Chapter 7.

Assessing the availability of nonacid cations to creeping bentgrass in sand rootzones

Abstract

Nonacid cation availability is assessed by soil nutrient analyses. We evaluated three soil testing methods (0.01 *M* $SrCl_2$, 1:5 H_2O, and Mehlich 3) for their ability to extract a plant-available fraction of the soil nonacid cations in four sands ranging in pH from 5.0 to 8.5. Creeping bentgrass [*Agrostis stolonifera* var. *palustris* (Huds.) Farw.] leaf content of nonacid cations was used as an index of nutrient availability in the soil. Creeping bentgrass (A-1) plants were grown from seed (7.5 g m^{-2}) in a greenhouse at Ithaca, NY. Nitrogen, S, and P were applied as fertilizers, and deionized water was applied as irrigation to prevent drought stress. Mehlich 3 extractable nonacid cations were not evaluated in the calcareous sand. Even in the non-calcareous sands, the 0.01 *M* $SrCl_2$ and the 1:5 H_2O were equivalent to the Mehlich 3 method in their ability to extract a plant-available fraction of soil nonacid cations. Leaf Ca, Mg, and K contents were within a currently accepted sufficiency range even at Mehlich 3 extractable Ca, Mg, and K levels that are classified as low. The Mehlich 3 test should be calibrated with more accuracy for creeping bentgrass grown on sand rootzones, and the 0.01 *M* $SrCl_2$ and 1:5 H_2O extraction methods should be tested in additional sands to better understand the practicality of their use as universal extractants for sand rootzones.

Introduction

The nonacid cations Ca, Mg, and K are essential plant nutrients. An additional nonacid cation, Na, can beneficially or adversely affect plant growth (Marschner, 1995).

Soil nutrient analyses are used to assess the availability of soil nutrients for uptake by plant roots. For each extraction method, the quantity of nutrient extracted is used as an index of availability. Calibration of the availability indices with a crop yield or quality response should be done in different soil types, and an equivalent of 20 site-years of data are desired for development of robust indices (Nelson and Anderson, 1977).

In the turfgrass field, there are two obstacles to proper interpretation of soil nutrient analyses. First, we are not aware of any studies relating extracted soil nutrients to turfgrass growth or quality across a representative range of soils and sites. Secondly, extracting solutions in use at commercial soil testing laboratories were developed for use in soils containing clay. Highly-maintained turfgrass is often established on sand rootzones, but no commercial laboratories offer tests that use an extracting solution designed for assessing the chemical status of sand rootzones.

Previous work (Woods et al., 2004; Woods et al., 2005a; Woods et al., 2005b) has shown that changes in extractable nonacid cations can be detected with greater facility when the extraction solution adjusts to the pH of sand samples. We have evaluated an extracting solution of 0.01 *M* $SrCl_2$ for its ability to extract K (Woods et al., 2005a; Woods et al., 2006) and Ca and Mg (Woods et al., 2005b) from a calcareous sand rootzone.

Carrow et al. (2003) have argued that traditional extracting solutions such as Mehlich 3 are better predictors of nutrient availability in low cation exchange capacity (CEC) sand rootzones than are water soluble nutrients. An alternative view has also been presented (Woods, 2004), in which water soluble nutrients are proposed as a useful predictor of nutrient status in sand rootzones. However, there are not enough data to support either view.

We conducted an experiment under greenhouse conditions to investigate the relationships between extractable soil nonacid cations and A-1 creeping bentgrass leaf content of nonacid cations. Leaf content of a particular nonacid cation was used as an indicator of that element's availability for root uptake in the soil. Three soil test methods were used to assess plant available nutrients: Mehlich 3, 0.01 *M* $SrCl_2$, and 1:5 H_2O. Our objective was to determine which of the extraction methods, if any, were most suited for assessment of plant-available nonacid cations in sand rootzones.

Materials and Methods

Four sand samples were obtained from established turfgrass sites. Sand properties are shown in Table 7.1. Samples were dried and passed through a 2 mm screen. Fir-cell containers (Ray Leach Conetainer, Model RLC3, Steuwe & Sons, Corvallis, OR) with 49 mL volume were prepared by placing 12 cm^2 pieces of 2-ply cheesecloth on the inside of each container to keep sand from spilling through the drainage holes. Dried sand was placed into the containers. For each sand, 13 replicate containers were prepared. Creeping bentgrass seed (A-1, Tee-2-Green, Hubbard, OR) was applied to each container at 7.5 g m^{-2}. The seeded containers were transferred to a greenhouse and deionized water was applied through a hand-operated spray bottle to maintain sufficient moisture for seed germination.

Table 7.1. Initial pH and extractable nonacid cations for the sands used in the study at Ithaca, NY. Four replicate measurements were made, and standard errors are shown in parentheses.

		Sand			
Measure	Method	A	B	C	D
pH	1:1 H_2O	4.99 – 5.00	6.10 – 6.18	7.25 – 7.30	8.42 – 8.50
	0.01 *M* $CaCl_2$	4.17 – 4.22	5.27 – 5.29	6.22 – 6.28	7.58 – 7.79
		mg kg^{-1}			
Ca	0.01 *M* $SrCl_2$	14 (1.0)	197 (3.7)	201 (3.6)	277 (9.4)
	1:5 H_2O	2 (0.1)	4 (0.1)	5 (0.3)	45 (0.7)
	Mehlich 3	151 (39)	469 (38)	413 (33)	17758 (202)
Mg	0.01 *M* $SrCl_2$	4 (0.1)	37 (0.4)	31 (1.2)	10 (0.1)
	1:5 H_2O	1 (0.1)	1 (0.1)	1 (0.1)	1 (0.1)
	Mehlich 3	26 (2.1)	84 (3.6)	63 (1.8)	270 (3.2)
K	0.01 *M* $SrCl_2$	4 (0.2)	43 (0.6)	48 (2.0)	9 (0.3)
	1:5 H_2O	2 (0.2)	14 (0.3)	40 (1.4)	5 (0.4)
	Mehlich 3	20 (2.0)	80 (0.6)	71 (1.3)	58 (0.6)
Na	0.01 *M* $SrCl_2$	0 (0.4)	7 (0.3)	1 (0.3)	0 (0.2)
	1:5 H_2O	0 (0.2)	3 (0.2)	0 (0.2)	0 (0.1)
	Mehlich 3	12 (0.5)	17 (2.0)	12 (1.0)	18 (0.9)

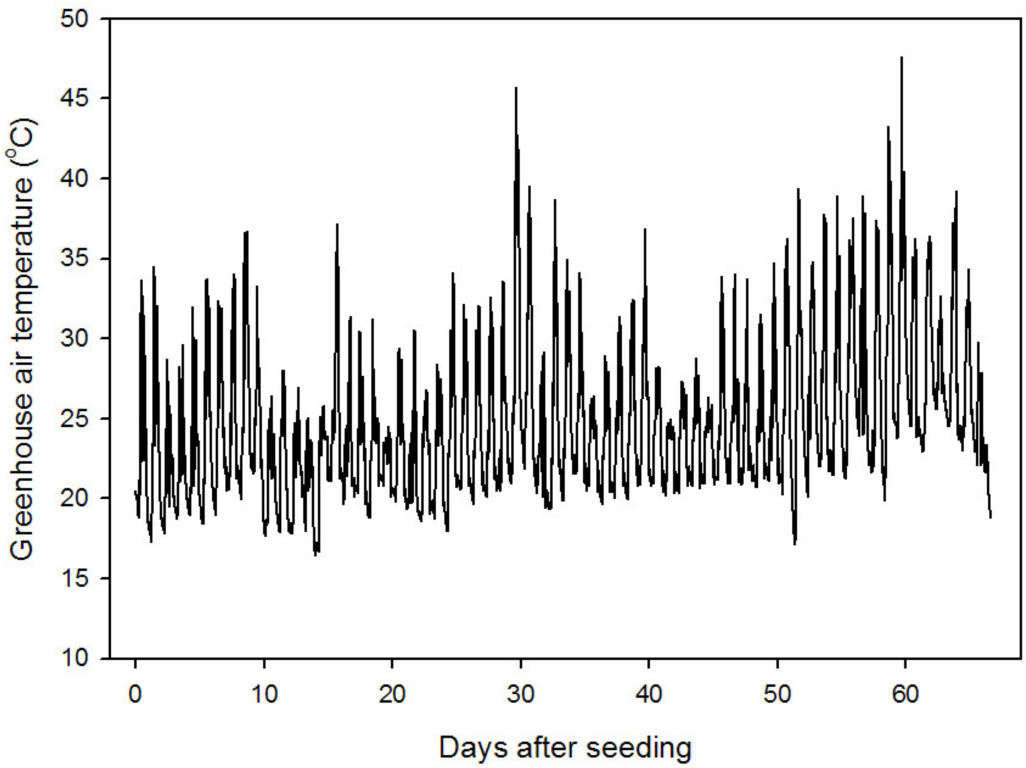

Figure 7.1. The greenhouse air temperature over the course of the experiment at Ithaca, NY.

After the seeds germinated, the grass was grown in the greenhouse with an average day (06:00 to 20:00) temperature of 27°C and an average night (20:00 to 06:00) temperature of 22°C. A datalogger (HOBO U12-012, Onset Computer Corporation, Bourne, MA) was used to record air temperature on 10 minute intervals; these results are shown in Fig. 7.1. The mass of each container was recorded approximately one time per week, and sufficient irrigation was applied to establish equivalent volumetric soil water content in each container. Additional irrigations with deionized water were applied as necessary to prevent wilting. All water was applied with graduated syringes.

Solutions of $(NH_4)_2SO_4$ and $NH_4H_2PO_4$ were prepared in deionized water and were applied to provide a total of 7 g N and 10 g P m^{-2} 65 d^{-1}. The relatively high P applications were made to ensure that adequate P was available to meet plant requirements. The bentgrass was trimmed with surgical scissors at a height of approximately 5 mm above the sand surface. The mass of fresh leaf clippings was immediately recorded, and the clippings were dried at 80°C for 48 h before dry weight of the clippings was recorded. Tissue water content (TWC) was calculated as:

$$\frac{\textit{Fresh weight} - \textit{Dry weight}}{\textit{Fresh weight}} \qquad [1]$$

Sixteen containers (4 of each sand) were randomly selected for destructive harvest 35 days after planting, sixteen more were harvested 50 days after planting, and the remaining 20 containers (5 of each sand) were harvested 65 days after planting. When destructively harvesting, all verdure was cut with surgical scissors and was weighed and dried as above. The sand was removed from the containers and was oven-dried overnight.

Nonacid cations were extracted from the dried sand samples by three methods: Mehlich 3 (Mehlich, 1984), 1:5 H_2O (Soil and Plant Analysis Council, 1999), and 0.01 *M* $SrCl_2$. The 0.01 *M* $SrCl_2$ extraction is a modification of the 0.01 *M* $CaCl_2$ method of Houba et al. (2000), with the 0.01 *M* $SrCl_2$ test using a 2 g sample and 20 mL solution and a shaking time of just 5 minutes. Nonacid cations were measured in solution by inductively-coupled plasma spectrometry (ICP).

Soil pH was measured in 1:1 H_2O and 1:1 0.01 *M* $CaCl_2$ suspensions. Nonacid cations in the leaf tissue were measured by a modified dry ash method (Greweling, 1976). Because of relatively low sample sizes (< 10 to > 40 mg dry tissue) the samples were ashed and dissolved in acid to a final volume of 8 mL. Nonacid cations were measured in the solution by ICP.

Data were plotted to show the relationship between extractable soil nonacid cations and corresponding leaf content of the nonacid cations for each container at the time it was destructively harvested. Comparisons between methods are based on visual interpretation of the plotted data.

Results and Discussion

Mehlich 3 data for sand D were omitted from the results because the extractant is not appropriate for calcareous sands.

Calcium

Leaf Ca content ranged from 1 to 26 g kg^{-1}. A reported sufficiency range for creeping bentgrass leaf Ca content is 1.5 to 7.6 g kg^{-1} (Anonymous, 2005). The 0.01 *M* $SrCl_2$ and 1:5 H_2O extraction removed fractions of soil Ca that were predictive of leaf Ca content in all four sands (Fig 7.2). In the three non-calcareous sands, the Mehlich 3 extractable Ca data were clustered by sand (Fig. 7.2), and the 0.01 *M* $SrCl_2$ or 1:5 H_2O extractable Ca appear to be more useful as indicators of Ca bioavailability.

Carrow et al. (2004) reported a sufficiency range for Mehlich 3 extractable Ca of 500 to 750 mg kg^{-1}. Only one non-calcareous sample had Mehlich 3 extractable Ca within this reported sufficiency range, whereas 89% of the leaf samples had Ca content within the sufficiency range reported by Anonymous (2005). This discrepancy between soil and plant sufficiency ranges can lead to misinterpretation of soil and plant analyses. Gratuitous fertilizer applications are sometimes recommended in attempts to meet these established but unproven sufficiency ranges.

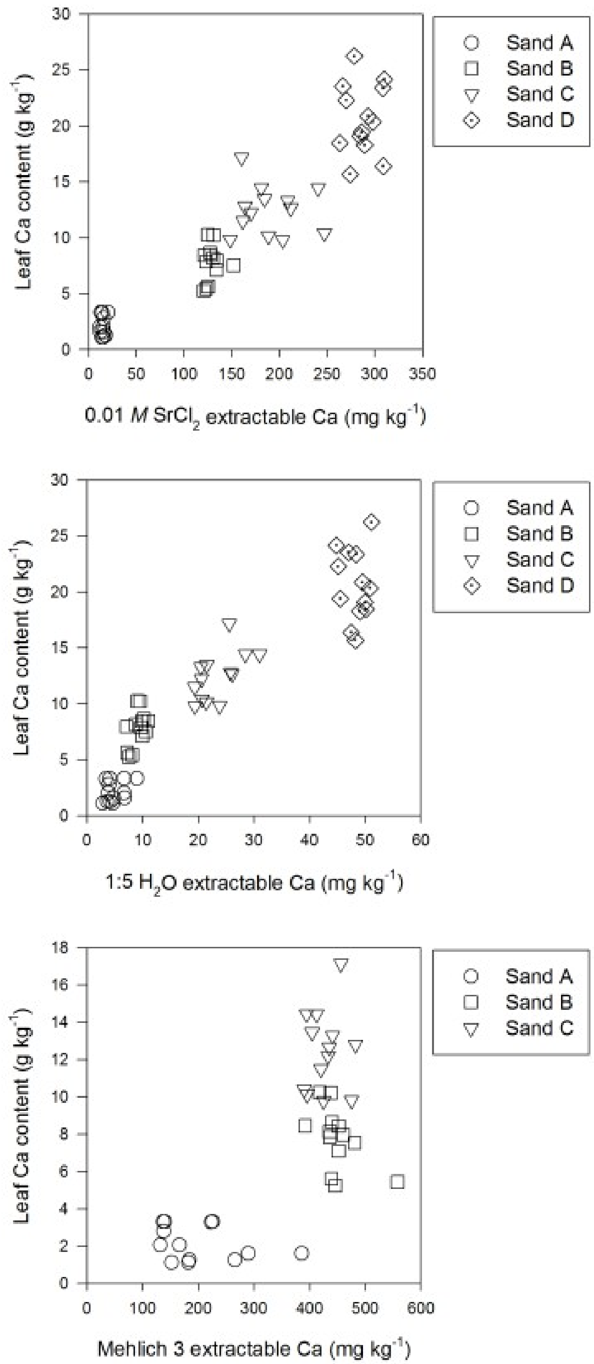

Figure 7.2. Scatter plot of extractable Ca and leaf Ca content for A-1 creeping bentgrass grown in a greenhouse at Ithaca, NY. Leaf Ca and soil Ca were measured on the same day through destructive harvests. Results are shown for 0.01 *M* $SrCl_2$, 1:5 H_2O, and Mehlich 3 soil test procedures.

Magnesium

Leaf Mg content ranged from 1.8 to 5.3 g kg^{-1} (Fig. 7.3). A sufficiency range for creeping bentgrass Mg content of 0.8 to 3.1 g kg^{-1} has been reported (Anonymous, 2005). Leaf Mg content was not influenced by extractable Mg at soil Mg above 5, 2, and 45 mg kg^{-1}, for the 0.01 *M* $SrCl_2$, 1:5 H_2O, and Mehlich 3 extractions, respectively (Fig. 7.3). The results for these four sands suggest that more extractable Mg from a sand may not be associated with a correspondent increase in plant uptake of Mg.

Potassium

Leaf K content on a dry matter basis (K_d) ranged from 5 to 25 g kg^{-1} (Fig. 7.4). Anonymous (2005) presented a sufficiency range for creeping bentgrass K content of 18 to 26 g kg^{-1}. Leaf K_d increased with extractable K from both the 0.01 *M* $SrCl_2$ and the 1:5 H_2O extractions in all sands. For the Mehlich 3 extraction, even with calcareous samples excluded, soil K was not well-correlated with K_d and extractable K was clustered by individual sands (Fig. 7.4). This is may be due to dissolution of mineral K during the extraction process. Although that K may become available to bentgrass roots over time, it may not be represented in the leaf tissue because it would not have been available to roots at the time of sampling.

Potassium status of leaves may be more rationally represented in units of mmol K L^{-1} tissue water (K_w) (Barraclough and Leigh, 1993; Woods et al., 2005). The K_w ranged from 57 to 269 mmol L^{-1}. Grass leaves well-supplied with K usually have K_w of about 200 mmol L^{-1}. The relationships between soil K and K_w are shown in Fig. 7.5. For these four sands, the K_w seemed to plateau at soil K above 12, 3, and 20 mg kg^{-1} by the 0.01 *M* $SrCl_2$, 1:5 H_2O, and Mehlich 3 tests, respectively.

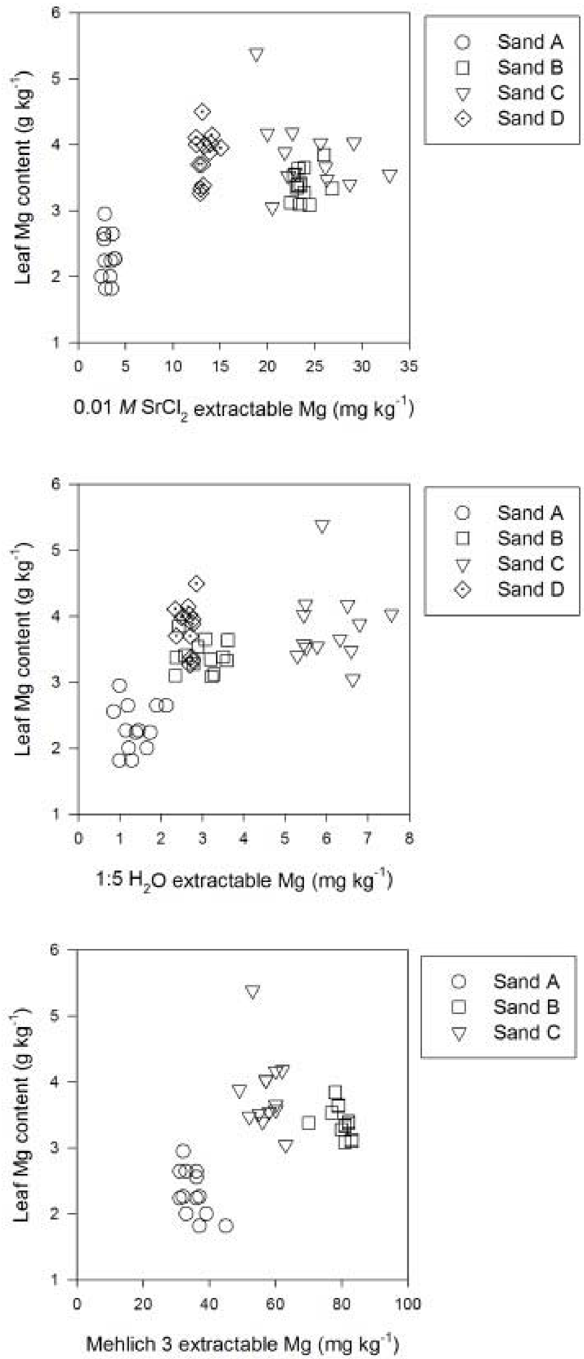

Figure 7.3. Scatter plot of extractable Mg and leaf Mg content for A-1 creeping bentgrass grown in a greenhouse at Ithaca, NY. Leaf Mg and soil Mg were measured on the same day through destructive harvests. Results are shown for 0.01 *M* $SrCl_2$, 1:5 H_2O, and Mehlich 3 soil test procedures.

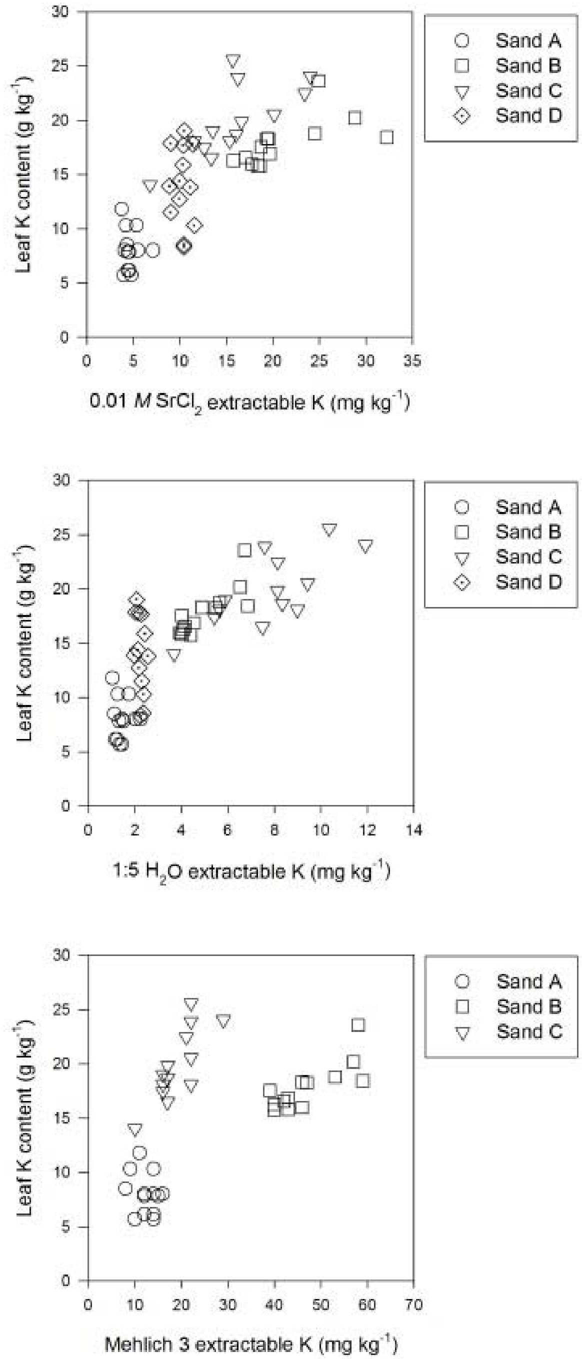

Figure 7.4. Scatter plot of extractable K and leaf K content for A-1 creeping bentgrass grown in a greenhouse at Ithaca, NY. Leaf K and soil K were measured on the same day through destructive harvests. Results are shown for 0.01 *M* $SrCl_2$, 1:5 H_2O, and Mehlich 3 soil test procedures.

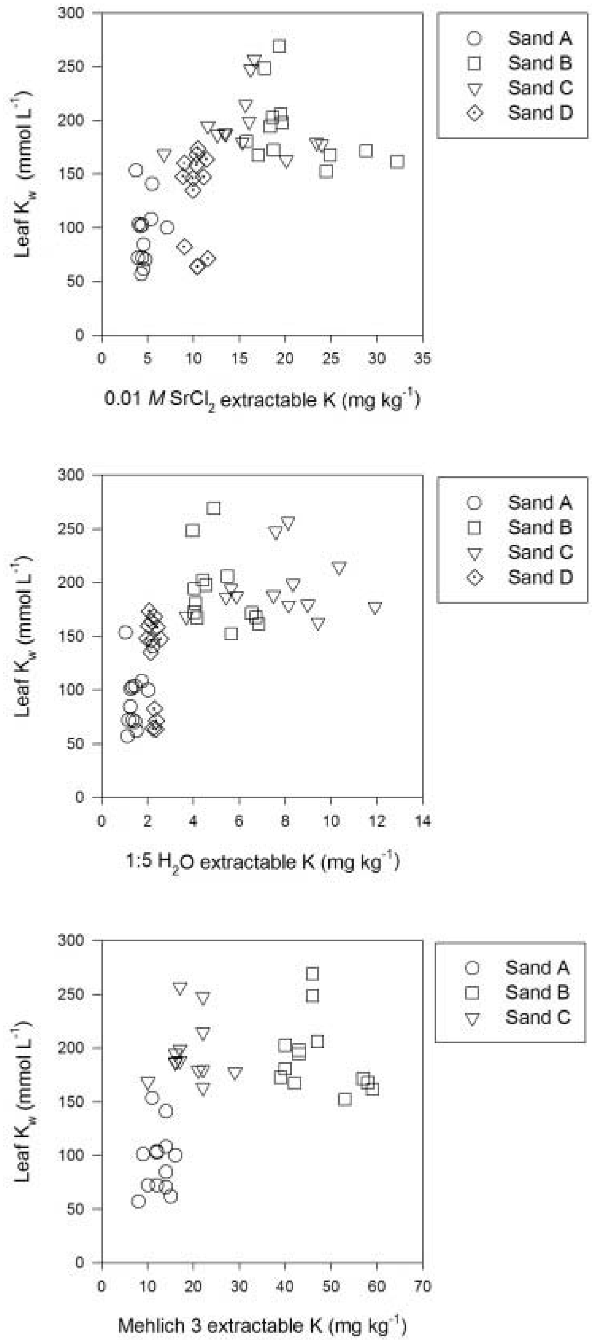

Figure 7.5. Scatter plot of extractable K and leaf K_w (mmol L^{-1}) content for A-1 creeping bentgrass grown in a greenhouse at Ithaca, NY. Leaf K_w and soil K were measured on the same day through destructive harvests. Results are shown for 0.01 *M* $SrCl_2$, 1:5 H_2O, and Mehlich 3 soil test procedures.

Carrow et al. (2004) reported a sufficiency range for extractable Mehlich 3 K in sand rootzones of 50 to 115 mg kg^{-1}. We found K_w to be at a sufficient level in the bentgrass leaves at Mehlich 3 K of 20 mg kg^{-1}.

Leaf K_d was compared with K_w as a predictor of daily dry matter production (Fig. 7.6). The dry matter production increased with K_w, but there was a plateau of dry matter production at K_d above 13 g kg^{-1}. These results show the potential of K_w as a more accurate indicator of creeping bentgrass K status, and the data suggest that a failure to account for leaf water content may create the appearance of luxury consumption of K.

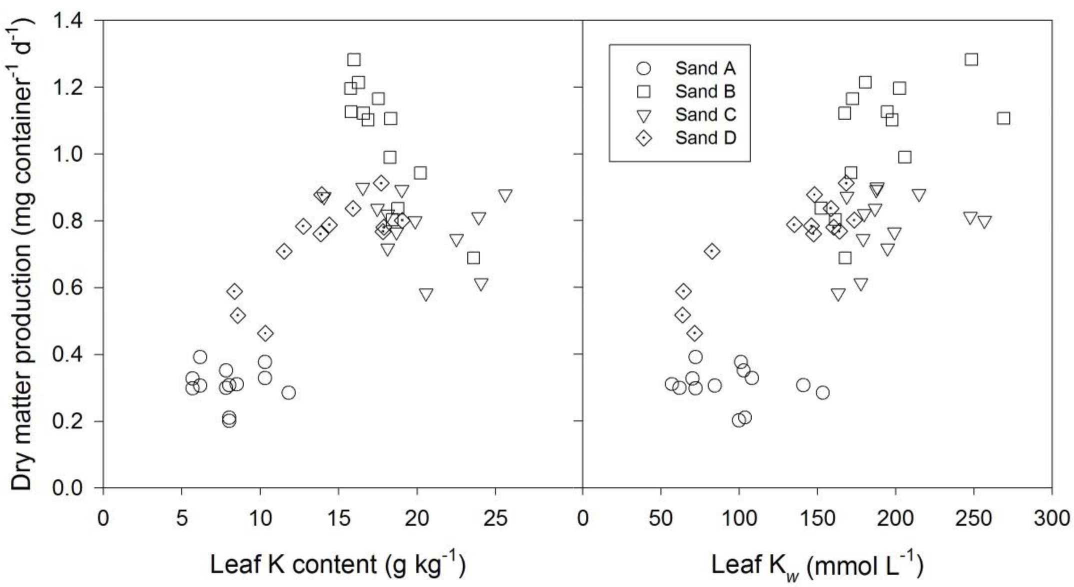

Figure 7.6. Daily dry matter production of A-1 creeping bentgrass grown in a greenhouse at Ithaca, NY, is plotted on leaf K content (g kg^{-1}) and on leaf K_w (mmol L^{-1}).

Sodium

Leaf Na content ranged from 0.1 to 2 g kg^{-1}. There were no instances in which soil Na was related to leaf Na content. This is probably because soil Na levels were too low to have a measurable impact on Na uptake. There were no consistent relationships between leaf K and leaf Na content. We expect that experiments in systems with more Na would show positive relationships between soil Na and leaf Na.

Conclusion

Extracting solutions which adjusted to the pH of the soil during the extraction process extracted Ca, Mg, and K fractions from the soil that were interpretable as indices of nutrient availability. Results from these four sands suggest that dilute salt or water-based extractants can extract plant-available fractions of Ca, Mg, and K. The 0.01 *M* $SrCl_2$ and 1:5 H_2O tests can predict nutrient availability in sands with a range of pH and extractable nonacid cations. Because these sands differed in pH and in extractable nonacid cations, the data were clustered to some degree by sand type, depending on the extractant and the particular cation (Figs. 7.2, 7.3, 7.4, and 7.5). Future experiments should consider the plant-availability of nonacid cations in a larger set of sands with a continuous gradient of extractable nonacid cations. The data shown here (Figs. 7.2, 7.3, 7.4, and 7.5) represent soil test results and leaf nutrient contents as measured on the same date. In practice, soil nutrient analyses are used to predict fertilizer needs or to assess soil nutrient levels. We consider it informative to assess plant-available nutrients in soil by sampling the soil and the plant as close in time as possible. It should be noted that in sand rootzones, and especially in those with low levels of plant-available nutrients, the correspondence between soil and plant nutrient levels may vary considerably if samples for soil and plant nutrient analyses are taken farther apart in time. In these four sands with soil and plant samples collected on the same day, our results suggest that Mehlich 3 sufficiency ranges for nonacid cations in sand rootzones should be re-evaluated. Future research should investigate these extractants and creeping bentgrass growth in a wider range of sands. The relationships between extractable nonacid cations and plant response should be considered to determine if soil test levels can predict future plant response in sand rootzones, or if the relationships are confined to detection of past or current plant response.

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