POTASSIUM MOVEMENT AND UPTAKE AS AFFECTED BY POTASSIUM SOURCE AND PLACEMENT

Except where reference is made to the work of others, the work describe in this thesis is my own or was one in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

____

Bradford Kenneth Young

____

Gobena Haluka
Associate Professor
Agronomy and Soils

____

Elizabeth A. Guertal, Chair
Professor
Agronomy and Soils

____

David Y. Han
Associate Professor
Agronomy and Soils

____

C. Wesley Wood
Professor
Agronomy and Soils

____

George T. Flowers
Dean
Graduate School

POTASSIUM MOVEMENT AND UPTAKE AS AFFECTED BY POTASSIUM SOURCE AND PLACEMENT

Bradford Kenneth Young

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
May 9, 2009

POTASSIUM MOVEMENT AND UPTAKE AS AFFECTED BY POTASSIUM SOURCE AND PLACEMENT

Bradford Kenneth Young

____
Signature of Author

____
Date of Graduation

VITA

Bradford Kenneth Young, son of Steven Young and Carol Clarkson, was born March 29, 1984, in Charlotte, North Carolina. He graduated from Seneca High School with honors in 2002. He attended Auburn University in Auburn, Alabama and graduated with a Bachelor of Science degree in Agronomy and Soils (Turfgrass Management) in May, 2006, where he was also a member of Kappa Alpha Order. He entered Graduate School at Auburn University in May, 2006.

THESIS ABSTRACT

POTASSIUM MOVEMENT AND UPTAKE AS AFFECTED BY POTASSIUM SOURCE AND PLACEMENT

Bradford Kenneth Young

Master of Science, May 9, 2009
(B.S., Auburn University, 2006)

59 Typed Pages

Directed by Elizabeth A. Guertal

Although downward loss of anions such as nitrate has been well-studied in high-sand turfgrass putting greens, leaching of cations such as potassium (K) has received less study. Moreover, turfgrass research with K has largely focused on two soluble forms of K: potassium chloride (KCl) and potassium sulfate (K_2SO_4). Thus, the objectives of this research project were to: 1) examine the effect of K fertilizer sources on bentgrass (*Agrostis palustris* Huds.) performance, 2) determine K levels in soil and plant tissue, and, 3) trace downward movement of K via incremental depth sampling. The 2 yr study was conducted on a 5 yr old existing bentgrass putting green (cv 'G2'), with treatments arranged in a randomized complete block design with 4 replications of each treatment. Treatments were K sources: 1) potassium chloride - KCl, 2) potassium sulfate - K_2SO_4, 3) resin-coated K_2SO_4, 4) potassium thiosulfate (KTS), and, 5) potassium nitrate - KNO_3. All K treatments were applied quarterly, with treatments applied according to the initial recommended soil-test level of 56 kg ha^{-1} K_2O. Treatments were applied either by a broadcast application or a vertical 'band' treatment. For the band treatment plots were first core aerified (1 cm diam. x 10 cm deep), and applied fertilizer was swept into aerification holes, followed by a sand topdressing. Broadcast treatments were also aerified, with topdress sand first applied, and K fertilizer then surface applied. Collected data included monthly clipping yield, monthly K content in clippings, monthly soil K (0-7 cm sampling depth), quarterly shoot density, and quarterly root mass. Extractable soil K over a 0-30 cm depth was also collected quarterly, with samples collected every 5 cm of depth. Over the 2 year study potassium application had no beneficial effects on turfgrass performance, and acceptable performance was achieved across a wide gradient of K content in soil and leaf tissue. Regardless of soil test K level, no deficiency symptoms were observed.

ACKNOWLEDGMENTS

The author would like to thank Dr. Elizabeth Guertal for her assistance with statistical analyses and guidance throughout the years. Thanks are also extended to Mr. William Bryce for his help and hard work with sampling and much assistance in the laboratory. Thanks are also due to my mother Carol and stepfather Stuart for their guidance and support during the course of my education.

Style manual or journal used: Publications Handbook and Style Manual of the American Society of Agronomy

Computer software used: Microsoft Excel 2003, Microsoft Word 2003, The SAS System for Windows v 9.1

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. LITERATURE REVIEW

Introduction

Bentgrass (*Agrostis palustris* Huds.) is a cool-season turfgrass commonly grown on putting greens in the Southeast due to its ability to provide a superior putting surface. However, high temperatures and humidity can be detrimental to this cool season grass, resulting in decreased rooting and thinned turf during the summer (Guertal et al., 2005; Huang and Liu, 2003). Intense management is required to keep stands alive and playable, including frequent applications of fungicides and fertilizers.

Another management practice on southeastern putting greens is high-sand (80-90%) greens (Ok et al., 2003). Such greens drain rapidly, providing an excellent growing medium for marginally adapted bentgrass. However, because the greens mix is high in sand, with a low nutrient holding capacity, applied fertilizers can move downward and be lost from the rooting system. Loss of nutrients, especially NO_3-N, from sand-based root zones has been well studied (Mangiafico and Guillard, 2007; Frank et al., 2006; Mangiafico and Guillard, 2006; Pare et al., 2006).

Although anion forms of plant nutrients (e.g. NO_3^-, SO_4^{2-}) are prone to loss via leaching, in the high sand greens mix of a putting green cations may also exhibit downward movement. Although K leaching in sand-based soils has been evaluated in other crops (Hochmuth et al., 2006; Alfaro et al., 2004), it has been relatively unstudied in turf systems (Erickson, et al., 2005). In high-sand conditions (up to 100%) of manufactured putting greens, many turf managers often simply assume that applied K may leach, and they make frequent applications of the nutrient on a preventative basis. Such applications are often not based on a soil test, and are often applied according to 'ratio' recommendations of around 1:1 N:K (Rodriguez et al., 2002; Snyder and Cisar, 2000).

Potassium (K) is an essential element for plant growth and is taken up from the soil solution by plant roots in the form of the potassium ion (K^+). Potassium is mobile in the plant, with deficiency symptoms appearing first in the lower leaves (Tisdale et al., 1991). Potassium is directly involved in enzyme activation, maintenance of water status, energy relations, translocation of assimilates and protein synthesis. In water relations, potassium regulates cellular turgor pressure to avoid wilt, in turn controlling the regulation of stomatal opening, greatly enhancing drought tolerance (McCarty, 2005).

Potassium and Water Use

Drought stress is commonly observed in many turfgrasses, and K is commonly associated with its alleviation. When K fertilizer was applied as KCL at rates up to 348 kg K ha^{-1} yr^{-1}, Kentucky bluegrass (*Poa pratensis* L.) had lower water use at the high rate of K fertilization, when compared to the 0 K control (Schmidt and Breuninger, 1981). The Kentucky bluegrass also recovered more quickly from drought when K fertilizer was present.

Increases in K fertility may not be well matched with concurrent increases in N fertility, however, as increases in N promoted excessive top growth of Kentucky bluegrass, which reduced tissue solute concentrations in the leaf, negatively affecting leaf osmotic potential (Carroll and Petrovic, 1991). Others have observed such nutrient interactions, where K applied alone had no effect on evapotranspiration, regardless of the rate applied (Ebdon et al., 1999). However, as in the previous study, when high rates of N were applied with the K water use increased as K fertilization rates increased (0, 87, 174, 261, and 348 kg K ha^{-1} yr^{-1}). When N and P were applied at recommended rates increasing rates of K fertilization minimized water use (Ebdon et al., 1999).

Accumulation of inorganic solutes such as K increases osmotic adjustment, which is responsible for regulating guard-cell turgor and stomatal aperture. Accounting for 59 to 65% of total ion concentration, K was the most prevalent ion solute in cell sap (Jiang and Huang, 2001). Drought preconditioned Kentucky bluegrass, where the plants were subjected to two 14d cycles of soil drying (when volumetric soil moisture reached 5%) and then allowed to recover, exhibited an 8 to 19% higher level of K than nonpreconditioned plants (Jiang and Huang, 2001).

Plant Uptake of Potassium

Potassium is an essential element and required by plants in relatively large amounts (McCarty, 2005). Potassium uptake in plants has been studied for close to 80 years (Bartholomew and Janssen, 1929). It can be taken up in excess of what plants actually require for normal growth, termed "luxury consumption" (Bartholomew and Janssen, 1929). In that study, various agronomic crops were grown in soils amended with K (at rates from 168 to 504 kg K ha^{-1}). Plant tissue was collected and analyzed for K content. From these season-long studies they concluded: 1) plants absorb considerably more K than needed early in the growing season, 2) K can be translocated, and, 3) plants translocate the extra K to growing plant parts as they mature.

Uptake of K by turfgrasses has also been evaluated in later research. When Kentucky bluegrass was fertilized with K at rates from 0 to 243 kg K ha^{-1} yr^{-1}, K content in clippings was maximized at K fertilization rates of 81 to 162 kg K ha^{-1} yr^{-1}. Potassium fertilization never affected clipping yield or turf quality, even when soil-test K was low (Fitzpatrick and Guillard, 2004).

When K was applied at rates of 0, 1, 2, 3, 5 and 6 g K m^{-2} 14 d^{-1}, the concentration of K in the soil solution increased as K rate increased (Woods et al., 2006). However, K application had no beneficial effect on turfgrass performance. In spite of high leachability characteristics of sand, soil K concentrations established by K fertilization applications persisted for more than 7 months after application ceased. Increases in extractable K were observed at less than 2 g K m^{-2} 14 d^{-1}, even though no K applications were made. It was hypothesized that non-exchangeable K was re-supplying K to exchangeable and soluble forms, as solution K activity decreased (Woods et al., 2006). Other have shown similar effects, where increased rates of K application (from 0 to 406 kg K ha^{-1} yr^{-1}) had no significant effect on turf quality (Johnson et al., 2003). However, as K increased in turf tissue there was a weak positive correlation with turf quality. Leaching of K through the sand-based putting green rootzone was also observed (Johnson et al., 2003).

The interaction of K and other plant nutrients has long been studied, as the presence of calcium (Ca) or magnesium (Mg) could inhibit K uptake (Stanford et al., 1941). In putting greens built from calcareous sands, for example, high levels of Ca may limit K uptake (Woods et al., 2006). Soils with lower levels of soluble Ca produced bentgrass with higher tissue K content, under high K application rates (Woods et al., 2006). In another study, application of K and Mg (each at 20 g m^{-2}) reduced soil Ca levels below those measured in plots not fertilized with Ca (Sartain, 1993). As K fertilization increased the result was a decrease in extractable soil Ca and Mg, as well as decreases in Ca and Mg tissue concentrations. There was an increased potential for Ca and Mg deficiencies when using high K fertilization rates, furthering the recommendation that rates of K higher than those that provide sufficient K levels for normal growth may be detrimental and should not be used (Miller, 1999).

Interactions of K with the other macronutrients (N and P) are often evaluated, especially using the fertilization concept of N:P:K or N:K ratios. When N, K and P were applied at varying rates (50 to 650 kg ha^{-1} for N and K; 50 to 50 kg ha^{-1} for P) in 30 different ratios, color, growth and density of perennial ryegrass (*Lolium perenne* L.) turfgrass was improved as N rate increased (Razmjoo and Kaneko, 1993). There was no response to increasing K or P. Fertilizers applied at a ratio of 9:5:1 (N:K:P) best promoted growth and winter quality of turf (Razmjoo and Kaneko, 1993). When four N:K ratios were examined (high N:high K, high N:low K, low N:high K, low N:low K) there were no measured differences in tissue P, K, Ca, Mg and S due to the ratio treatment, only tissue N increased as N increased (McCrimmon, 1998). Tissue K was typically in the low end of the sufficiency level for K, regardless of K rate. Increasing K fertilization beyond a K:N ratio of 0.5 to 1 had no effect on hybrid bermudagrass quality, growth, or root weight, nor did increasing K increase tissue K (Snyder and Cisar, 2000). In another study ratios of 1:0:0.8 and 1:0:1.7 were insufficient for optimum growth of hybrid bermudagrass. Greater coverage was observed when the P part of that ratio was increased to 0.4, but the effect of increasing K in the ratio was not further evaluated in the study (Rodriguez et al., 2002).

Different species of turfgrass require K in varying amounts, and the amount in tissue may also vary. Regardless of K application rate and soil type, potassium concentrations in leaf tissues were higher in “Tifdwarf” than in “Tifway” indicating that K uptake could be species or cultivar specific (Miller, 1999). A sufficiency range of tissue K content was identified in Carrow et al. (2001) as 383 to 767 mmol K kg^{-1} (15 to 30 g K kg^{-1}). Leaf tissue K content of creeping bentgrass was greater when grown in acid sands (pH 5.4) than in calcareous sands (pH 7.3) (Sheard et al., 1985).

Potassium and Winter-Kill

Potassium plays an important role in the accumulation and synthesis of carbohydrates in plants. Increased levels of total nonstructural carbohydrates (TNC) are thought to be a mechanism of freezing tolerance in turfgrass. Elevated TNC levels within the plant are thought to contribute to enhanced cold hardiness.

High rates of K fertilization are thought to enhance cold tolerance in turfgrass. However, due to the many physiological functions and high mobility between plant organs and cells, the direct effects of K are difficult to identify (Wagner, 1967). Winterkill is often the result of desiccation damage. Thus, K concentrations in the plant aid in maintaining water status and may be responsible for improvements in winter hardiness. However, research that supports this hypothesis is not abundant, and the ability of K to prevent winter damage of turf is not supported in the literature. For example, rates of K exceeding those to provide sufficient levels for normal growth did not provide enhanced cold resistance in bermudagrass rhizomes, as measured via the electrolyte leakage test (Miller and Dickens, 1996b).

In the Miller and Dickens studies (1996 a and b), potassium sources (KCl and K_2SO_4) were applied at rates of 0, 12, 24, 49, 98, and 195 kg K ha^{-1} per growing month on a native loamy sand, and at 0, 24, 49, 98, 195, and 390 kg K ha^{-1} per growing month on a sand-peat greensmix. These rates were applied to simulate those commonly applied by turf managers to achieve enhanced winter cold hardiness. In this study, however, neither cold tolerance, carbohydrate levels, or turf quality were significantly affected by increasing rates of K fertilization (Miller and Dickens, 1996 a and b). Late-season application (Oct) of K at rates of 0, 4.1, or 8.2 g K m^{-2} never affected fall hybrid bermudagrass color or TNC (Goatley et al., 1994). Although not directly related to cold tolerance, wear tolerance of Kentucky bluegrass has also been shown to be unrelated to increasing rate of K fertilization (Carroll and Petrovic, 1991).

Root and rhizome weights of 'Tifton 44' coastal bermudagrass were significantly increased, and survival to winter exposure was observed when K (as KCl) was applied at a maximum rate of 140 kg K ha^{-1} yr^{-1} (Belesky and Wilkinson, 1983). Winter survival of 'Coastal' bermudagrass was favored by a high ratio of applied K to N (448 kg N ha^{-1} yr^{-1} and 224 kg K ha^{-1} yr^{-1}) (Adams and Twersky, 1960). Decreased winter kill of 'Coastal' bermudagrass was observed with increasing levels of K when the N level was held constant and winter survival was favored by a high ratio of K to N (K_2O applied at 224 kg ha^{-1}) (Reeves et al., 1970). The most cold resistance in alfalfa was produced with a ratio of 5:2 of K_2O to P_2O_5 (Reeves et al., 1970). The major differences in these research papers is: 1) they were performed on forage crops, and 2) K fertilizer was often applied at much lower rates than applied in turf-type bermudagrass research. These lower potassium fertilization rates (224 to 336 kg K ha^{-1} yr^{-1}) reflect soil test recommendations for a soil that tests medium to low in K (Adams et al., 1994). They do not reflect the higher K rates of a greens-based turfgrass system.

Potassium Fertilization

Limited retention of K is observed in sand based putting greens with low cation exchange capacity (CEC) and high infiltration rates, which increases the chance for K to leach. Thus, K is often applied in frequently throughout the year to obtain adequate turfgrass performance (Carrow et al., 2001). Other options for reducing K loss in sand-based putting greens may include the use of slow-release K sources, which are made slow-released by a physical coating of wax, plastic, sulfur or resin (Snyder and Cisar, 1992).

Irrigation and clipping removal on sand based putting greens can limit a steady supply of plant available K. Controlled-release products have been developed by coating soluble K salts with sulfur, plastic, or resins to help alleviate this problem. When KCl and K_2SO_4 sources were compared with resin-coated K_2SO_4 (3-4 month release) and sulfur-coated K_2SO_4 on 'Tifgreen' bermudagrass, turf harvested from controlled-release treatments contained significantly more K in clippings three months after fertilization than clippings from plots fertilized with KCl and K_2SO_4. Twelve months following application, clippings from plots treated with resin-coated K_2SO_4 (5-6 month release) and resin-coated K_2SO_4 (8-9 month release) contained higher amounts of K than any other treatments in the study. The source providing the greatest retention of K within the granule resulted in lowest K in clippings, and the source providing the highest clipping K was provided by the source exhibiting quickest release (Snyder and Cisar, 1992).

Researchers have been able to document increases in tissue K as K fertilization rates increased (Liu et al., 1995; Sartain, 2002; Ebdon et al., 1999). However, such increases were usually not linear, and were maximized at some K rate that was not related to soil-test sufficiency levels (Woods et al., 2006). These increases in K were often not matched by improvement in turf quality.

A vast majority of the K fertilization research was performed on cool-season grasses, especially Kentucky bluegrass. Less studied are the intensively managed systems of high-sand bentgrass putting greens. Last, there is only one published study which examined various K sources, especially when including the newer slow-release materials (Snyder and Cisar, 1992).

Objective

There is a lack of research which explores the effect of K sources on bentgrass putting greens. Thus, the objective of this research is to examine the effect of K sources on soil-test and tissue K, examining soil-test K both over time and within the profile of a sand-based putting green.

II. MATERIALS AND METHODS

The study was conducted at the Auburn University Turfgrass Research Unit (TGRU), located in Auburn, AL. The project was conducted on a 4 year old USGA-type (80% sand, 20% composted rice hulls) 'G-2' creeping bentgrass putting green. Soil test results prior to application of K fertilizer treatments were: 30 kg ha^{-1} P, 76 kg ha^{-1} K, 38 kg ha^{-1} Mg, and 300 kg ha^{-1} Ca, with a pH of 5.4 (Adams et al., 1994).

Beginning in Aug 2006 the following K fertilizers were applied at a rate of 56 kg K_2O ha^{-1}: 1) KCl, muriate of potash (KCl, 0-0-60, 2) K_2SO_4, sulfate of potash (K_2SO_4, 0-0-50), 3) polymer-coated K_2SO_4 (Polyon, 0-0-50), 4) KNO_3, potassium nitrate 13.8-0-44.5, and, 5) potassium thiosulfate ($K_2S_2O_2$, 0-0-25-17S). A zero K control was also included, and all plots received N as ammonium nitrate equal to that applied in the KNO_3 treatment. The K rate was based on the initial soil-test recommendation (Adams et al., 1994). Data collection began on 29 Aug 2006 and ended on 9 Sept 2008.

Potassium fertilizer treatments were applied 4 times a year (Aug, Nov, Feb, May). The same K rate (56 kg K_2O ha^{-1}) was applied to all plots, regardless of soil test. This was done to prevent treatments or applications varying in rates of applied K, which would have confounded the study. All K treatments were applied at the same K rate via two methods: 1) surface broadcast application, or, 2) subsurface placement at the bottom of 10 cm deep (1.3 cm diam.) aerification holes, hereafter called the 'band treatment'. All plots were equally aerified, and then the banded K treatments were applied to the surface and swept into the aerification holes with stiff bristle push brooms in several directions to maximize incorporation. Surface K treatment plots were first topdressed with sand to fill holes prior to fertilizer application, and then K fertilizer treatments were broadcast applied. Fertilizers were broadcast hand applied in a ‘checker-board’ fashion, except for the KTS, which was a liquid formulation and was sprayed, undiluted, directly on the foliage using a CO_2 sprayer with four Teejet ‘8004’ nozzles that delivered 91mL of product to the plot. Irrigation (0.6 cm) was applied immediately after application of all products.

The experiment design was a 5 x 2 factorial of K source and K placement (plus an aerified control plot), with treatments arranged in a randomized complete block design of 4 replications with plot dimensions of 2.1m x 2.7m. Putting green maintenance included vertical mowing at a 19 mm depth using a Graden (Graden Industries, 26-28 Scammel Street, Campbellfield 3061 Victoria, Australia) walk-behind vertical mower. Greens were vertical mowed on 6 July 2006, 20 July 2006, 1 Jan 2007, 15 Mar 2007, and 12 Apr 2007, with all debris removed after vertical mowing. Topdressing with sand was performed on 3 Nov 2006, 6 Dec 2006, 13 Apr 2007 (after vertical mowing), 30 Apr 2007, 15 June 2007, and 7 May 2008. Topdressing sand was applied using a walk-behind topdresser and swept in after application. The putting green was mowed at a height of 0.04 mm, six of seven days a week using a ‘round the clock’ mowing pattern to discourage directional growth. Specific chemical and fertilizer applications for the study conducted at the TGRU are outlined in Table 1.

Data Collection

Collected data included monthly soil K content (0-7.6 cm depth), and quarterly (Aug, Nov, Feb, May) soil K content partitioned by depth (0-25 cm deep, 5 cm depth increments). Depth samples were collected just before K fertilizer application, using the methods described below.

Clippings were collected each month by mowing the vertical borders of the plots and then mowing one mower width of the plot (53 cm). Collected tissue was dried in a forage dryer at 55 C. Dry weights were taken to determine total biomass, and 0.5 g of dry tissue was then weighed and dry-ashed in a muffle furnace at 700 C. Ashed samples were first diluted with 10mL of 1N HNO_3 and placed on a hot plate at 150 C until the HNO_3 was completely evaporated; 10mL of 1N HCl was added and placed on the hot plate for 15 minutes. The extractant was filtered through Whatman 40 filter paper into a 100mL volumetric flask and brought to volume with distilled water (Hue and Evans, 1986). The samples were then analyzed for ppm K via atomic absorption (AA) spectrophotometry used in atomic emission or flame emission mode (Instrumentation Laboratory, Video 12 spectrophotometer, Wilmington, MA).

Monthly soil samples, three random samples per plot, were taken with a 7.6 cm wide horizontal profiler to a depth of 7.6 cm. Organic material was removed at the soil thatch interface and samples were bulked and air dried for subsequent K analysis. A subsample of 5.0 g of soil was weighed and extracted with 20mL of Mehlich extractant (Hue and Evans, 1986). The extractant was filtered through Whatman 42 filter paper and analyzed for ppm K via AA spectrophotometry, as described above.

Soil samples (0-25 cm deep, 5 cm depth increments) were collected quarterly. Five random samples per plot (1.9 cm diameter soil probe), were collected to a 25 cm depth just prior to the next K fertilizer application. Samples were extracted with Mehlich extractant (Hue and Evans, 1986), and analyzed via AA spectrophotometry for K concentration, as previously described.

Samples of turf were removed twice per year (July and Sept) for determination of shoot density. At each sampling 5 plugs (1.9 cm diam.) were removed from each plot and all shoots within each plug were hand-counted. Quality ratings using a 1-9 qualitative scale were also taken after each fertilization, with a "1" assigned to completely dead turf, and a "9" to ideal turf of high quality. Quality ratings were taken if turf damage (due to fertilizer application) was visible, starting at 24 hrs after application, and continuing until damage was no longer visible.

III. RESULTS AND DISCUSSION

Monthly Soil Sampling (0-7.6 cm sampling depth)

The main effects of K source, K placement and their interaction all affected extractable soil K (0-7.6 cm) in various sampling months. The interaction of K source and placement was significant on 3 of the 12 sampling dates (Table 2) (July 2007, Sept 2007 and Dec 2007), with K source alone significant on the other sampling dates (Table 3). The placement of K was only significant at one sampling: January, 2008.

Table 2 shows the means for soil K (0-7.6 cm) for sampling dates when K source x placement was significant. In general, there were few differences due to fertilizer placement, with the significant effects occurring in July 2007 (KNO_3), September 2007 (KCL) and December 2007 (coated K_2SO_4 and KNO_3). In all but one case there was more measurable K from broadcast treatments than banded, a result of accumulated K at the soil surface in the broadcast treatments. The large difference in the KCl treatment is likely a result of the large prill size of that ag-grade material.

Sampling months in which the K source x placement interaction were not significant (Table 2) are shown in Table 3. In most months there were few differences due to K source, and any plot that received K fertilizer had greater extractable K than measured in the unfertilized control plots. Extractable K was low in all plots, and subsequent application of K at 56 kg K_2O ha^{-1} (Aug, 2006, Nov, 2006, Feb, 2007, May, 2007, Aug, 2007, Nov, 2007, Feb, 2008, and May, 2008) was not sufficient to increase soil-test K to recommended sufficiency levels (Figure 1) (Adams et al., 1994). Failure to identify differences in extractable K due to K source is not uncommon (Waddington et al., 1972; Sartain, 2002), although differences in soil K due to the use of slow-release K sources have been noted (Snyder and Cisar, 1992).

Placement of K was significant in one of 12 sampling dates, January, 2008. In this case, broadcast applied K had significantly higher extractable K in broadcast treatments as compared to band treatments.

Quarterly Depth Sampling (0-25 cm)

On 4 of 6 sampling dates there were differences in extractable K due to K source: November, 2006, May, 2007, August, 2007 and February, 2008. There was no difference in extractable K (at any sampling depth) in Feb, 2007 or Nov, 2007. In the first sampling (November, 2006) plots that received any K fertilizer had more extractable K (0-5 cm depth) than measured I the control plots (Figure 2).

When analyzed by depth, there was significantly more soil K at increased depths from the K_2SO_4 treatment than from the coated K_2SO_4 treatment (Figure 2). This may indicate that some downward movement of the soluble K_2SO_4 source was occurring. Others have observed differences in the pattern of K leaching over time, with fertilizer source affecting leaching rate, but not total K losses via leaching (Alfaro et al., 2004).

By the February, 2007, depth sampling there were no differences in soil K (at any depth) due to K source, with the exception of soil from KTS-treated plots (Figure 3).

Since KTS was applied as a foliar spray, surface accumulation may have occurred, leading to the greater amount at the 0-5 cm sampling depth.

By May 2007, plots receiving no K had lower extractable K than measured in any plot receiving K fertilizer (Figure 4). When analyzed at each sampling depth there were few differences in extractable K due to K source, and no evidence of increased retention or leaching due to K source. For every K source there was greater extractable K at the surface, with a subsequent decrease in soil K as sampling depth increased (Figure 4).

By August 2007, extractable K in all plots had dropped, as compared to previous months (Figures 2-5). Average soil-test K for all treatments was 7.1 $\mu g\ g^{-1}$ a very low soil test rating for a bentgrass putting green (Figure 5) (Adams et al., 1994). There were few differences in extractable K due to source. Any plot treated with K fertilizer had greater K at lower sampling depths, with significantly more K measured at the lowest 3 depths (10-25 cm) (Figure 5).

One year after depth sampling was initiated (Nov, 2007, Figure 6), extractable K in the unfertilized plots was still lowest, with no significant differences due to K source, at any sampling depth. In February, 2008, the addition of any K source increased soil extractable K, as compared to the control, but there were no differences due to K source (Figure 7). Throughout the progression of the experiment extractable K decreased over time, and no one K source consistently outperformed the other with respect to persistence in the soil profile. This is especially true when comparing coated K_2SO_4 to uncoated K_2SO_4. As fertilizer prices continue to increase it is hard to justify the increased cost of a coated product versus readily available K soluble sources. Soil Mehlich extractable K sufficiency levels were never obtained (Adams et al., 1994), although K deficiency symptoms were never observed. Mehlich extractable K levels suggest that 30 mg K kg^{-1} soil may be adequate for optimum growth (Sartain, 2002). These findings are consistent with those of Johnson et al., (2003) that potassium levels throughout the soil profile indicated leaching of K within the root zone. It may be that our sampling interval over depth (every 3 months) was not frequent enough to catch leaching K, especially in the sand-based green used in this study. Conversely, our relatively low rate of applied K may have rapidly become incorporated into less-soluble forms, not extracted by Mehlich extract. As proposed by others, this K fraction may not have leached, but have become less soluble, with slow subsequent release from the non-exchangeable form (Wood et al., 2006).

Tissue K Content

The interaction of K source and placement significantly affected tissue K content at 2 of 16 sampling dates (July and October 2007) (Table 4). Interactions at these two sampling dates was not substantial, and occurred because plots that received KCL (Oct, 2007) had tissue K that was unaffected by application of K fertilizer. Although not always significant (Table 4), plots receiving broadcast K_2SO_4 had greater K in tissue, than when the K source was band-applied.

The main effects of K source and K placement affected tissue K content at many sampling dates (Tables 5 and 6). When examined over the various months of collection there was not one particular K source that stood out. Although there were month-to-month differences in tissue K due to K source, none of these responses were consistent. For example, in Oct, 2006, K control in bentgrass sprayed with KTS was lowest, possibly a result of visible phytotoxicity to plots from the August spray application. However, similar phytotoxicity (from KTS sprays, with visible damage lasting 1 wk) was observed at other applications, and subsequent tissue K content was unaffected (Table 5).

As the experiment continued, and soil K declined (Figures 2-5), the most consistent result was that tissue K in any fertilized plot was greater than in the unfertilized control. Similar results have been shown in other research. Increased K fertilization increased tissue K and showed a weak correlation with turfgrass quality (Johnson et al., 2003). In a study conducted on Kentucky bluegrass and creeping bentgrass, less N was required to attain maximum quality as the level of K increased and it is possible to that higher levels of K fertilization may affect requirements for N (Christians et al., 1979). Tissue K response to K fertilization was nonlinear; responses regarding quality and yield were not correlated to tissue K concentration (Fitzpatrick and Guillard, 2004). Extractable K values alone may not be adequate to predict available K to turfgrass (Fitzpatrick and Guillard, 2004). Slow release K sources remain largely unstudied and few articles are available documenting their performance. Research conducted using both KCL and K_2SO_4 sources with three coatings: sulfur coated, resin-coated, and poly-vinyl chloride coated reported that the source providing the greatest retention (polymer coated) of K within the fertilizer granule resulted in the lowest level of K in the clippings, and the source with the least retention (sulfur coated) provided the highest K in the clippings (Snyder and Cisar, 1992). Potassium application had no beneficial effect on turfgrass performance (Woods et al., 2006). In addition to agreement with these findings, K deficiency symptoms were never observed throughout the two year (Aug, 2006- Aug, 2008) duration of the study (Woods et al., 2006).

Placement of K (band or broadcast) affected tissue K content on 4 of 16 sampling dates (Table 6). At 3 of the 4 dates (Apr, 2007, Dec, 2007, Jan, 2008) there was significantly more K in bentgrass tissue from plots in which K was surface broadcast, as compared to band applied. Overall, band application of K rarely increased tissue K (only 1 significant time, Jan, 2007). Band incorporation of K appears to offer no benefits for efficient K application, as neither soil K retention or K uptake by bentgrass were improved by the practice.

Clipping yield and shoot density

The interaction of K source and placement affected shoot density in fall, 2007 (Table 7), while only the main effect of K source was significant in the fall, 2006 sampling (Table 8).

In 2006, plots that received applications of KTS had a significantly lower shoot density as compared to the unfertilized control (Table 7). There were no other differences in shoot density due to K source, and none (other than KTS) had better or poorer shoot density than compared to the control. Although KCL, with its' high salt content, is often thought of as a fertilizer with a tendency to burn turf we did not observe it here, and shoot density was unaffected by the use of this fertilizer.

In 2007, the interaction of K source and placement affected shoot density because plots receiving broadcast application of KCL had a significantly higher shoot density than measured in plots receiving broadcast KCL (Table 8). The only other result was that plants receiving broadcast coated K_2SO_4 had greater shoot density than the control. There was no difference due to placement among the other K treatments.

There were few differences in clipping yield due to K source that existed throughout the duration of the study. Source was significant in 5 of 17 sampling dates (Table 9), placement in 4 of 17 dates (Table 10), and there were two times when the interaction of K source and placement affected yield (Table 11).

There were no consistent differences in clipping yield due to K source at any sampling (Table 9). Clipping yield from unfertilized plots did not differ from fertilized, regardless of the month of sampling (Table 9).

There were 4 times in which the placement of fertilizer significantly affected clipping yield (Table 10), although effects were mixed. At 2 of the dates the addition of any K fertilizer (Dec, 2006 and Feb, 2008) decreased clipping yield, regardless of the method of application. In the other two sampling dates plots that received K fertilizer as band application had greater clipping yield than in broadcast (Oct, 2006) or the control (March, 2007). Lack of clipping yield response has been shown in previous work. For example, clipping weights, in general, were not influenced consistently by K source or K rate; increases due to K have increased over time (Waddington et al., 1972). There was no identifiable positive effect of K on clipping yield and quality even when soil extractable K levels test low (Fitzpatrick and Guillard, 2004). Few K source by placement interactions on clipping yield were observed (Table 11) June, 2007 and October, 2007.

Differences due to method of placement were largely absent at these two sampling dates, with the exception of the K source K_2SO_4 (Table 11). Results were again mixed with that source, with a greater clipping yield from band and unfertilized plots in June 2007, and a greater yield from broadcast and control plots in October, 2007.

Regardless, clipping yields in any fertilized plot were never better than in the unfertilized control.

The findings of this study are in agreement with the majority of the literature that exists on prior K research. Potassium application had no beneficial effects on turfgrass performance and acceptable performance was achieved across a wide gradient of K content in soil and leaf tissue. Regardless of soil test K, no deficiency symptoms were observed. Soil K recommendations should be reevaluated as to avoid gratuitous applications of K fertilizers (Wood et al., 2006). Measured parameters of turfgrass quality were not affected by K fertilization, even when extractable soil K content was low (Cisar et al., 1992). Total K losses and average K concentration in leachates were not affected by K fertilizer source (Alfaro et al., 2004). There is no benefit to applying K at rates in excess of those that provide sufficient K levels for normal plant growth (Miller and Dickens, 1996). Severe K deficiencies were observed in the absence of K fertilization. Increasing K fertilization beyond a K/N fertilization ratio of 0.5 to 1 had virtually no effect on turfgrass appearance or growth (Snyder and Cisar, 2000).

IV. CONCLUSIONS

Over 2 years there was little difference in bentgrass performance due to K source: clipping yield, tissue K and uptake of K by bentgrass were rarely affected by source. Downward movement of K in the soil profile was largely unaffected by K source. Bentgrass color and quality were unaffected by K source. This research project agrees with other published studies that demonstrate little turfgrass response to K fertilization.

LITERATURE CITED

Adams, E.W., and M. Twersky. 1960. Effect of soil fertility on winter killing of Coastal bermudagrass. Agron. J. 52:325–326.

Adams, J.F., C.C. Mitchell, and H.H. Bryant. 1994. Soil test fertilizer recommendations for Alabama crops. Agronomy and Soils Department. Auburn University. Auburn, AL.

Alfaro, M.A., S.C. Jarvis, and P.J. Gregory. 2004. Factors affecting potassium leaching in different soils. Soil Use Mngt. 20(2):182–189.

Bartholomew, R.P., and G. Janssen. 1929. Luxury consumption of potassium by plants and its significance. J. Amer. Soc. Agron. 21(7):751–765.

Belesky, D.P., and S.R. Wilkinson. 1983. Response of ‘Tifton 44’ and ‘Coastal’ bermudagrass to soil pH, K, and N source. Agron. J. 75:1–5.

Carroll, M.J., and A.M. Petrovic. 1991. Nitrogen, potassium, and irrigation effects on water relations of Kentucky bluegrass leaves. Crop Sci. 31:449–453.

Carrow, R.N., D.V. Waddington, and R.E. Rieke. 2001. Turfgrass soil fertility and chemical problems. John Wiley & Sons, New York.

Christians, N.E., D.P. Martin, and J.F. Wilkinson. 1979. Nitrogen, phosphorus, and potassium effects on quality and growth of Kentucky bluegrass and creeping bentgrass. Agron. J. 71:564–567.

Ebdon, J.S., A.M. Petrovic, and R.A. White. 1999. Interaction of nitrogen, phosphorus, and potassium on evapotranspiration rate and growth of Kentucky bluegrass. Crop Sci. 39:209–218.

Erickson, J.E., J.L. Cisar, G.H. Snyder, and J.C. Volin. 2005. Phosphorus and potassium leaching under contrasting residential landscape models established on a sandy soil. Crop Sci. 45(2):546–552.

Fitzpatrick, R.J., and K. Guillard. 2004. Kentucky bluegrass response to potassium and nitrogen fertilization. Crop Sci. 44:1721–1728.

Frank, K.W., K.M. O'Reilly, J.R. Crum, and R.N. Calhoun. 2006. The fate of nitrogen applied to a mature Kentucky bluegrass turf. Crop Sci. 46(1):209–215.

Goatley, J.M. Jr., V. Maddox, D.J. Lang, and K.K. Crouse. 1994. 'Tifgreen' bermudagrass response to late-season application of nitrogen and potassium. Agronomy Journal. 86(1):7–10.

Guertal, E.A, E. Van Santen, and D.Y. Han. 2005. Fan and syringe application for cooling bentgrass greens. Crop Sci. 45(1):245–250.

Hochmuth, G.J., J.K. Brecht, and M.J. Bassett. 2006. Fresh-market carrot yield and quality did not respond to potassium fertilization on a sandy soil validated by Mehlich-1 soil test. HortTechnology 16(2):270–276.

Hue, N.V. and C.E. Evans. 1986. Procedures used for soil and plant analysis by Auburn University Soil Testing Laboratory. Agron. and Soil Dept. Series. No 106. Alabama Ag. Exp. Station/Auburn Univ.

Huang, B. and X. Liu. 2003. Summer root decline: production and mortality for four cultivars of creeping bentgrass. Crop Sci. 43(1):258–265.

Jiang, Y., and B. Huang. 2001. Osmotic adjustment and root growth associated with drought preconditioning-enhanced heat tolerance in Kentucky bluegrass. Crop Sci. 41:1168–1173.

Johnson, P.G., R.T. Koenig, and K.L. Kopp. 2003. Nitrogen, phosphorus, and potassium responses and requirements in calcareous sand greens. Agron. J. 95:697–702.

Lui, H., R.I. Hull, and D.T. Duff. 1995. Comparing cultivars of three cool-season turfgrasses for potassium uptake kinetics and potassium recovery in the field. Journal of Plant Nutrition. 18(3):467–485.

Mangiafico, S.S., and K. Guillard. 2007. Nitrate leaching from kentucky bluegrass soil columns predicted with anion exchange membranes. Soil Sci. Soc. Am. J. 71(1): 219–224.

Mangiafico, S.S., and K. Guillard. 2006. Fall fertilization timing effects on nitrate leaching and turfgrass color and growth. J. Environ. Qual. 35(1):163–171.

McCarty, L.B. 2005. Best golf course management practices. 2nd Edition, Prentice-Hall Inc., Upper Saddle River, NJ.

McCrimmon, J.N. 1998. Effect of nitrogen and potassium on the micro-nutrient content of fifteen bermudagrass cultivars. Comm. Soil Sci. Plant Analy. 29(11-14):1851–1861.

Miller, G.L., and R. Dickens. 1996a. Bermudagrass carbohydrate levels as influenced by potassium fertilization and cultivar. Crop Sci. 36:1283–1289.

Miller, G.L., and R. Dickens. 1996b. Potassium fertilization related to cold resistance in bermudagrass. Crop Sci. 26:1290–1295.

Miller, G.L. 1999. Potassium application reduces calcium and magnesium levels in bermudagrass leaf tissue and soil. HortScience 34(2):265–268.

Ok, C.H., S.H. Anderson, and E.H. Ervin. 2003. Amendments and construction systems for improving the performance of sand-based putting greens. Agron. J. 95:1583–1590.

Pare, K., M.H. Chantigny, K. Carey, W.J. Johnston, and J. Dionne. 2006. Nitrogen uptake and leaching under annual bluegrass ecotypes and bentgrass species: a lysimeter experiment. Crop Sci. 46(2):847–853.

Razmjoo, K., and S. Kaneko. 1993. Effect of fertility ratios on growth and turf quality of perennial ryegrass (*Lolium perenne L.*) in winter. J. Plant Nutri. 16(8):1531–1538.

Reeves, S.A., Jr., G.G. McBee, and M.E. Bloodworth. 1970. Effect of N, P, K, tissue levels and late fall fertilization on the cold hardiness or Tifgreen bermudagrass (*Cynodon dactylon X C. transvaalensis*). Agron. J. 62:659–662.

Rodriguez, I.R., G.L. Miller, and L.B. McCarty. 2002. Bermudagrass establishment on high sand-content soils using various N-P-K ratios. HortScience. 37(1):208–209.

Sartain, J.B. 2002. Tifway bermudagrass response to potassium fertilization. Crop Sci. 42(2):507–512.

Sartain, J.B. 1993. Interrelationships among turfgrasses, clipping recycling, thatch, and applied calcium, magnesium, and potassium. Agron. J. 85(1):40–43.

Schmidt, R.E., and J.M. Breuninger. 1981. The effects of fertilization on recovery of Kentucky bluegrass turf from summer drought. p. 333–339. *In* R.W. Sheard (ed.) Proc. 4th Int. Turfgrass Res. Conf. Huddleston & Barney, Woodstock, ON.

Sheard, R.W., M.A. Haw, G.B. Johnson, and J.A. Ferguson. 1985. Mineral nutrition of bentgrass on sand rooting systems. Int. Turfgrass Soc. Res. J. 5:469–485.

Snyder, G.H., and J.L. Cisar. 1992. Controlled-release potassium fertilizers for turfgrass. J. Amer. Soc. Hort. Sci. 117(3):411–414.

Snyder, G.H., and J.L. Cisar. 2000. Nitrogen / potassium ratios for bermudagrass turf. Crop Sci. 40(6):1719–1723.

Stanford, G., J.B. Kelley, and W.H. Pierre. 1941. Cation balance in corn grown on high-lime soils in relation to potassium deficiency. Soil Sci. Soc. Am. Proc. 6:335–341.

Tisdale, S.L., W.L. Nelson, J.D. Beaton, and J.L. Havlin. 1991. Soil fertility and fertilizers. 5th Edition, Macmillan Publishing Company, New York, NY.

Waddington D.V., E.L. Moberg, and J.M. Duich. 1972. Effect of N source, K source, and K rate on soil nutrient levels and the growth and elemental composition of Penncross creeping bentgrass, *Agrostis palustris* Huds. Agron. J. 64:562–565.

Wagner, R.E. 1967. The role of potassium in the metabolism of turgrasses. p. 55. In Agronomy Abstracts. ASA, Madison, WI.

Woods, M.S., Q.M. Ketterings, F.S. Rossi, and A.M. Petrovic. 2006. Potassium availability indices and turfgrass performance in a calcerous sand putting green. Crop Sci. 46:381–389.

Table 1. Schedule of fertilizer and pesticide applications to the Penn G-2 bentgrass green, TGRU, Auburn, AL.

Date	Material Applied	Rate
8/8/2006	34-0-0†	2.4 g N m^{-2}
8/30/2006	34-0-0	2.4 g N m^{-2}
10/6/2006	34-0-0	1.2 g N m^{-2}
10/20/2006	21-0-0	1.2 g N m^{-2}
11/9/2006	21-0-0	1.2 g N m^{-2}
11/27/2006	21-0-0	1.2 g N m^{-2}
12/11/2006	21-0-0	1.2 g N m^{-2}
12/20/2006	21-0-0	1.2 g N m^{-2}
8/15/2006	Chlorothalonil Zn	1.9 mL m^{-2}
9/7/2006	Iprodione	1.3 mL m^{-2}
10/12/2006	Iprodione	1.3 mL m^{-2}
11/10/2006	Fenarimol	1.5 oz/1000
12/11/2006	Chlorothalonil	1.3 mL m^{-2}
9/7/2006	Orthene	3.4 kg ha^{-1}
10/20/2006	Orthene	4.4 kg a.i. ha^{-1}
11/9/2006	Bensulide	6.7 kg a.i. ha^{-1}
1/4/2007	21-0-0	1 g N m^{-2}
1/12/2007	0-46-0	4.9 g P_2O_5 m^{-2}
1/17/2007	0-46-0	4.9 g P_2O_5 m^{-2}

Date	Material Applied	Rate
1/19/2007	15.5-0-0	4.9 g N m^{-2}
2/12/2007	15.5-0-0	2.4 g N m^{-2}
2/19/2007	0-46-0	4.9 g P_2O_5 m^{-2}
2/27/2007	0-46-0	4.9 g P_2O_5 m^{-2}
3/12/2007	15.5-0-0	2.4 g N m^{-2}
3/21/2007	21-0-0	1 g N m^{-2}
3/21/2007	Ferromec 15.5-0-0[†] 6% iron	1 mL m^{-2}
4/6/2007	21-0-0	1 g N m^{-2}
4/18/2007	21-0-0	1 g N m^{-2}
5/3/2007	21-0-0	1 g N m^{-2}
5/18/2007	21-0-0	1 g N m^{-2}
6/4/2007	21-0-0	1 g N m^{-2}
6/15/2007	21-0-0	1 g N m^{-2}
7/2/2007	21-0-0	2 g N m^{-2}
7/16/2007	21-0-0	2 g N m^{-2}
7/30/2007	21-0-0	1 g N m^{-2}
8/13/2007	21-0-0	1 g N m^{-2}
8/28/2007	21-0-0	1 g N m^{-2}
9/14/2007	21-0-0	1 g N m^{-2}
9/28/2007	21-0-0	1 g N m^{-2}
10/10/2007	21-0-0	1 g N m^{-2}

Date	Material Applied	Rate
10/26/2007	21-0-0	1 g N m^{-2}
11/16/2007	21-0-0	1.5 g N m^{-2}
11/30/2007	21-0-0	1.5 g N m^{-2}
12/14/2007	21-0-0	1 g N m^{-2}
1/4/2007	Chlorothalonil and Aluminum tris (O-ethyl phosphate	1.3 mL m^{-2}
2/28/2007	Iprodione	1.3 mL m^{-2}
3/26/2007	Iprodione	1.3 mL m^{-2}
4/27/2007	Chlorothalonil	1.3 mL m^{-2}
5/17/2007	Iprodione	1.3 mL m^{-2}
6/11/2007	Chlorothalonil	1.3 mL m^{-2}
6/28/2007	Iprodione	1.3 mL m^{-2}
7/3/2007	Azoxystrobin	1.3 mL m^{-2}
7/12/2007	Iprodione	1.3 mL m^{-2}
8/3/2007	Fenarimol	0.5 mL m^{-2}
9/7/2007	Chlorothalonil	9 kg ha^{-1}
9/26/2007	Fenarimol	0.5 mL m^{-2}
10/16/2007	Chlorothalonil	1.3 mL m^{-2}
11/19/2007	Chlorothalonil	1.3 mL m^{-2}
12/14/2007	Fenarimol	0.5 mL m^{-2}
4/10/2007	Fipronil	9.7 g m^{-2}
5/15/2007	Flutalonil	1.4 mL m^{-2}

Date	Material Applied	Rate
9/18/2007	Bensulide	18.7 L ha^{-1}
10/8/2007	Carbaryl	9.4 L ha^{-1}
1/7/2008	21-0-0	1 g N m^{-2}
1/25/2008	21-0-0	1 g N m^{-2}
1/31/2008	0-46-0	4.9 g P_2O_5 m^{-2}
2/1/2008	21-0-0	2.4 g N m^{-2}
2/8/2008	21-0-0	1 g N m^{-2}
2/12/08	0-46-0	4.9 g P_2O_5 m^{-2}
2/25/2008	21-0-0	1 g N m^{-2}
3/12/2008	21-0-0	1 g N m^{-2}
3/13/2008	0-46-0	4.9 g P_2O_5 m^{-2}
3/27/2008	21-0-0	1 g N m^{-2}
4/18/2008	21-0-0	1 g N m^{-2}
5/2/2008	21-0-0	1 g N m^{-2}
1/10/2008	Chlorothalonil	1.3 mL m^{-2}
2/4/2008	Iprodione	1.3 mL m^{-2}
3/6/2008	Bensulide	18.7 L ha^{-1}
4/3/2008	Iprodione	1.3 mL m^{-2}
4/16/2008	Bensulide	18.7 L ha^{-1}
4/28/2008	Iprodione	1.3 mL m^{-2}
5/13/2008	Iprodione	1.3 mL m^{-2}

† analysis is presented as percent N-P2O5-K2O

Table 2. Interaction of K source and method of placement on soil K content (0 to 7.6 cm depth).

	Coated K_2SO_4	K_2SO_4	KCl	KNO_3	KTS†
---------------------------µg g^{-1}---------------------------					
---------------------------July 2007---------------------------					
Band	9.5 a[††]	10.0 a	8.6 a	9.4 b	12.2 a
Broadcast	10.4 a	10.2 a	8.7 a	12.7 a	10.1 a
Control	4.5 b	4.5 b	4.5 b	4.5 c	4.5 b
---------------------------September 2007---------------------------					
Band	13.9 a	11.5 a	9.8 b	14.0 a	17.4 a
Broadcast	11.4 a	12.9 a	20.7 a	17.8 a	14.1 a
Control	5.7 b	5.7 b	5.7 c	5.7 b	5.7 b
---------------------------December 2007---------------------------					
Band	9.8 a	8.1 a	8.9 a	8.3 b	7.8 a
Broadcast	7.0 b	9.3 a	12.5 a	13.5 a	9.3 a
Control	3.9 c	3.9 b	3.9 b	3.9 c	3.9 b

† Denotes Potassium Thiosulfate

†† Within each K source and sampling date means followed by the same letter are not significantly different from each other at $\alpha = 0.05$.

§ Method of placement was either surface broadcast or incorporated in a vertical band created from a 1-cm diam. x 10-cm deep aerification tine.

Table 3. Mehlich extractable soil K as affected by K source and sampling date, 2006-2008.

----------Dates----------			
	Jan 07	June 07	Oct 07
----------$\mu g\ g^{-1}$----------			
Ctd K_2SO_4	7.9 ab‡	16.2 a	11.1 a
K_2SO_4	8.0 ab	16.4 a	11.3 a
KCL	6.7 b	14.3 a	10.7 a
KNO_3†	8.3 ab	14.4 a	11.3 a
KTS	9.3 a	13.8 a	11.1 a
Control	8.4 ab	8.3 b	9.9 a

† Denotes Potassium Thiosulfate

‡ Means followed by the same letter (within each sampling month) are not significantly different from each other via mean separation at $\alpha = 0.05$.

Table 4. Interaction of K source and method of application[§] on tissue K content in a bentgrass putting green, Auburn, AL.

	Coated K_2SO_4	K_2SO_4	KCL	KNO_3	KTS[†]
----------July 2007----------					
----------%----------					
Band	2.5 a[‡]	2.4 a	2.2 a	2.6 a	2.4 a
Broadcast	2.3 a	2.5 a	2.5 a	2.5 a	2.4 a
Control	1.3 b	1.3 b	1.3 b	1.3 b	1.3 b
----------Oct 2007----------					
Band	2.1 a	1.9 ab	1.9 a	2.0 a	2.5 a
Broadcast	2.1 a	2.2 a	1.9 a	2.1 a	1.9 ab
Control	1.3 b	1.3 b	1.3 a	1.3 b	1.3 b

† Denotes Potassium Thiosulfate.

‡ Within each K source and sampling date means followed by the same letter are not significantly different from each other via means separation at $\alpha = 0.05$.

§ Method of placement was either surface broadcast or incorporated in a vertical band created from a 1-cm diam. x 10-cm deep aerification tine.

Table 5. Tissue K in creeping bentgrass as affected by K source and sampling date, Auburn, AL.

----------Date----------						
	Oct 06	Nov 06	Dec 06	Apr 07	July 07	Jan 08
----------%----------						
K Source						
Coated K_2SO_4	1.9 bc‡	1.7 a	1.3 b	1.4 b	2.4 ab	1.6 a
K_2SO_4	1.9 bc	1.2 c	1.6 a	1.6 a	2.5 ab	1.4 b
KCl	2.5 ab	1.6 ab	1.6 a	1.5 ab	2.4 b	1.5 ab
KNO_3	2.7 a	1.3 bc	1.7 a	1.6 a	2.6 a	1.4 b
KTS†	1.6 c	1.4 bc	1.7 a	1.6 a	2.4 b	1.5 ab
Control	2.2 abc	1.3 bc	1.1 c	1.0 c	1.3 c	0.8 c

† Denotes Potassium Thiosulfate

‡ Within each sampling date means followed by the same letter are not significantly different from each other using means separation at $\alpha = 0.05$.

Table 6. Tissue K in creeping bentgrass as affected by method of placement and sampling date, Auburn, AL.

Method	----------------------------------Date--			
	Jan 07	Apr 07	Dec 07	Jan 08
--% K--				
Band†	2.1 a	1.5 b	1.7 b	1.4 b
Broadcast	1.6 ab	1.6 a	1.9 a	1.6 a
Control	1.3 b	1.0 c	1.0 c	0.8 c

† Method of placement was either surface broadcast or incorporated in a vertical band created from a 6.4-mm diam. x 76-mm deep aerification tine.

‡ Within each sampling date, means followed by the same letter are not significantly different from each other at α= 0.05.

Table 7. Shoot density of bentgrass as affected by K source, Auburn, AL.

	----------------------Date---------------------
	Aug 2006
Source	------------------ Shoots cm^{-2}---------------
K_2SO_4	14.2 ab‡
Coated K_2SO_4	15.8 a
KCL	17.3 a
KNO_3	16.3 a
KTS†	11.6 b
Control	17.6 a

† Denotes Potassium Thiosulfate

‡ Means followed by the same letter are not significantly different from each other at $\alpha = 0.05$.

Table 8. Interaction of K source and method of placement on bentgrass shoot density, Sept, 2007.

	Coated K_2SO_4	K_2SO_4	KCL	KNO_3	KTS[†]
---Shoots cm^{-2}---					
Band	22.0 ab[‡]	21.6 a	28.7 a	20.1 a	20.0 a
Broadcast	24.0 a	20.2 a	19.7 b	22.0 a	21.95 a
Control	19.3 b	19.3 a	19.3 b	19.3 a	19.3 a

† Denotes Potassium Thiosulfate

‡ Within each K source, differences followed by the same letter are not significantly different from each other at $\alpha = 0.05$.

Table 9. Differences in bentgrass clipping yield as affected by K source and sampling date, TGRU.

	Date									
	Aug 06	Sept 06	Dec 06	Jan 07	Mar 07	Jun 07	Aug 07	Oct 07	Dec 07	Jan 08
	$g\ plot^{-1}$									
K Source										
Ctd K_2SO_4	3.0 a	2.3 a	2.9 ab	3.0 a	3.1 ab	7.6 a	19.3 a	5.5 b‡	7.3 b	1.3 a
K_2SO_4	2.6 a	2.0 ab	2.8 b	3.3 a	3.1 ab	7.2 a	17.9 a	5.3 b	8.4 a	1.3 a
KCl	2.7 a	2.2 ab	2.6 b	2.8 a	3.2 a	7.5 a	18.0 a	6.2 a	7.6 ab	1.3 a
KNO_3	2.7 a	1.8 ab	2.6 b	2.8 a	2.9 ab	7.2 a	20.9 a	5.9 ab	7.7 ab	1.6 a
KTS†	2.6 a	1.7 b	2.7 b	2.6 a	3.1 ab	7.6 a	17.7 a	5.5 b	8.2 a	1.5 a
Control	2.8 a	1.7 b	3.1 a	2.7 a	2.7 b	7.8 a	19.0 a	5.8 ab	8.1 ab	1.5 a

† Denotes Potassium Thiosulfate

‡ Within each sampling date, differences followed by the same letter are not significantly different from each other at $\alpha = 0.05$.

Table 10. Effect of fertilizer placement on bentgrass clipping yield, Auburn, AL.

Method	------------------------------------Date--			
	Oct 2006	Dec 2006	March 07	Feb 08
	---------------------------------grams plot^{-1}--------------------------------------			
Band	3.1 a[†]	2.8 b	3.2 a	7.1 b
Broadcast	2.7 b	2.6 b	3.0 ab	6.9 b
Control	3.1 a	3.1 a	2.7 b	8.7 a

† Within each sampling date, differences followed by the same letter are not significantly different from each other at $\alpha = 0.05$.

‡ Method of placement was either surface broadcast or incorporated in a vertical band created from a 6.4-mm diam. 76-mm deep aerification tine.

Table 11. Interaction of K source and placement on bentgrass clipping yield.

	Coated K_2SO_4	K_2SO_4	KCL	KNO_3	KTS[†]
---June 2007---					
Band	8.1 a[‡]	7.8 a	7.2 a	7.0 a	7.4 a
Broadcast	7.2 a	6.6 b	7.7 a	7.3 a	7.7 a
Control	7.8 a	7.8 a	7.8 a	7.8 a	7.8 a
---Oct 2007---					
Band	6.2 a	5.1 b	6.2 a	6.0 a	5.6 a
Broadcast	4.8 b	5.6 a	6.1 a	5.8 a	5.5 a
Control	5.8 a	5.8 a	5.8 a	5.8 a	5.8 a

† Denotes Potassium Thiosulfate.

‡ Within each K source and sampling date, differences followed by the same letter are not significantly different from each other at $\alpha = 0.10$.

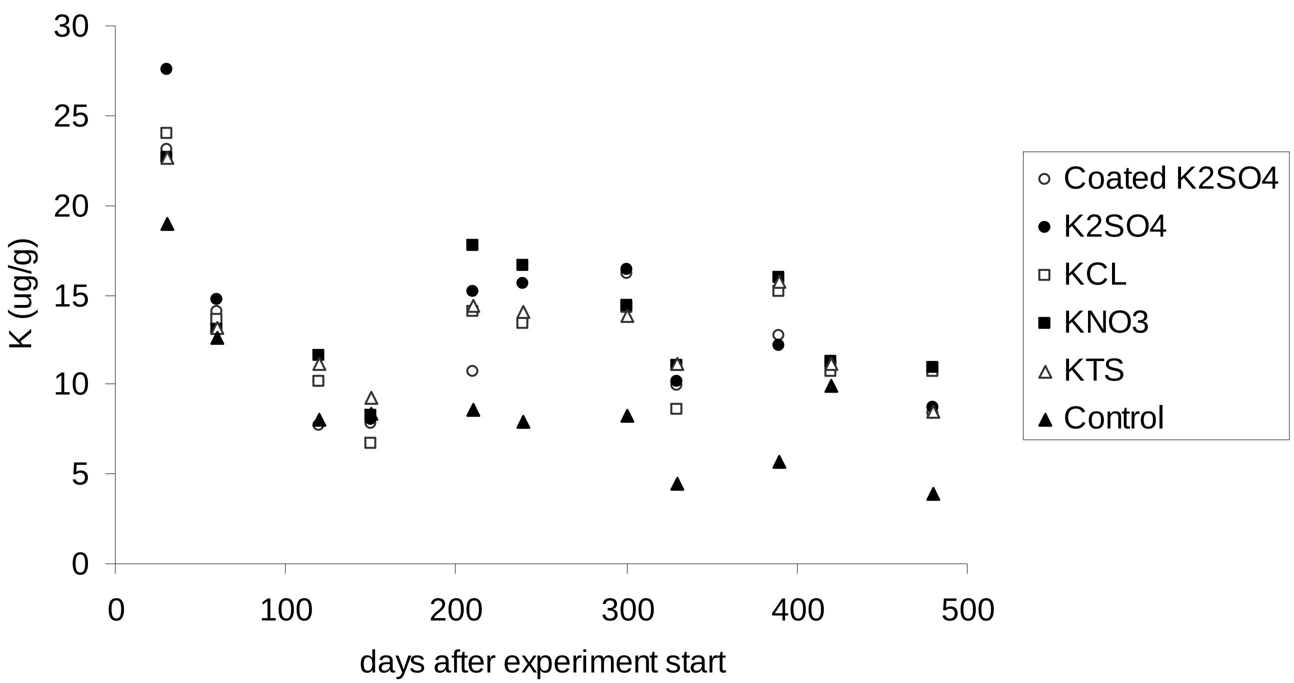

Figure 1. Mehlich extractable soil K (0-7.6 cm depth) as affected by K source and date of sampling, TGRU, 2006-2008. K fertilizer applied on Aug 2006 (0 days), Nov 2006 (90 days), Feb 2007 (180 days), May 2007 (270 days), Aug 2007 (360 days) and Nov 2007 (450 days).

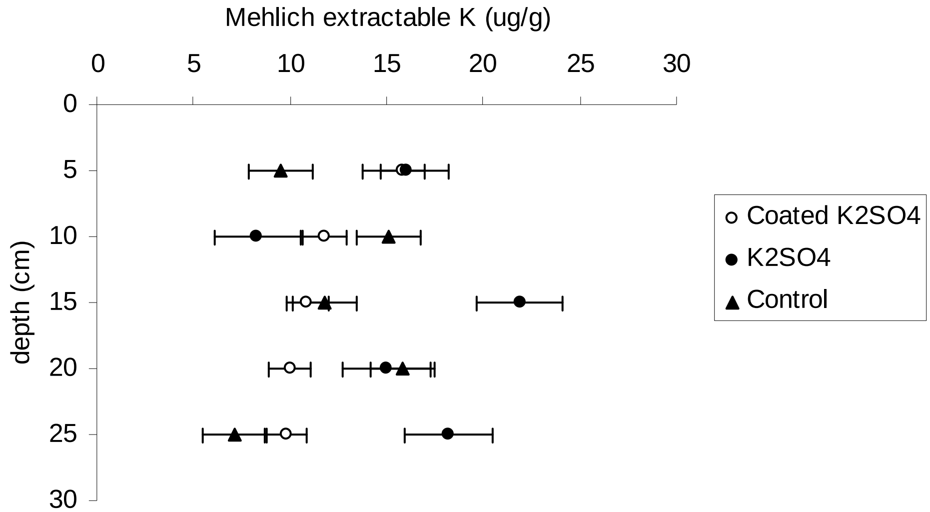

Figure 2. Mehlich extractable K as affected by K source and sampling depth, November, 2006, Auburn, AL.

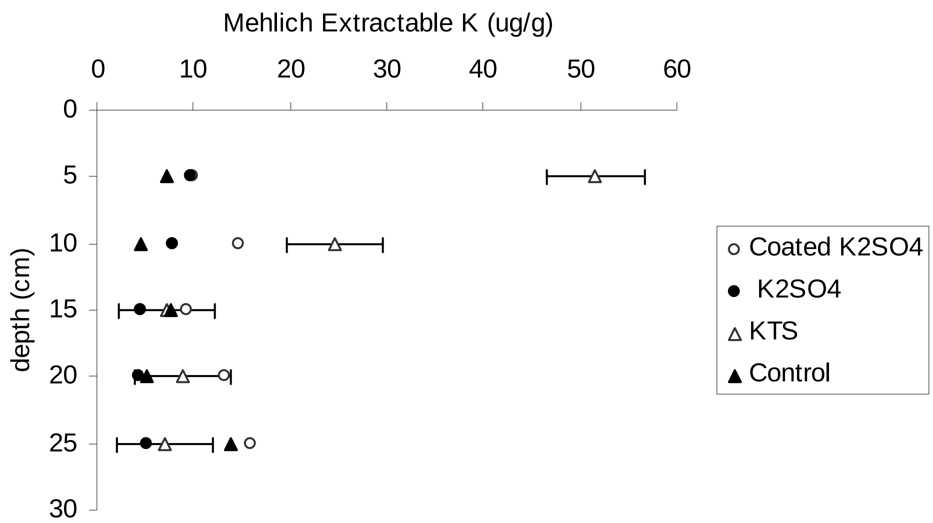

Figure 3. Mehlich extractable K as affected by K source and sampling depth, February, 2007, Auburn, AL.

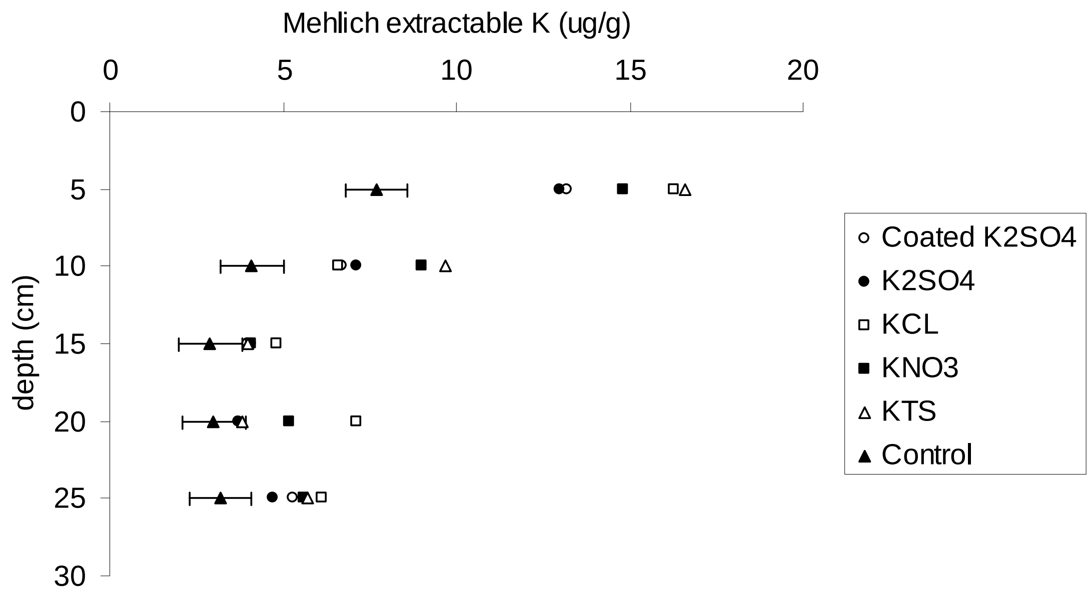

Figure 4. Mehlich extractable K as affected by K source and sampling depth, May, 2007, Auburn, AL.

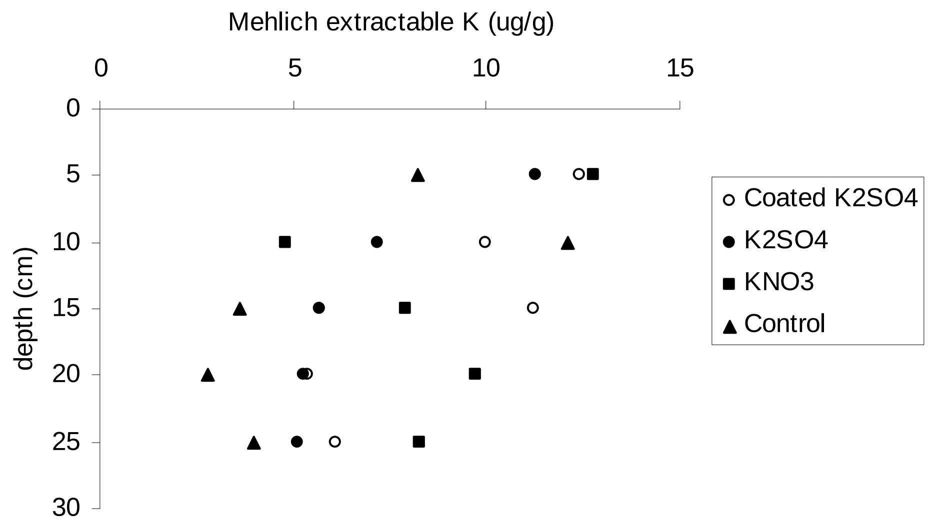

Figure 5. Mehlich extractable K as affected by K source and sampling depth, August, 2007, Auburn, AL.

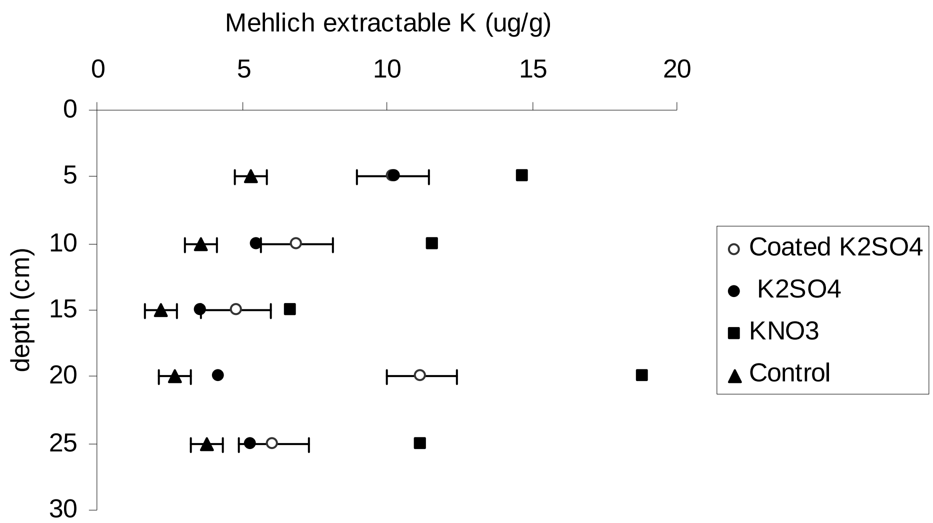

Figure 6. Mehlich extractable K as affected by K source and sampling depth, November, 2007, Auburn, AL.

Figure 7. Mehlich extractable K as affected by K source and sampling depth, February, 2008, Auburn, AL.