Chapter 5.

Potassium supply rate as measured by exchange membranes in a calcareous sand

Abstract

Cation exchange membranes (Plant Root Simulator (PRS)-probes, Western Ag Innovations, Saskatchewan, Canada) were used to evaluate the K supply rate in a calcareous sand putting green. Creeping bentgrass [*Agrostis stolonifera* var. *palustris* (Huds.) Farw.] leaf K content was used as an indicator of K bioavailability. On all 14 measurement dates in 2002 and 2003, the K supply rate increased in experimental plots to which K fertilizer had been applied. On 9 of the 12 dates when leaf samples were collected, K content in leaf samples increased with K supply rate. Potassium supply rate is a meaningful indicator of K bioavailability, and exchange membranes offer potential for assessment of *in situ* variability in K supply. However, the sensitivity of the exchange membranes to changes in soil K supply over time presents obstacles to simple interpretation of supply rate measurements.

Introduction

The K status of sand rootzones is usually assessed by soil nutrient analyses. These rapid tests measure the K removed from a dried soil sample by an extracting solution such as Mehlich 3, ammonium acetate, or sodium acetate (Carrow et al., 2004). Ideally, a local research database would be available to link the quantity of K extracted to a turfgrass growth or quality response. From that database, one could develop a system for classifying sites as low, medium, or high in K, and a fertilizer program could be based on such classifications. However, very few studies have evaluated turfgrass growth or quality in response to extractable soil K across a range of soil types.

A number of recent studies have found no response of creeping bentgrass to applied K, even in sand rootzones that were classified as low in extractable K (Dest and Guillard, 2001; Fulton, 2002; Johnson et al., 2003; Nikolai, 2002; Woods et al., 2006). These results indicate that additional research is needed to better understand creeping bentgrass requirements for K in sand rootzones. In calcareous rootzones, where plant-available K can be depressed because of the high Ca^{2+} : K^+ ratio of the soil solution (Peech and Bradfield, 1943), the interpretation of soil test results can be further complicated.

Diffusion is the primary mechanism of K supply to plant roots (Marschner, 1995). Nutrient analyses of dried soil measure only a mass of K, but ion exchange membranes can be used to measure K^+ flux in the rootzone. Ion exchange membranes have been used to assess ammonium, nitrate, and phosphate leaching from turfgrass sites (Easton and Petrovic, 2004) and nitrate availability to turfgrass (Kopp and Guillard, 2002; Mangiafico and Guillard, 2005). Exchange membranes can be used under field or laboratory conditions, and the multifarious uses of these materials in agricultural and environmental research have been reviewed in two thorough papers (Qian and Schoenau, 2002; Skogley and Dobermann, 1996).

We investigated the use of ion exchange membranes for the measurement of plant-available K in a calcareous sand rootzone. Our objectives were to measure the K supply rate in a creeping bentgrass putting green fertilized with K at different rates, and to evaluate the feasibility of ion exchange membranes as a tool for assessing soil K status in turfgrass systems.

Potassium Applications

Twenty-four rectangular plots (91 cm by 328 cm) were laid out on an L-93 creeping bentgrass research putting green (pH 8.3) at the Cornell University Turfgrass and Landscape Research and Education Center in Ithaca, NY. A detailed description of the chemical and physical properties of this sand can be found in Woods et al. (2005). The 1 *M* ammonium acetate extractable K in June 2002 was 36 mg kg^{-1}, which is classified as low (Carrow et al., 2004).

Six rates of K fertilizer were applied as treatments in a completely randomized design with four replications of each treatment. Potassium fertilizer was applied to the plots as K_2SO_4 at 6 rates (0, 1, 2, 3, 5, and 6 g K m^{-2}) at 14 day intervals during the 2002 and 2003 growing seasons. All K applications were made with a CO_2-pressurized sprayer (R&D Sprayers, Opelousas, LA) calibrated to deliver 167 mL solution m^{-2} at 345 kPa. Thirteen applications were made in 2002 from 5 June to 19 Nov.; twelve applications in 2003 were sprayed from 2 June to 1 Nov. Nitrogen was applied equally to each plot (19 g m^{-2} in 2002, and 14 g m^{-2} in 2003), as was P (3 g P m^{-2} yr^{-1}). No other fertilizers were applied over the course of the study.

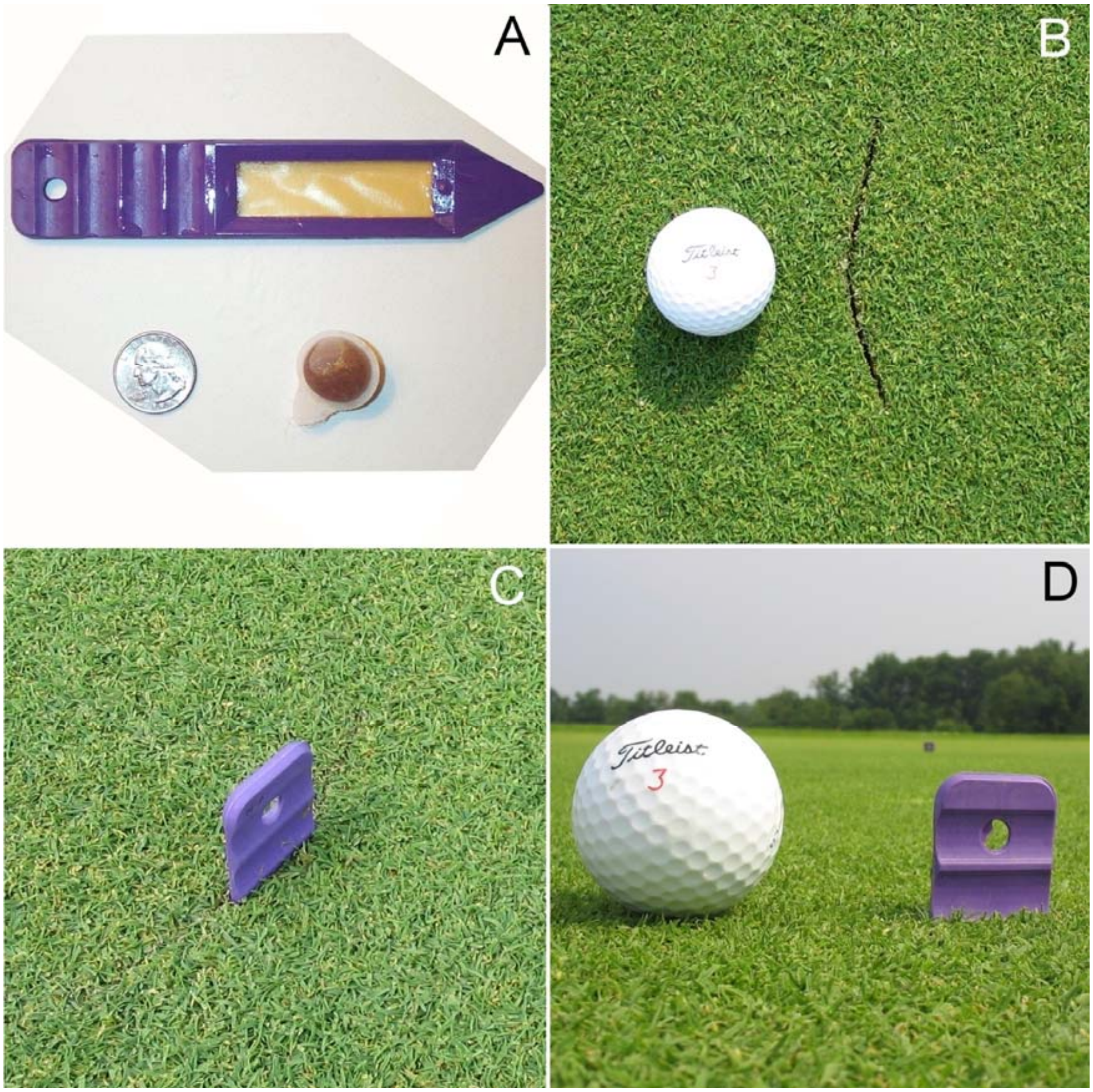

Figure 5.1. In frame A, one PRS-probe (Western Ag Innovations, Saskatoon, Saskatchewan, Canada) is shown with a U.S. 25-cent piece and a Unibest resin bag (Unibest Intl. Corp, Pasco, WA) for size comparison. A spade was used to make a vertical slit in the green, as shown in frame B. The PRS-probe was placed into the slit (frame C), and soil contact with the probe was ensured by applying pressure through the foot around the probe, closing the slit. The probe was left in the soil for 24 h (frame D), and upon removal the adsorbed cations were eluted and quantified.

Cation exchange membranes (Plant Root Simulator (PRS)-probe, Western Ag Innovations, Saskatoon, Saskatchewan, Canada) were used for measurements of soil K supply rate every 28 days from June to November each year. Measurements were initiated 13 days after the previous K fertilizer application, except for additional measurements made on 4 June 2002, 25 Mar. 2003, and 1 June 2003. The PRS-probes and method of insertion are shown in Fig. 5.1. Briefly, PRS-probes were inserted vertically in the putting green, with the membrane surface in contact with the rootzone from 2.5 to 7.5 cm in depth. One PRS-probe was placed at a random location in each of the 24 plots. After 24 hours of insertion, the probes were removed from the rootzone and any adjoined soil was washed off with deionized water. Adsorbed cations were removed from the membrane with 0.5 *M* HCl and were measured in the eluate by inductively-coupled plasma spectrometry (ICP). After elution, the probes were saturated with Na^+ from $NaHCO_3$ and re-used. Because the probes have a fixed surface area and were inserted in the soil for a specific time, the units of ions adsorbed to the membranes are reported as $\mu g\ K\ cm^{-2}\ 24\ h^{-1}$.

Potassium supply rates increase with potassium application

The 24 h K supply rate was measured on 15 occasions from June 2002 to November 2003. The first measurement in 2002 was prior to any K applications, and the supply rates were equal in all plots. On each of the 14 subsequent measuring dates, the PRS-probes measured an increase in K supply rate in the plots to which K fertilizer had been applied (Fig. 5.2). Statistical differences were evaluated using linear mixed models fit to these repeated measures data using the MIXED procedure in SAS STAT software (SAS, version 9.1, Cary, NC).

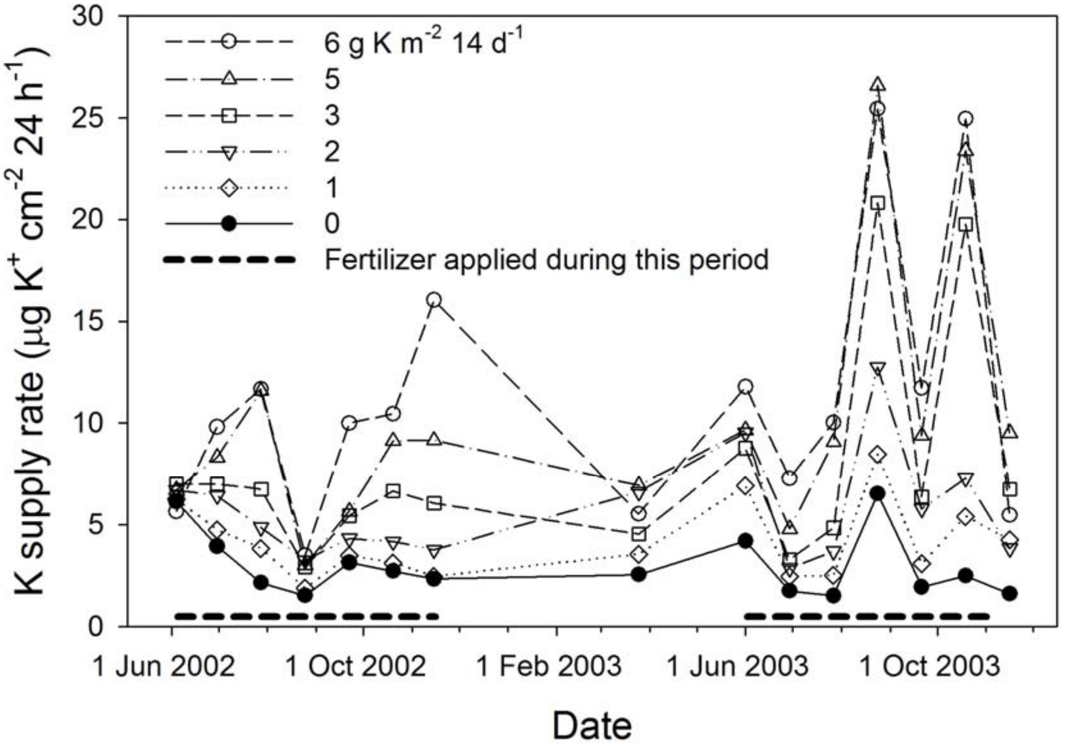

Figure 5.2. The K supply rate as measured on a calcareous sand creeping bentgrass putting green at Ithaca, NY, in 2002 and 2003. Supply rates are shown individually for each of the K fertilizer treatments.

Although the K fertilizer rate was constant at each application date, the K supply rates fluctuated from one measurement date to the next. These fluctuations capture the variability in K supply over time as it is affected by solution K^+ activity, leaching, soil temperature, soil water content, root uptake of K, release of K from mineral forms in the soil, and other contributing factors. Potassium supply rate increased during June and July of 2002, but the supply rate plummeted by mid-August after a series of heavy irrigation events had occurred at the test site. The K supply rate increased again in the fall of 2002, and differences in supply rate continued into March and June of 2003, more than 4 and 6 months respectively after the previous K fertilizer application.

In this sand, with a cation exchange capacity (CEC) of just 1.2 $\text{cmol}_c\ \text{kg}^{-1}$, we had not expected that K applied in 2002 would influence the K supply rates in the following year. The K supply rates measured in August and October of 2003 were larger than at any other dates in this study. Although measurements of soil moisture, temperature, and weather conditions were made during the time of probe insertion, these data were not able to explain the variations we observed in K supply rate. Therefore, we believe that the measured K supply rates represent the intensity of K supply to the roots during the insertion time, and not simply changes in environmental conditions.

The K supply rates in plots receiving no additional K ranged from 1.5 to 6.5 μg K cm^{-2} 24 h^{-1} with a mean baseline K supply rate of 3.1 μg K cm^{-2} 24 h^{-1} (standard error = 0.22). These rates represent the baseline K supply for this calcareous sand rootzone. In both 2002 and 2003, the baseline K supply rate decreased from June to November. However, the mean baseline K supply rate in 2003 was the same as in 2002, suggesting that K is released to solution from a form other than K fertilizer. Dest and Guillard (2001) have shown that creeping bentgrass may not respond to K fertilizer in sands with sufficient nonexchangeable K, and investigations of extractable K at this site suggest that nonexchangeable K may be a source of plant-available K in the absence of K fertilizer (Woods et al., 2006).

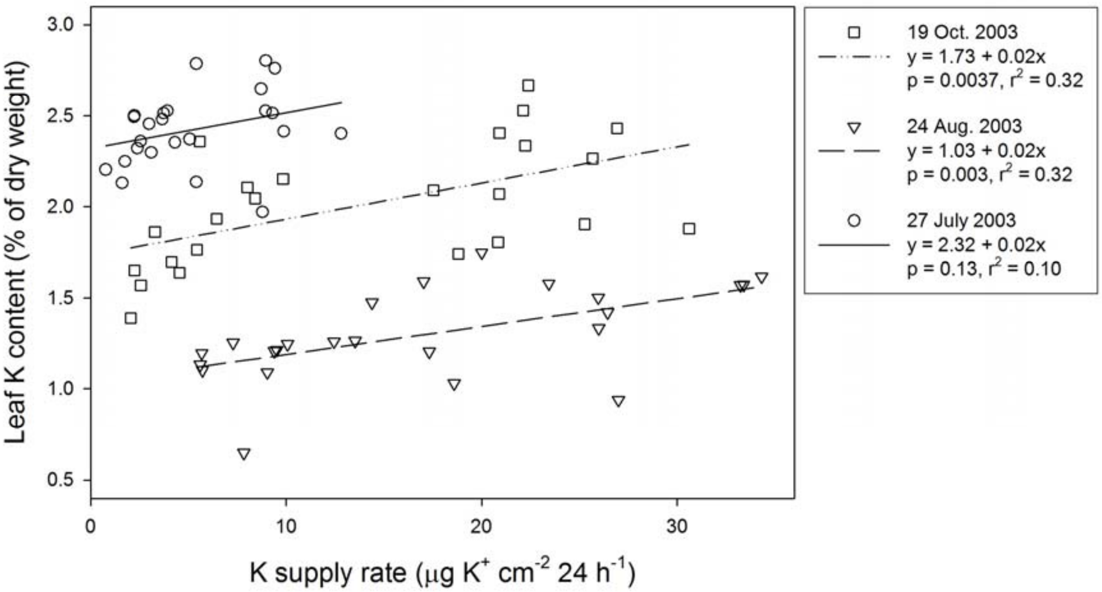

Figure 5.3. Representative relationships between K supply rate and creeping bentgrass leaf K content on 3 dates in 2003 at Ithaca, NY.

Leaf K content increases with greater K supply rate

When K fertilizer had been applied 13 days prior to K supply rate measurement, there was a consequent increase in leaf tissue K content with greater K supply. This effect was detected on 9 of 12 sampling dates. Predictive relationships between K supply rate and leaf K content were calculated using the REG procedure in SAS STAT software (SAS version 9.1, Cary, NC). Representative relationships are shown in Fig. 5.3.

The leaf tissue content varied over time, most likely because of environmental conditions, soil K supply, and leaf water content. Therefore, the leaf K content, although at any one date related to soil K supply, could not be predicted based on K supply rate (Fig. 5.3). This result is in agreement with previous work (Woods et al.,

2005) that showed creeping bentgrass leaf K content varied across time at equivalent levels of extractable soil K.

A feasible method of measuring K?

On a golf course, ion exchange membranes must be used in such a way that they do not interfere with maintenance practices or golf play. We inserted the probes vertically, and approximately 3 cm of the probe assembly was above the turf surface. The PRS-probe could be inserted into the soil at a 45 degree angle, and this would keep the membrane within the 10 cm rootzone and allow for complete insertion of the probe into the soil. Alternatively, membranes can be manually placed in the soil, or other frame designs could be developed specifically for turfgrass systems, where an extended handle on the probe is not desirable.

Although the potential interference of exchange membranes with turfgrass maintenance and sports play are easily overcome, a more intractable argument against their use is that the ion supply rate data are difficult to interpret. The PRS-probes were sensitive to K fertilizer-induced changes in the rootzone, and 24 h K supply rate was an acceptable measure of bioavailable K, as indicated by the positive relationship between K supply rate and leaf K content on individual sampling dates. However, variability among sampling dates makes it difficult to interpret the data for K fertility management over longer periods. Paradoxically, the very precision with which the membranes measured K supply rate in the rootzone resulted in data that were difficult to classify as low, medium, or high.

There are some intriguing uses of ion exchange membranes that remain to be investigated in turfgrass systems. Exchange membranes can be used for rapid (1 h) assessment of K supply rate (Qian et al., 1996), or be left in the soil for hours, days, or even weeks (Qian and Schoenau, 2002; Skogley and Dobermann, 1996). Longer-term insertion of exchange membranes captures not only the immediate nutrient supply, but also diffusion and release of K from mineral or non-exchangeable forms. If exchange membranes come into equilibrium with the surrounding solution, and no longer serve primarily as a sink, the membrane acts as a dynamic exchanger (Cooperband and Logan, 1994), and the ions adsorbed to the membrane in that situation represent the ions as they are affected by perturbations to the soil solution. As such, the use of exchange membranes to assess the diffusion and release of K from non-exchangeable forms in sand rootzones may help to explain the response or lack of response to K fertilizer at a particular site.

Although it remains difficult to interpret K supply rates on turfgrass sites today, the ability of exchange membranes to capture the *in situ* variability in soil K supply may offer insights into a better understanding of K nutrition in turfgrass sand rootzones.

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