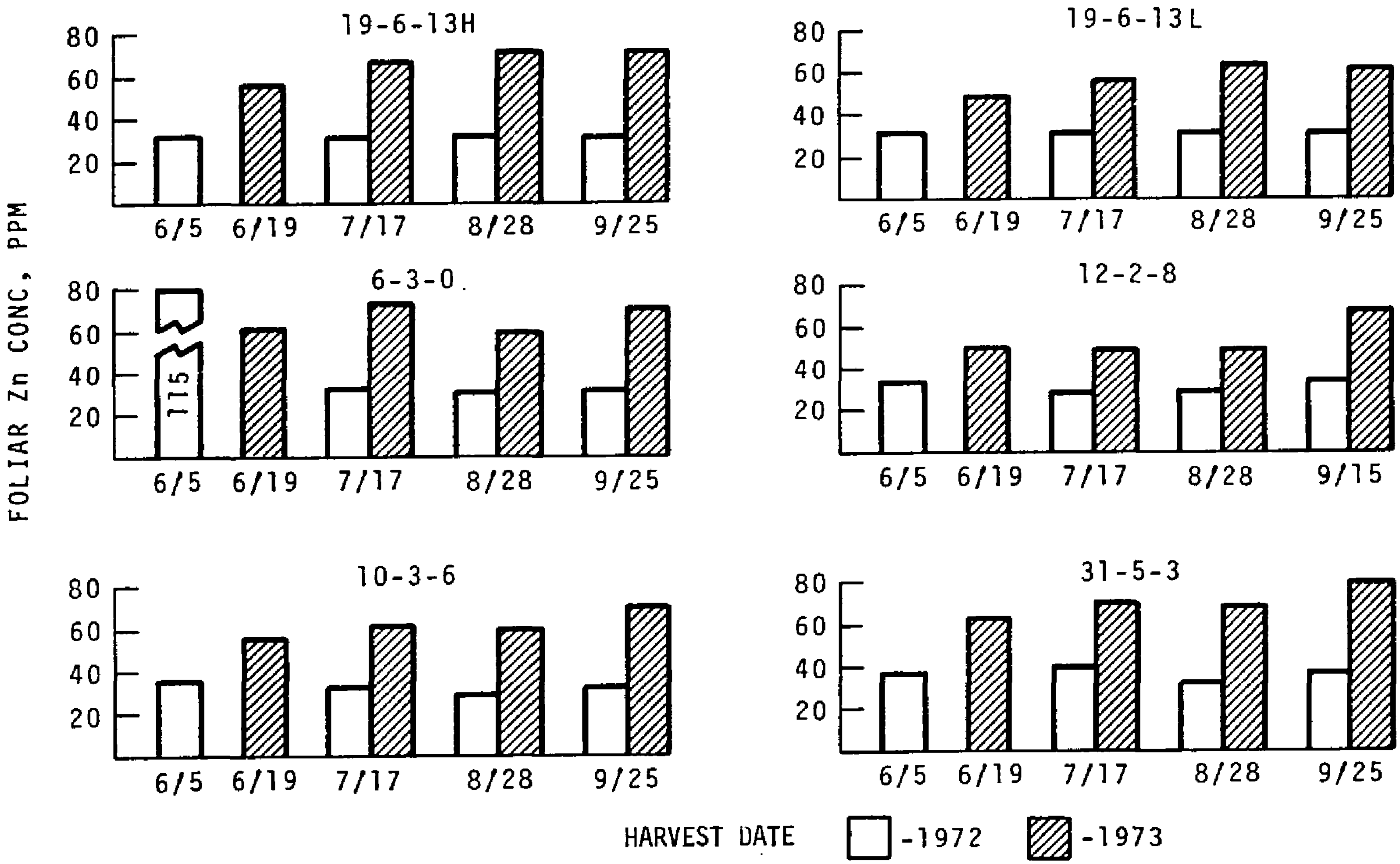

FOLIAR Mn CONC, PPM
19-6-13H
19-6-13L
6-3-0
12-2-8
10-3-6
31-5-3
300
200
100
6/5
6/19
7/17
8/28
9/25
HARVEST DATE
-1972
-1973

Figure 17. Levels of Zn in foliage of Penncross creeping bentgrass during 1972 and 1973 as influenced by fertilizer treatments under field conditions


FOLIAR Zn CONC, PPM
19-6-13H
19-6-13L
6-3-0
115
12-2-8
10-3-6
31-5-3
80
60
40
20
6/5 6/19 7/17 8/28 9/25
9/15
HARVEST DATE
-1972
-1973

Most turfgrasses are maintained culturally and nutritionally in a state of high vegetative reproduction, thus creating a relatively high need for P during the season. The upward trend in P levels in this study may be the result of a slow build up of soil P due to excessive applications of fertilizer P.

The downward trend in foliar levels of K during the season may be due to a higher relative need for K in early season to support such processes as carbohydrate translocation which, according to Beard (3), occurs at a higher rate in turfgrass plants early in the season than it does later in the season.

These trends strongly suggest that the nutritional needs of the plant change during the growing season. When complete fertilizers are used the turfgrass manager cannot adjust P and K rates in consideration of soil nutrient levels, plant needs for individual nutrients, environmental factors, differences in soils, desired growth responses and any seasonal differences in nutrient needs.

CONCLUSIONS

GREENHOUSE STUDY

The balance between N and K on an elemental basis in the growing medium has a strong effect on both shoot and root growth in the turfgrass plant. In a turfgrass nutrition program, careful consideration should be given to the fertilizer N-K ratio and the rate of application. When a treatment of 60 ppm N-60 ppm K was used in hydroponic culture the greatest top growth was produced; by reducing the N level to 10 ppm and maintaining 60 ppm K in the nutrient solution the greatest root growth was achieved. There was no advantage for either increased shoot or root growth to increasing N or K concentration above these levels.

Varying N-K ratios in the nutrient solution do have a depressing effect on the uptake of other nutrient elements. While the various treatments used in this study did not result in any visual deficiencies of the other elements, based on leaf symptoms, it is possible than an imbalance of N and K could result in deficiencies of other elements if they are in short supply based on changes which did occur, such as the depression of tissue Mg with increased levels of K in hydroponic culture.

With the increased use of sand as a growth medium in the commercial production of turfgrass and in its management, it is apparent that N supplied in excess of K in terms of elemental concentration may result in reduced root growth and that K should equal or exceed N.

FIELD STUDY

The fertilizers used in this study all resulted in an acceptable putting surface in both 1972 and 1973 when applied according to the rates indicated by their producers.

Foliar levels of N resulting from applications of the fertilizers with the lowest levels of slow-release N declined slowly after the initial application over both growing seasons. A fairly uniform level of N over both growing seasons was produced by the fertilizers that had the higher percentages of water-insoluble N. If it is desirable to maintain a uniform level of N in the turfgrass plant during the growing season, the fertilizer program must provide for more frequent applications of fertilizers that are low in water-insoluble N.

There was not a great deal of difference in the foliage levels of the other nutrient elements analyzed in this study that could be attributed to the application of the various fertilizers; however, the application of the 6-3-0 did result in the increased foliar levels of Cu, Fe, Mn and Zn. This suggests that the continued use of this material could result in high soil levels of these nutrients, perhaps to the point of eventually affecting growth adversely. It is also evident that the over supply of nutrients, such as P in this study, could, in the long term, have an undesirable effect on growth.

Most turfgrass managers utilize the commercially available fertilizers containing various levels of N, P and K and base their application rates on their experience analyzing visual factors such as leaf color, plant density and overall uniformity of stand. The use of soil test data is not a standard practice among many turfgrass managers.

Nitrogen plays an important role in improving turfgrass color, density and uniformity. The above plant characteristics are important criteria for fertilizer application. The rate at which N is applied then determines the rate the other nutrients contained in the fertilizer are applied. As indicated by the high levels of P found in this study, N rates, while satisfying the N requirements of the plant, provided more than an adequate level of P. The data of this study suggest that turfgrass nutritional programs should be based on the separate application of mineral elements. In this manner the application rates for P and K would better reflect the plant's requirements for those elements.

Turfgrass managers do not have the resources, other than soil test results, to evaluate their nutritional programs. Research should aid turfgrass managers in developing nutritional programs that supply the plant with optimum levels of nutrients, no more and no less.

APPENDIX

Table 14. Nitrogen levels in turfgrass foliage as influenced by fertilizer treatments. Values represent %N as a mean of three replications

FERTILIZER	HARVEST DATES - 1972								
TREATMENT	6/5	6/19	7/3	7/17	7/31	8/14	8/28	9/11	9/25
19-6-13H	6.73b	6.14a	6.44a	6.36a	5.46a	6.29a	6.18a	5.09c	5.62b
19-6-13L	6.58b	6.19a	6.20ab	6.12b	5.50a	5.47b	5.36b	5.00cd	5.07c
6-3-0	4.47d	4.10c	4.51c	4.10d	5.01b	4.42d	4.51cd	4.70d	4.53d
12-2-8	6.05c	5.70b	4.52c	4.24d	4.45c	4.86c	4.23de	5.70b	5.50b
10-3-6	6.11c	5.67b	4.17d	3.82e	4.35c	4.03e	3.92e	5.59b	5.49b
31-5-3	7.11a	5.79b	6.12b	5.74c	5.52a	4.88c	4.77c	6.68a	6.48a

FERTILIZER	HARVEST DATES - 1973							
TREATMENT	6/19	7/3	7/17	7/31	8/14	8/28	9/11	9/25
19-6-13H	6.32a	6.30a	6.43a	5.84a	5.78a	5.82a	6.21ab	5.80bcd
19-6-13L	5.48b	6.01ab	5.55bc	5.72a	5.60ab	5.37b	6.00b	5.37d
6-3-0	5.46b	5.59abc	4.92cd	5.18abc	5.26ab	4.68c	5.76b	5.59cd
12-2-8	5.46b	5.05c	4.71d	4.96bc	4.92ab	4.76c	6.12ab	6.08bc
10-3-6	5.40b	5.18bc	4.44d	4.88c	4.90b	4.67c	6.41ab	6.36ab
31-5-3	6.12a	6.17a	5.72b	5.71ab	5.51ab	5.19bc	6.68a	6.79a

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 15. Phosphorus levels in turfgrass foliage as influenced by fertilizer treatments. Values represent %P as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE 1972 6/5	7/17	8/28	9/25	1973 6/19	7/17	8/27	9/25
19-6-13H	0.69b	0.58N.S.	0.60b	0.52N.S.	0.79ab	0.68c	0.92b	0.94c
19-6-13L	0.63b	0.58	0.62ab	0.57	0.65c	0.77bc	1.17ab	1.02bc
6-3-0	0.98a	0.64	0.69a	0.62	0.74abc	0.84b	1.28a	1.12ab
12-2-8	0.62b	0.63	0.69a	0.62	0.68bc	0.83bc	1.33a	1.00bc
10-3-6	0.71b	0.63	0.68ab	0.60	0.76abc	1.03a	1.27a	1.18a
31-5-3	0.69b	0.62	0.68ab	0.60	0.82a	0.70bc	1.13ab	1.10ab

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 16. Potassium levels in turfgrass foliage as influenced by fertilizer treatments. Values represent %K as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE 1972 6/5	1972 7/17	1972 8/28	1972 9/25	1973 6/19	1973 7/17	1973 8/28	1973 9/25
19-6-13H	3.27a	3.15a	2.80N.S.	2.32N.S.	3.47N.S.	3.49a	2.67a	2.91a
19-6-13L	2.97b	3.08a	2.56	2.41	3.68	2.67ab	2.57ab	2.60ab
6-3-0	1.98c	2.40b	2.46	2.27	3.02	3.09ab	2.42ab	2.44b
12-2-8	2.97b	2.69b	2.45	2.34	3.24	3.18ab	2.43ab	2.89a
10-3-6	2.77b	2.39b	2.51	2.32	3.19	2.46b	2.67a	2.79ab
31-5-3	2.92b	2.37b	2.42	2.33	2.99	2.96ab	2.27b	2.92a

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 17. Calcium levels in turfgrass foliage as influenced by fertilizer treatments. Values represent %Ca as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE 1972				1973			
	6/5	7/17	8/28	9/25	6/19	7/17	8/28	9/25
19-6-13H	0.37N.S.	0.35b	0.37b	0.38b	0.38ab	0.38ab	0.45ab	0.41b
19-6-13L	0.34	0.37b	0.37b	0.38b	0.36bc	0.36ab	0.42ab	0.42b
6-3-0	0.40	0.48a	0.45ab	0.48ab	0.39ab	0.46ab	0.46ab	0.41b
12-2-8	0.38	0.45a	0.39ab	0.43ab	0.31c	0.34b	0.37b	0.36b
10-3-6	0.38	0.46a	0.39ab	0.49a	0.40ab	0.45ab	0.41ab	0.43b
31-5-3	0.35	0.52a	0.46a	0.54a	0.43a	0.47a	0.49a	0.65a

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 18. Magnesium levels in turfgrass foliage as influenced by fertilizer treatments. Values represent %Mg as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE							
	1972				1973			
	6/5	7/17	8/28	9/25	6/19	7/17	8/28	9/25
19-6-13H	0.13N.S.	0.11b	0.11b	0.12b	0.26ab	0.20b	0.22b	0.26b
19-6-13L	0.13	0.12b	0.11b	0.12b	0.23bc	0.21b	0.24ab	0.26b
6-3-0	0.13	0.14ab	0.15a	0.17a	0.26ab	0.27a	0.28a	0.33a
12-2-8	0.13	0.13ab	0.14ab	0.16ab	0.21c	0.21b	0.25ab	0.27ab
10-3-6	0.13	0.12b	0.12ab	0.14ab	0.24bc	0.25ab	0.26ab	0.29ab
31-5-3	0.15	0.16a	0.15a	0.16ab	0.28a	0.24ab	0.27ab	0.33a

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 19. Copper levels in turfgrass foliage as influenced by fertilizer treatments. Values represent ppm Cu as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE 1972				HARVEST DATE 1973			
	6/5	7/17	8/28	9/25	6/19	7/17	8/28	9/25
19-6-13H	16B	17a	16N.S.	13b	18ab	18ab	21N.S.	20b
19-6-13L	16b	17a	16	14b	18ab	19ab	21	21ab
6-3-0	54a	16ab	18	16ab	18ab	23a	27	24ab
12-2-8	17b	15b	16	16ab	17b	18ab	21	22ab
10-3-6	17b	17b	16	18a	19a	18ab	25	26a
31-5-3	15b	17a	17	16ab	19a	16b	20	21ab

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 20. Iron levels in turfgrass foliage as influenced by fertilizer treatments. Values represent ppm Fe as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE 1972 6/5	1972 7/17	1972 8/28	1972 9/25	1973 6/19	1973 7/17	1973 8/28	1973 9/25
19-6-13H	294bc	203b	155N.S.	152N.S.	361N.S.	289N.S.	290N.S.	233N.S.
19-6-13L	251c	230ab	142	136	402	255	211	217
6-3-0	1131a	455a	210	225	525	452	222	378
12-2-8	354b	178b	125	160	372	233	214	231
10-3-6	338bc	306ab	140	154	406	381	202	256
31-5-3	317bc	301ab	145	165	464	341	216	238

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 21. Manganese levels in turfgrass foliage as influenced by fertilizer treatments. Values represent ppm Mn as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE 1972				HARVEST DATE 1973			
	6/5	7/17	8/28	9/25	6/19	7/17	8/28	9/25
19-6-13H	85N.S.	70N.S.	65c	107b	170abc	157b	172b	160c
19-6-13L	79	81	88bc	133ab	149c	158b	211ab	180bc
6-3-0	147	94	104abc	139ab	151bc	155b	231ab	204abc
12-2-8	106	105	131a	195a	207a	216a	280a	266a
10-3-6	126	103	108abc	170ab	195a	214a	219ab	255ab
31-5-3	87	101	122ab	110b	173abc	170b	205ab	211abc

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 22. Zinc levels in turfgrass foliage as influenced by fertilizer treatments. Values represent ppm Zn as a mean of three replications

FERTILIZER TREATMENT	HARVEST DATE 1972 6/5	7/17	8/28	9/25	1973 6/19	7/17	8/28	9/25
19-6-13H	36b	33N.S.	35a	33N.S.	57ab	65ab	71a	69b
19-6-13L	34b	33	33ab	29	51b	58ab	63ab	61c
6-3-0	115a	34	34a	36	62a	74a	63ab	71b
12-2-8	35b	31	30ab	36	52b	52b	53b	66bc
10-3-6	38b	33	29b	35	57ab	62ab	60ab	70b
31-5-3	38b	40	36a	38	63a	72a	67a	81a

Means having letters in common are not significantly different at 5% level by Duncan's Multiple Range Test.

BIBLIOGRAPHY

1. Adams, W. H., P. J. Bryan, and O. E. Walker. 1974. Effects of cutting height and N nutrition on growth pattern of turfgrass. Proceedings of the Second International Turfgrass Research Conference. E. C. Roberts, ed. Amer. Soc. Agron., Madison, Wis.

2. Bear, F. E. 1950. Cation and anion relationships in plants and their bearing on crop quality. Agron. Jour. 42:176-178.

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

4. Blaser, R. E., and W. E. Stokes. 1943. Effect of fertilizer on growth and composition of Carpet and other grasses. Fla. Ag. Exp. Sta. Bul. No. 390.

5. Boeker, P., and W. O. von Boberfeld. 1974. Influence of various fertilizers on root development in a turfgrass mixture. Proceedings of the Second International Turfgrass Research Conference. E. C. Roberts, ed. Amer. Soc. Agron., Madison, Wis.

6. Burton, G. W., and E. H. DeVane. 1952. Effect of rates and method of applying different sources of nitrogen upon the yield and chemical composition of Bermudagrass, Cynodon dactylon (L). Agron. Jour. 44:128-132.

7. Davis, R. R. 1969. Nutrition and Fertilizers in Turfgrass Science. Monograph No. 14. A. A. Hanson, and F. V. Juska, eds. Amer. Soc. of Agron., Madison, Wis.

8. Devlin, R. M. 1967. Plant Physiology. Reinhold Publishing Corp., New York.

9. Eheart, J. F., and W. B. Ellett. 1941. The effect of certain nitrogenous fertilizers on the chemical and vegetative composition and yield of pasture plants. Va. Ag. Exp. Sta. Bul. No. 75.

10. Evans, E. M., L. E. Ensinger, B. D. Doss, and O. L. Bennett. 1961. Nitrogen and moisture requirements of Coastal Bermuda and Pensacola Bahia. Auburn Ag. Exp. Sta. Bul. No. 337.

11. Fagan, T. W., and H. T. Watkins. 1932. The effect of manures on the nitrogen and mineral content of the produce of contrasting pasture types. Welsh. Jour. Agr. 8:192-196.

12. Gauch, H. G. 1972. Inorganic Plant Nutrition. Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa.

13. Gilbert, F. A., A. H. Bowers, and M. D. Sanders. 1958. Effect of N sources in complete fertilizers on bluegrass turf. Agron. Jour. 50:320-323.

14. Goss, R. L. 1975. Fertilizer programs for high and low budget golf clubs. The Greenmaster 11(7):2-12.

15. Griffith, W. K., M. R. Teel, and H. E. Parker. 1964. Influence of N and K on the yield and chemical composition of orchardgrass. Agron. Jour. 56:473-475.

16. Juska, F. V., A. A. Hanson, and A. W. Hovin. 1970. Growth of Merion Kentucky bluegrass to fertilizer and lime treatments. Agron. Jour. 62:25-27.

17. Knoop, W. E. 1969. Correlation between macro element deficiency symptomology and chemical composition of major warm season turfgrass. Unpublished M.S.A. thesis, University of Florida.

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

19. Kresge, C. B., and S. E. Younts. 1963. Response of orchardgrass to potassium and nitrogen fertilization on a Wickham silt loam. Agron. Jour. 55:161-164.

20. Landua, D. P., A. R. Swoboda, and G. W. Thomas. 1973. Response of coastal bermudagrass to soil applied sulfur, magnesium and potassium. Agron. Jour. 65:541-544.

21. Lawton, K., and M. B. Tesar. 1957. Yield, K content and root distribution of alfalfa and bromegrass grown under three levels of applied potash in the greenhouse. Agron. Jour. 50:148-151.

22. Liebhardt, W. C. 1968. Effect of potassium on carbohydrate metabolism and translocation. The role of potassium in agriculture. V. J. Kilmer, S. E. Younts, and N. C. Brady, eds. Amer. Soc. Agron., Madison, Wis.

23. Lobenstein, C. W. 1967. Green grass and grass roots. The Golf Superintendent 35(1):32-34.

24. MacLeod, L. B. 1965. Effect of N and K on the yield and chemical composition of alfalfa, bromegrass, orchardgrass and Timothy grown as pure species. Agron. Jour. 57:261-266.

25. Madison, J. H. 1971. Principles of turfgrass culture. Van Nostrand Reinhold Co., New York, N. Y.

26. Mays, D. A. and G. L. Terman. 1969. Sulfar coated urea and uncoated soluble nitrogen fertilizer for fescue forage. Agron. Jour. 61: 489-492.

27. McLean, E. O. 1957. Plant growth and uptake of nutrients as influenced by levels of nitrogen. Soil Sci. Soc. Amer. Proc. 21:219-220.

28. Miller, R. W. 1974. Effect of deficient nutrient solutions on the concentration of 16 mineral elements in clippings of Kentucky 31 tall fescue. Proceedings of the Second International Turfgrass Research Conference. E. C. Roberts, ed. Amer. Soc. Agron., Madison, Wis.

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

30. Monroe, C. A., G. D. Coorts, and C. R. Skogley. 1969. Effects of N-K levels on the growth and chemical composition of Kentucky bluegrass. Agron. Jour. 61:294-296.

31. Nielsen, K. F., and R. K. Cunningham. 1964. The effects of soil temperatures and forms and level of nitrogen on growth and chemical composition of Italian Ryegrass. Soil Sci. Soc. Amer. Proc. 28:213-218.

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

33. Prince, A. B. 1954. Yield and chemical composition of annual ryegrass and crimson clover as affected by nitrogen and potassium fertilization. Soil Sci. 78:445-452.

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

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

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

37. Teel, M. R. 1968. The effect of K on the organic acid and nonprotein N content of plant tissue. The Role of Potassium in Agriculture. V. J. Kilmer, W. E. Younts, and N. C. Brady, eds. Amer. Soc. Agron., Madison, Wis.

38. Vicente-Chandler, J., R. W. Pearson, F. Abruna, and S. Silva. 1962. Potassium fertilization of intensively managed grasses under humid tropical conditions. Agron. Jour. 54:450-453.

39. Vose, P. B. 1962. Nutritional response and shoot/root ratio as factors in the composition and yield of genotypes of perennial ryegrass. Annuals of Bot. N. S. 26:425-437.

40. Waddington, D. V., E. L. Moberg, and J. M. Duich. 1972. Effect of N source and K rate on soil nutrient levels and the growth and elemental composition of Penncross creeping bentgrass. Agron. Jour. 64:562-566.

41. Walker, W. M., and J. Pesek. 1963. Chemical composition of Kentucky bluegrass as a function of applied nitrogen, phosphorus and potassium. Agron. Jour. 55:247-250.

42. Washko, W. W. 1949. Effect of K upon the N and mineral content of bromegrass. Agron. Jour. 41:101-103.

43. Wright, N. 1962. Root weight and distribution of Blue Panicgrass, Panicum antidolate Retz., as affected by fertilizers, cutting height and soil moisture stress. Agron. Jour. 54:200-202.

BIOGRAPHICAL DATA

Name in Full:

William Edward Knoop

Date of Birth:

August 24, 1936

Place of Birth:

Norwalk, Ohio

Secondary Education:

William Chrisman High School, Independence, Missouri

Collegiate Institutions attended:	Dates	Degrees
Iowa State University	1962-1965	B.S.
University of Florida	1968-1969	M.S.A.

Publications:

Knoop, W. E. 1971. Tissue testing - a new approach to turf fertilization. Grounds Maintenance. August issue, pp 29-30.

Estes, G. O., W. E. Knoop, and F. D. Houghton. 1973. Soil-plant response to surface-applied mercury. Jour. Env. Qual. 2:451-452.

Knoop, W. E. 1971. A truly balanced fertilizer benefits turf growers. Better Crops, Fall issue, pp 28-29.

Knoop, W. E. 1972. Turf nutrition. Weeds, Trees and Turf. February issue, p 14.

Knoop, W. E. 1975. Soil testing. The Golf Superintendent. January issue, pp 17-19.

Knoop, W. E. 1975. The golf course superintendent and the fertilizer crisis. The Golf Superintendent. February issue, pp 22-23.

Positions held:	Dates
Extension Turgrass Specialist, University of New Hampshire	1970-1974
Director of Education, Golf Course Superintendent's Association of America	1974-1976