CORRELATION OF SOIL TEST VALUES OF PHOSPHORUS AND POTASSIUM WITH RESPONSE OF 'PENNCROSS' CREEPING BENTGRASS (AGROSTIS PALUSTRIS HUDS.)

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ABSTRACT OF THE THESIS

Correlation of Soil Test Values of Phosphorus and Potassium with Response of 'Penncross' Creeping Bentgrass (*Agrostis palustris* Huds.)

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The interpretation of soil test results for making phosphorus and potassium fertilizer recommendations for turfgrasses are based on studies with field crop and forage grass yield. Yield is not always an indication of optimum plant growth in turfgrass culture and may result in impairment of quality turf. Grass species grown for turf also respond differently to soil nutrient levels than other crops. This leads to erroneously interpreting soil test results.

Greenhouse studies were conducted for the purpose of correlating soil test values of phosphorus and potassium with yield, shoot and root growth of 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.) grown in a soil with a high sand content. Five levels of soil phosphorus and potassium were established at pH 5.0 and 6.0 in separate experiments for each nutrient. Phosphorus was extracted from the soil by the modified Morgan, double acid and Bray-1 solutions. Potassium was extracted by the modified Morgan, double acid and neutral normal ammonium acetate solutions.

A field experiment was conducted to study the effect of three soil phosphorus levels at pH 5.0 and 6.0 on the yield, shoot and root growth and turfgrass quality of Penncross creeping bentgrass maintained as putting green turf. Three phosphorus fertilizer rates (0, 29 and 59 kg P/ha) were applied to the soil phosphorus and pH levels to study the change in bentgrass growth to changes in extractable phosphorus. The soil and extracting solutions for phosphorus were the same as used in the greenhouse investigation. The relationship between soil phosphorus and leaf tissue phosphorus were studied.

Clipping yield and shoot and root growth were reduced at the lowest level of soil phosphorus compared with other levels in the greenhouse and field investigations. Turfgrass quality was also decreased on bentgrass growing in the low phosphorus soil in the field. Phosphorus fertilization increased shoot growth with the greatest change in growth occurring with phosphorus additions to the low soil phosphorus level. Soil potassium levels had little affect on bentgrass growth in the greenhouse investigation.

Correlation coefficients relating extractable phosphorus and potassium with bentgrass response from the greenhouse studies were not closely related. Correlations between soil test values for phosphorus and plant response from the field investigation were lower than the greenhouse values.

Phosphorus deficiency symptoms on the foliage of bentgrass and a low percent of phosphorus in the leaf tissue were found on plants grown in the low phosphorus soil. Leaf tissue phosphorus was closely related to available soil phosphorus extracted by the three chemical solutions. The modified Morgan was the most accurate and consistent method for predicting available soil phosphorus for bentgrass in this investigation.

The data presented show that none of the extracting procedures can be used satisfactorily for predicting response of bentgrass from soil test values of phosphorus and potassium found by these methods. The results indicate that the extractants for phosphorus be used only to monitor soil phosphorus levels in order to maintain soil levels above the minimal soil phosphorus values found in this investigation. More studies are needed to evaluate other soil testing methods to provide a better assessment of available phosphorus and potassium for bentgrass culture.

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INTRODUCTION

Fertilizer recommendations for turfgrasses are based largely from calibration data obtained with field crops and forage grasses. The main crop response used in correlating soil test levels of phosphorus and potassium has been yield. However, in turfgrass culture, yield is not always an indication of optimum plant growth and in some instances results in impairment of quality turf. Levels of plant nutrients that result in optimum turfgrass response may be either too low or too high than levels required for other crops. Therefore, turfgrass response characteristics other than yield need to be correlated with soil test values of essential nutrients.

No formal studies on correlating and calibrating soil test levels of phosphorus and potassium with response of turfgrasses have been undertaken to date. The need for this data becomes increasingly important for a number of reasons. One is the need to refine fertilizer recommendations to optimize growth and to use fertilizers efficiently. Secondly, areas of fine turfgrasses cultured on sands and other coarse textured soils, which are inherently infertile, have increased greatly. This condition makes it difficult to establish turfgrasses and to maintain levels and balance of nutrients after a good stand of grass is achieved. Therefore the need to calibrate levels of phosphorus and potassium extracted from different soils with turfgrass response is obvious.

The objective of this research was to study (1) several extracting procedures for the purpose of evaluating their use as indexes of available phosphorus and potassium to creeping bentgrass and (2) to study the change in response of creeping bentgrass with changes in available soil phosphorus for the purpose of improving phosphorus fertilizer recommendations for bentgrass culture. The study was divided into two phases. The first phase involved greenhouse experiments designed to correlate soil test values for phosphorus and potassium with yield, shoot growth and root development of creeping bentgrass. The second phase was a field experiment designed to calibrate three chemical methods to provide fertilizer phosphorus recommendations for creeping bentgrass establishment and maintenance.

LITERATURE REVIEW

Studies measuring the growth response of turfgrasses to fertilizer applications of phosphorus and potassium have been conducted under a wide range of conditions.

McVey (1967) reported a significant growth response of turfgrass seedlings to phosphorus fertilization, especially on soils deficient in phosphorus but also on some soils measuring high in phosphorus. Rates as low as 0.0074 kg P/92.9m^2 stimulated plant growth on phosphorus deficient soils. Westfall et al. (1971) reported increased seedling density of Windsor Kentucky bluegrass (Poa pratensis L.) with phosphorus treatments on a phosphorus deficient soil.

Van Dam (1979) showed that a single application of 1.14 kg P/ 92.9m^2 to an 'Alta' tall fescue (Festuca arundinacea Schreb) turf deficient in phosphorus corrected the condition. Mean soil test values for phosphorus determined by the Olsen method measured 6.9 ppm which was in the phosphorus deficient range.

Yield of tall fescue on unlimed soils increased with increments of phosphorus up to 159 kg P/ha as reported by Shoop et al. (1961). The maximum yield on limed soil was obtained with only 20 kg P/ha. In the same study, the maximum yield of redtop (Agrostis alba L.) was achieved with 40 kg P/ha on unlimed soils and 20 kg P/ha on limed soils. A difference in turfgrass species response to phosphorus fertilization on unlimed soils is evident.

The need to apply the correct amount of potassium was demonstrated in studies by Goss (1965). When 325 kg K/ha was applied to a putting green turf, 47% of the added potassium was recovered in the plant. When 162 kg K/ha was applied, 93% of the potassium was recovered. A waste of potassium can result from using high fertilizer rates of potassium, especially on soils where nutrients are easily leached. Turf quality was reduced when no potassium was applied in the same investigation. Markland et al. (1967) found root response of Washington creeping bentgrass to potassium treatments of 0, 50 and 100 ppm was expressed by a quadratic function with 50 ppm resulting in maximum yield. Plants were grown in solution culture pots in a greenhouse. Christians et al. (1979) reported an increase in tissue production with potassium additions at low levels of nitrogen on putting greens composed of calcareous sands, but tissue production which decreased at high levels of nitrogen was not influenced by additions of potassium. Observations indicated that plant response to these high pH greens is different than greens constructed of other sands.

Monroe et al. (1969) reported an increase in yield of clippings, root weights, tillering and rhizome development of Kentucky bluegrass with potassium fertilization in a greenhouse study. However, the magnitude of the increase was associated with the amount of nitrogen applied. Nitrogen had no effect on the percent potassium found in the leaf tissue and leaf tissue nitrogen and potassium had no significant effect on leaf tissue phosphorus.

High correlations between clipping yield and applied nitrogen and between yield and turf quality on Kentucky bluegrass were reported by Calhoun et al. (1964). However, the effect of phosphorus and potassium on Kentucky bluegrass was limited. Calhoun et al. suggests that quality ratings as a means of predicting nitrogen requirements seems justified. Schmidt et al. (1979) indicated that drought recovery of common Kentucky bluegrass was closely related to soil phosphorus content. Recovery from summer drought was inhibited with high nitrogen if soil phosphorus was low suggesting the importance of balance nutrition.

Root growth of several bentgrass species was shown by Bell and DeFrance (1944) to decline with increased phosphorus fertilization although available phosphorus in the soil was considered adequate for growth in plots receiving no phosphorus. Turf quality was not affected by phosphorus treatments however, and it was suggested that the added phosphorus may have made conditions more favorable for root decomposition accounting for the difference in root weight between the treatments. Sprague (1933), working with Virginia creeping bentgrass, showed evidence indicating that a low pH may mask the effect of phosphorus on root growth by creating an environment where non-functional roots accumulate.

Holt and Davis (1948) found a reduction of root growth in Norbeck and Arlington creeping bentgrass when potassium was withheld from plants growing in a white quartz sand in the greenhouse. There was no effect on root growth when phosphorus was withheld. Turf cover of the grasses was decreased by the absence of both nutrients.

Although there is enough evidence to document the effect of phosphorus and potassium fertilization on turfgrass response, little work has been undertaken to relate soil test values of phosphorus and potassium with turfgrass response and to study the changes in plant response with changes in soil phosphorus and potassium.

Turner (1976) reported that fertilizer recommendations for phosphorus and potassium were based on wide differences in ranges of phosphorus and potassium from soil test results in a survey taken on soil testing programs among seven different soil testing laboratories in the Northeast. The ranges for phosphorus were greater than for potassium. Four of the laboratories that used the double acid extraction procedure classified low phosphorus from 12 to 90 kg P/ha, medium phosphorus from 43 to 114 kg P/ha and high phosphorus from 67 to 123 kg P/ha. According to Turner (1976), the probable reason for the discrepancies in fertilizer recommendations was due to the absence of studies relating soil test values to turfgrass response. Beard (1973) comments on the arbitrary use of field crop and pasture studies with some modifications in forming fertilizer recommendations for turfgrasses. He further comments on the paucity of studies that relate nutrient levels in the soil to turfgrass response and stresses the need for correcting this problem in the future. Madison (1971), although realizing the value of soil tests, suggested they are often overrated for regular use. He suggests the concept of critical values for plant nutrients may be a better method of assessing the nutrient needs of turfgrasses.

Latham (1973) cautioned about the difficulties in handling the nutritional needs of grasses grown on putting greens with very high sand content, which may suffer from over or under fertilization. He emphasized this as an important reason for the soil test. Latham also stressed the need to monitor magnesium on these soils because of their normally low cation exchange capacity. Davis (1969) emphasized the importance of correlating soil tests with plant response but further points out the difficulties with turfgrasses in precisely measuring a single response such as yield in field corn. Because of this, few correlation studies have been done. Davis (1969) further illustrates the problems with plant tissue analysis. He found that potassium content of Kentucky bluegrass leaf tissue varied more with time than with potash fertilization and that plots in the study that received no potassium for eight years showed no signs of potassium deficiency.

The soil texture and type of clay mineral affects the relative availability of potassium. Hanway et al. (1962) reported that corn grown on coarse textured soils had more potassium in the leaves than corn grown on fine textured soils although both tested the same for soil potassium at the start. This indicated a difference in the pattern of release from the two soils. Doll and Lucas (1972) state that most crops do not respond to applied potassium when exchangeable potassium is greater than 170 pp2m for sands and loamy sands. Jorden et al. (1966) found that coastal bermudagrass (Cynodon dactylon L. Pers.) responded to potassium applications only when the soil test value for potassium was below 40 ppm in the surface of a loamy sand and sandy loam soil or when the plant tissue contained less than 1.0% potassium. Colby and Bredakis (1966) found bentgrasses to have the unusual ability to utilize potassium from mineral sources in the soil and they raised a serious question on the value of soil tests for recommending potassium fertilization on bentgrass species.

When copper and zinc were applied at different rates to a golf green soil mixture, Watson et al. (1979) reported an increase in copper and zinc uptake by creeping bentgrass at high soil phosphorus levels and they found toxicity to bentgrass occurred at low soil levels of copper and zinc when high levels of soil phosphorus were maintained. Zinc uptake and toxicity to bentgrass was greater at pH 5.7 than at pH 6.2. The data suggest the sensitivity of bentgrass to nutrient levels when grown in high sand putting green soil mixtures and the need for closely monitoring phosphorus levels.

Blaser (1968) reported that of 223 putting greens tested for soil phosphorus that were five years or older, 69% tested very high while none tested low. In 46 new putting greens less than five years old, none tested very high in phosphorus while 37% tested low. This indicates a build up of phosphorus in old greens over a period of years even though clippings are removed. It also suggests the need for phosphorus on putting greens that have been recently built. The low soil test values found in soils on new putting greens is in part indicative of the present fertilizer programs that emphasize low phosphorus. Blaser (1968) further reported that none of the old greens tested very high in available potassium, only 7% tested high and 39% tested low. The same low trend followed for the new greens.

Paul (1973) suggests that soil test values for California soils of less than 8 ppm phosphorus estimated by the sodium bicarbonate solution are probably deficient in phosphorus and some phosphorus should be applied. He suggests that although the critical values for potassium are not known for turfgrasses, that potassium fertilization is required if available potassium is less than 50 ppm in the soil. This value is established for grains. Morgan (1941) discusses the nutrient requirements of various crops for Connecticut and places bentgrasses in the lowest group of four possible classes in relationship to their requirements for phosphorus and potassium. He places Kentucky bluegrass in the medium and low group for their respective requirements.

Watschke et al. (1977) found a highly significant correlation between soil test values of phosphorus using the Bray no. 1 method with plant tissue phosphorus of Merion Kentucky bluegrass in a November harvest clipping from a field experiment. However, in the same study, no significant correlation was found between soil test values for phosphorus and clipping yield. A significant correlation between soil test values for phosphorus and clipping yield was demonstrated in a greenhouse study by the same investigators. Hall and Miller (1974) reported a better correlation between tissue phosphorus of Merion Kentucky bluegrass and maximum yield than with soil test values for phosphorus and maximum yield in a greenhouse study. Ozus and Hanway (1966), in a greenhouse study, found tissue phosphorus and yield of common ryegrass (Lolium multiflorum L.) to be highly correlated with soil test values of phosphorus over several harvest dates.

Using multiple regression equations, Walker and Pesek (1963) reported that applied nitrogen and phosphorus had a more significant effect upon the percent potassium in the leaf tissue of Kentucky bluegrass than the variation caused by the application of potassium. Although nitrogen and potassium significantly affected the percent leaf tissue phosphorus, applied phosphorus accounted for the greatest variation in percent phosphorus in the leaf tissue of Kentucky bluegrass. Critical values for percent leaf tissue phosphorus and potassium for Kentucky bluegrass were established by Walker and Pesek (1967) as 0.25% and 1.74%, respectively. Critical values are those defined for maximum yield beyond which luxury consumption occurs. However, the critical value of phosphorus was found by the investigators to depend on the percent potassium in the tissue and similarly the critical value of potassium was dependent on the percent leaf tissue phosphorus. Lunt et al. (1974) reported minimum tissue levels of 0.4% for phosphorus and 1.0% for potassium in Newport Kentucky bluegrass associated with maximum yield.

Lathwell et al. (1958) found that soil test values for phosphorus determined by several extracting procedures gave a better correlation with phosphorus uptake by five crops studied on twenty-one different soil types than with cumulative or relative yield. Philips and Barber (1959) reported that total potassium uptake in German millet (Seteria italica L.) and corn (Zea mays L.) was a more reliable means of estimating available soil potassium than the percent potassium in the leaf tissue. They further indicated that total uptake of potassium was less effected than percent leaf tissue potassium by variations in nitrogen and phosphorus. This raises a question of the value of using percent nutrients in the leaf tissue for assessing available soil nutrients. It is unlikely that total uptake of nutrients in turfgrasses in the field is obtainable because of the large amount of labor needed in accumulating clippings over the duration of the growing season.

Before better fertilizer recommendations for turfgrasses based on soil tests results for phosphorus and potassium can be made, the relationship between turfgrass response and levels of available phosphorus and potassium in the soil must be better understood. A large amount of work has been carried out to correlate and calibrate soil test values for phosphorus and potassium with other crops.

Studies by Song and Seatz (1953) relating soil test value of phosphorus and potassium with a large number of crops including corn, small grains and permanent pasture species over a large number of experimental sites resulted in a non-significant correlation with phosphorus on all crops and with potassium on all crops with the exception of corn. A more thorough characterization of the soil was suggested to improve the relationship between soil test values and crop response. Baumgardner and Barber (1956) showed the effect of soil catenas and drainage profiles on the regression of soil test values of phosphorus with alfalfa (Medicago sativa L.). Bishop et al. (1958) reported a slight improvement in the correlation coefficient using multiple regression analysis by including several soil properties as independent variables with yield of phosphorus in German millet as the dependent variable. However, the inclusion of the soil variables in the regression equation did not result in a significant difference in the correlation coefficient over the extracting solution used alone. Only a small percentage of the variation in the relationship of soil phosphorus to the uptake of phosphorus in millet was accounted for by the soil properties.

Attoe and Truog (1949) reported a change in the relationships between soil phosphorus and yield of a legume hay on two soils over a period of six years using a partial correlation resulting in a high value of r = 0.88 to a low of r = 0.02. When the effect of potassium was taken into account, a large improvement in the coefficient of correlation was achieved ranging from a high value of r = 0.94 to a low of r = 0.69. A poor relationship between response of a legume-grass combination grown for hay on a large number of experimental sites to soil test values for phosphorus and potassium was reported by Lawton et al. (1947) using four different extracting methods. However, increased hay yields were attributed to phosphorous fertilization.

The National Soil Test Work Group (1956) reported higher correlations between soil test values for phosphorus and potassium with percentage yield had been obtained in greenhouse investigations than in field experiments on a large number of soils and crops tested. The difference between the correlations found were accounted for by a number of uncontrolled variables in the field work such as temperature, rainfall, cultural practices and plant pests. The report also emphasizes the great influence laboratory techniques have on differences in correlations obtained between soil laboratories that use the same extractants.

Fitts and Nelson (1956) state that greenhouse studies are useful in comparing extracting procedures, however, calibration of the methods with plant response in the field is essential for making fertilizer recommendations.

The influence of phosphorus and potassium fertilization on turfgrasses has been cited. The insufficiency of background data for fertilizer recommendation of phosphorus and potassium to turfgrass and the problems in assessing turfgrass response to soil test values of phosphorus and potassium have been emphasized. Several studies have shown the relationship of soil phosphorus with yield and percent phosphorus in the leaf tissue of a few turfgrass species. Studies showing the relationship between other crops and soil test values were cited.

MATERIALS AND METHODS

The research project was divided into two phases, four greenhouse and one field experiment.

Greenhouse Experiments

Greenhouse experiments were conducted to study the relationship between creeping bentgrass growth and soil test values and leaf tissue content of phosphorus and potassium. Harvests of the whole plant were taken on two different dates for each nutrient which gave a total of four separate greenhouse experiments. The first potassium and phosphorous experiments were terminated at the end of 15 weeks from seeding on January 16 and January 23, 1979 respectively. The second phosphorus experiment was terminated at the end of 26 weeks on April 10, 1979 and the second potassium experiment at 42 weeks on July 27, 1979. The soil used in the greenhouse studies was the same soil used in the field investigation as described in the materials and methods section on the field experiment that follows.

Five levels of soil phosphorus were established at two pH levels designated pH_1 and pH_2 in the two phosphorus experiments. Monocalcium phosphate, $Ca(H_2PO_4)_2 \cdot H_2O$, was added to the soil to furnish the following rates of phosphorus: 0, 30, 60, 92 and 133 pp2m. These were designated as P_0, P_1, P_2, P_3 and P_4 respectively. Potassium chloride, KCl was applied to the soil to establish five levels of potassium in the potassium experiments at the following rates of potassium: 0, 74, 174, 219 and 293 pp2m and these were designated as K_0, K_1, K_2, K_3 and K_4 respectively. Potassium was applied to the soil for all phosphorus variables in the phosphorus experiments at a rate of 219 pp2m. Phosphorus was applied to the soil to the potassium variables in the potassium experiments at a rate of 133 pp2m. Nitrogen in the form of urea was applied to the soil at a rate of 100 pp2m in each experiment. Magnesium sulfate was added to the soil in each experiment to supply 40 pp2m of magnesium to avoid low magnesium. Aluminum sulfate was added to adjust soil pH on the designated low pH treatment which was designated pH_1. All chemicals were thoroughly mixed with the soil for each treatment. The soil was moistened and each treatment placed in a plastic bag. The soil was equilibrated with all treatments for a 12 week period. Soil tests were made after the equilibration period and are reported in Tables 1 and 2.

After the equilibration period, 4.8 kg of air dry soil was placed in 17.5 cm diameter plastic containers. Each container was seeded with 10 seeds of Penncross creeping bentgrass. The potassium and phosphorus experiments were seeded on September 29 and October 6, 1978 respectively. The containers were thinned to five plants per container four weeks after seeding.

Each soil phosphorus and potassium level was replicated four times. A randomized complete block design was utilized for the 2x5 factorial experiments.

Maintenance nitrogen was applied at the rate of 50 pp2m to all experiments on November 17, 1978. Further nitrogen applications at rates of 25 pp2m and 50 pp2m were supplied to the second phosphorus experiment on January 15 and February 13, 1979 respectively. Additional maintenance nitrogen was applied to the second potassium experiment on January 15 at 25 pp2m and at 50 pp2m on February 13, April 1, April 25, May 21 and July 13, 1979. All applications of urea were dissolved in water and applied to the soil surface.

Two additional potassium treatments were reapplied to the second potassium experiment. Potassium was applied at the rate of 0, 74, 174, 219 and 293 pp2m on April 25 and at 0, 83, 166, 332 and 664 pp2m on July 3, 1979. Potassium chloride was dissolved in water and applied to the soil surface.

Evaluations of plant response were made on yield, number of shoots produced and oven dry weight of roots.

Data was subjected to analysis of variance. Duncan's multiple range test was used to compare means. Correlation coefficients were calculated to determine the effectiveness of the soil testing procedures as indexes of available phosphorus and potassium to creeping bentgrass. The Statistical Analysis System from The SAS Institute, Raleigh, North Carolina was used. Computations were done on a IBM 360 at the University of Connecticut Computer Center.

Yield

Clippings from the first phosphorus experiment were collected on December 26, 1978 and January 23, 1979 and those from the second experiment were taken on December 23, 1978 and January 22, March 6 and April 10, 1979. Clippings on the first potassium experiment were collected on November 22, December 23, 1978 and January 16, 1979. Clipping harvests were combined within each experiment to assess yield.

Table 1. Soil nutrient values and pH obtained from the soil used in the phosphorus experiments after the 12 week equilibration period.

Treatment designation	soil extracting procedure												pH
	Modified Morgan				double acid				Bray-1	1N NH_4OAC			
	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	Mg	
	kg/ha												
pH_1P_0	X2.0	210	1350	270	30	210	1650	235	45	220	1400	250	4.5
pH_1P_1	8.0	252	2140	305	34	315	1920	260	51	307	1777	325	4.5
pH_1P_2	15.0	234	2000	285	72	285	1970	242	88	265	1800	295	4.5
pH_1P_3	18.0	192	1740	235	103	295	2100	240	146	262	1800	290	4.6
pH_1P_4	20.0	222	2060	275	108	300	2100	250	113	270	2000	300	4.6
pH_2P_0	2.5	246	1680	310	15	380	2600	415	22	317	1777	350	5.3
pH_2P_1	13.0	222	1555	275	34	300	2250	325	42	205	1200	225	5.4
pH_2P_2	24.0	198	1620	285	59	365	2170	295	72	295	1570	330	5.4
pH_2P_3	28.5	206	1480	265	88	395	2370	317	90	307	1620	340	5.4
pH_2P_4	37.0	228	1630	285	81	250	1800	265	95	282	142	400	5.4

Table 2. soil nutrient values and pH obtained from the soil used in the potassium experiments after the 12 week equilibration period.

Treatment designation	soil extracting procedure												
	Modified Morgan				double acid				Bray-1	IN NH_4 OAC			
	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	Mg	pH
	kg/ha												
pH_1K_0	18	30	1720	260	96	40	1600	227	126	25	1520	250	4.5
pH_1K_1	16	74	1450	225	102	120	1900	267	132	100	1620	300	4.6
pH_1K_2	23	150	1950	280	98	170	1650	225	108	165	1550	265	4.6
pH_1K_3	18	194	1650	255	85	330	2150	320	98	290	1550	310	4.6
pH_1K_4	27	370	2540	340	103	365	1770	247	120	317	1520	260	4.6
pH_2K_0	31	30	1360	235	87	35	2020	300	94	22	1420	270	5.4
pH_2K_1	39	74	1500	265	102	105	2000	300	118	92	1420	275	5.4
pH_2K_2	38	132	1370	245	90	235	2350	365	90	152	1250	255	5.4
pH_2K_3	43	212	1480	270	103	325	2350	355	82	260	1650	260	5.5
pH_2K_4	42	306	1600	305	101	370	2050	307	94	340	1450	290	5.4

Clippings from the second potassium experiment were collected on November 22 and December 23, 1978 and January 15, March 6, April 23, June 4 and July 27, 1979. Clipping harvests from the first four dates were combined for yield. All remaining clippings from April 25, June 4 and July 27, 1979 were weighed separately to assess yield for each date respectively.

Plant samples were dried each time clippings were harvested at 70°C for 24 hours to determine oven dry weight.

<u>Shoot Production</u>

The five plants grown in each container were removed at the termination date of the two phosphorus experiments and the first potassium experiment. The number of shoots were counted and the data is reported as the average number of shoots per plant. Data was transformed by calculating the square root of shoot counts before statistical analysis. Data is presented in original form.

<u>Root Weights</u>

Root weights were taken at the completion of each experiment. The plants were removed from the containers, the above ground portion of the plants was clipped off and the soil was washed gently from the roots with a fine spray of water. The roots were oven dried at 70°C for 48 hours. Oven dry weight of the roots were taken after which the roots were ashed at 600°C for two hours. The ash weight was subtracted from the oven dry weight to determine root dry weight.

<u>Extractable P and K Measurements</u>

The soil from each container was saved after the termination of each investigation for soil tests. Three chemical procedures, modified

Morgan ($1.25\underline{N}CH_3COOH$ + $0.625\underline{N}$ NH_4OH, pH 4.8)(McIntosh, 1969), double acid ($0.05\underline{N}$ HCL + $0.025\underline{N}$ H_2SO_4) (Soil Testing Division, Department of Agronomy, Raleigh, North Carolina, 1958) and Bray-1 ($0.025\underline{N}$ HCL + $0.03\underline{N}$ NH_4F) (Bray and Kurtz, 1945) were used for phosphorus extraction. Potassium, calcium and magnesium were extracted with the modified Morgan, double acid and the neutral normal ammonium acetate extraction (Scholleberger and Simon, 1945). Phosphorus in the extract was determined by the molybdenum blue method, potassium and calcium by flame emission spectroscopy and magnesium by the modified lake colorimetric procedure(Flannery and Steckel, 1964). Laboratory procedures described in Reference Methods for Soil Testing (The Council on Soil Testing and Plant Analysis, 1974) were followed for the double acid, Bray-1 and neutral normal ammonium acetate extraction methods. Table 3 shows the procedures used with important data. Soil pH was measured from a 1:1 soil/water suspension with a pH meter.

Leaf Tissue Analysis

Clippings were analyzed for phosphorus, potassium, calcium and magnesium. Tissue was ground in a Wiley mill using a 20 mesh screen after drying. A 300 mg tissue sample was digested in a nitric-perchloric acid mixture and the content of phosphorus, potassium, calcium and magnesium was analyzed using the procedure described by Steckel and Flannery (1965). One out of five samples was determined in duplicate. Results are presented as percent nutrient element in the leaf tissue on a dry weight basis.

Table 3. Extractants and laboratory procedures used in obtaining soil nutrient values.

Extractant	Abbrev.	Extractant pH	Vol. of soil sample	Soil extractant ratio	Shaking action and speed	Shaking time-minutes
Modified Morgan	NH_4OAC	4.8	4 cm^3	1:5	Reciprocating 120 + ocillations/ min	15
double acid	DA	1.4	4 cm^3	1:5	Reciprocating 180 + ocillations/ min	5
Bray No. 1	Bray-1	2.3	2.5 cm^3	1:10	Reciprocating 180 + ocillations/ min	5
neutral normal ammonium acetate	1<u>N</u> NH_4 OAC	7.0	4 cm^3	1:5	Reciprocating 180 + ocillations/ min	5

Table 4. Soil test results of available nutrients before initiation of the experiment and other soil properties.

	Nutrient level							Exchangeable cations¶			
Extractant	P	K	Ca	Mg	pH	O.M.†	CEC¶	Ca	Mg	K	Na
	--------kg/ha-----					-%-	meq/100g	-----meq/100g-----			
NH_4OAC	2	50	1400	250	6.3	2.72	6.74	6.26	1.13	0.20	0.10
double acid	19	45	1500	-							
Bray-1	10	-	-	-							
1N NH_4 OAC	-	40	1300	260							

†Organic matter determined by Walkley and Black method (1934)
¶Cation exchange capacity and exchangeable cations were determined by ammonium saturation described by Chapman (1965).

Field Experiment

A field experiment was conducted to calibrate soil test levels of phosphorus for the purpose of developing more accurate phosphorus fertilizer recommendations for creeping bentgrass establishment and maintenance. The experiment was conducted in 1978 and 1979 on the putting green nursery of the Shorehaven Country Club in Norwalk, Connecticut.

The soil was a mixture of 8 parts sand and 2 parts organic matter by volume. The organic matter is described as a Typic Medisaprist in the order Histosols according to the current system of classification, Fletcher (1975). Soil tests were made prior to the initiation of the experiment and the results are reported in Table 4.

Additional properties of the soil are also presented in Table 4. The nursery was seeded on June 10, 1978 with Penncross creeping bentgrass. The turf was mowed at 5.56 mm cutting height three to four times per week throughout the growing season. Irrigation was used to supplement rainfall. Nitrogen was applied in increments during the growing season over the experimental area to supply 2.04 kg N/92.9 m^2 in 1978 and 1.82 kg N/92.9 m^2 in 1979.

Two pH levels were established by applying aluminum sulfate at 1.82 kg/plot to half of the plots on May 31, 1978. This gave a pH of approximately 5.0 which was designated pH_1. The remaining plots were left at pH 6.3 which was designated pH_2. Phosphorus was applied on June 9, 1978 prior to seeding at 0, 59 and 118 kg P/ha to establish three levels of soil phosphorus designated as P_0, P_1 and P_2 respectively. Phosphorus was raked into the soil to a 3 cm depth. A phosphorus fertilizer treatment was applied on May 22, 1979 to a mature sod at rates of 0, 29 and 59 kg P/ha designated as PA_0, PA_1 and PA_2. Phosphorus was applied in the form of triple superphosphate. Two potassium treatments were applied in the form of potassium chloride on May 22 and August 1, 1979 to supply 0 and 74 kg K/ha to all phosphorus and pH treatments.

The 2x2x3x3 factorial experiment was arranged in a split plot design. Potassium was assigned to the main plots in a randomized complete block design. Residual soil phosphorus levels, fertilizer phosphorus treatments and pH were assigned to subplots within each main plot. Treatment combinations for subplots are shown in Table 5. Four replications (blocks) were used. Plot size was 1.52 m x 3.05 m. Data were subjected to analysis of variance. Means were separated using Duncan's multiple range test. Correlation coefficients were calculated to measure the closeness of fit between plant response, soil test values for phosphorus and tissue phosphorus. The Statistical Analysis System from the SAS Institute was used with the calculations done at the University of Connecticut Computer Center.

Yield

Grass clippings were collected in a grass catcher of a putting green mower from a 1.32 m^2 area in the center of each plot to assess yield response. Yield represented 3 days growth at each harvest. Yields were taken on October 20, 1978 and May 8, July 2 and September 26, 1979. Plant samples were dried at 70°C for 48 hours and the dry weight of each sample was determined.

Shoot Growth

Two 9.4 cm^2 plugs of Penncross creeping bentgrass were selected at random from each plot and the number of individual plants were counted. The samples were taken at least 45 cm from the edge of each plot. Shoot counts were made on October 27, 1978, May 14, July 9 and September 28, 1979. Data were subjected to a square root transformation before statistical analysis. Data are presented in original form.

Root Growth

Two 9.4 cm^2 sod plugs were removed to a depth of 15 cm to measure root growth. The plugs were placed on a screen and the soil was washed gently from the roots with a fine spray of water. The aerial portion of the plant was clipped off and the roots were oven dried at 70°C for 48 hours. Oven dry weight of the roots was taken after which the roots were ashed at 600°C for two hours. The ash weight was subtracted from the oven dry weight to determine the root dry weight. Root samples were collected on November 10, 1978 and on May 16, July 9 and September 28, 1979.

Quality Rating

Visual estimates for turf quality were made periodically in 1978 and 1979. A 0 to 10 scoring system was used in 1978. Ratings were initiated one month after seeding. Zero indicated no turf cover and 10 indicated ideal quality and maximum density. A 1-9 scoring system was used in 1979 after the turf was fully established. The rating scale was based upon density, color and freedom from disease. One indicated very poor quality turf and nine indicated excellent quality. A rating to assess a phosphorus deficiency that appeared on plots in October 1978 was made using a scoring system of zero to two. Zero indicated no discoloration and two indicated severe discoloration. A turf color rating was made on April 19, 1979 with a scoring system from 1-5. One indicated poor color and five indicated excellent color. Data were transformed into degrees arcsin before statistical analysis. Data are presented in original form.

Available Soil Nutrients

Ten random plugs of soil at a 7.5 cm depth were taken with a 2 cm diameter soil probe from each plot on October 27, 1978 and on May 9, July 11 and October 10, 1979. The same chemical extractants and laboratory procedures described in the section on materials and methods for the greenhouse experiments were used for soil samples collected in the field.

Leaf Tissue Analysis

Clippings were retained for tissue analyses of phosphorus, potassium, calcium and magnesium from clippings collected to assess yield. The same procedure was followed in determining the nutrient content of the leaf tissue as used in the greenhouse experiments except that the leaf tissue was not ground before digestion.

Table 5. Treatment designations showing the three way factorial combination of residual soil phosphorus levels (P), fertilizer phosphorus treatment applied on May 22, 1979 (PA) and pH levels making up the subplots.†

	P_0		P_1		P_2	
	pH_1	pH_2	pH_1	pH_2	pH_1	pH_2
PA_0	$PA_0P_0pH_1$	$PA_0P_0pH_2$	$PA_0P_1pH_1$	$PA_0P_1pH_2$	$PA_0P_2pH_1$	$PA_0P_2pH_2$
PA_1	$PA_1P_0pH_1$	$PA_1P_0pH_2$	$PA_1P_1pH_1$	$PA_1P_1pH_2$	$PA_1P_2pH_1$	$PA_1P_2pH_2$
PA_2	$PA_2P_0pH_1$	$PA_2P_0pH_2$	$PA_2P_1pH_1$	$PA_2P_1pH_2$	$PA_2P_2pH_1$	$PA_2P_2pH_2$

† K_0 and K_1 treatments were applied to all subplots.