

EFFECTIVENESS OF STANDARD SOIL TESTS FOR ASSESSING POTASSIUM AVAILABILITY IN SAND ROOTZONES

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Potassium (K) is the most abundant cation in the cytoplasm, and large amounts are needed for optimum plant growth. In sand rootzones with low cation exchange capacity (CEC), commonly used for putting greens, K availability may be limited, especially when the sands are calcareous. Tools are needed to assess K availability and to direct K management for such calcareous sands. The objectives of this study were to: (i) evaluate six extraction methods (1 N NH₄OAc, Mehlich 3, Morgan, 0.01 M CaCl₂, 0.01 M SrCl₂, and water) for their effectiveness in quantifying soil extractable K following K fertilizer applications; and (ii) to ascertain how the extractable K was related to tissue K concentrations. Potassium was applied as K₂SO₄ at six rates (0, 3, 6, 13, 19, and 25 g K m⁻² 56 days⁻¹) to a creeping bentgrass [*Agrostis stolonifera* var. *palustris* (Huds.) Farw.] putting green grown on a calcareous sand rootzone. The potassium was applied at 2-week intervals (4 applications within the 56-day period) and repeated during two different irrigation regimes. Soils were sampled and analyzed after the fourth application. Each extraction method detected an increase in soil extractable K following K fertilizer application. The K concentrations were lowest in the water extracts and highest in the Mehlich 3 extracts, irrespective of irrigation regime, but less K was recovered under higher irrigation intensity. Creeping bentgrass tissue K content increased with K application rate. However, maximum tissue K content was obtained at lower soil K levels under the high irrigation intensity than under the lower irrigation intensity. Our results show that each extraction method could be used to detect an increase in extractable K and to predict an increase in tissue K content. Nevertheless, factors other than soil K concentration also affected the tissue K content, which suggests that soil K concentrations may not be a reliable predictor of tissue K content in this sand rootzone. (Soil Science 2005;170:110-119)

Key words: Potassium, soil testing, sand rootzone, Mehlich 3, ammonium acetate, Morgan, strontium chloride, extraction methods.

SANDS are used widely as a well-drained growing medium for turfgrass sites (USGA Staff, 1993). A major disadvantage of both acidic and calcareous sands is low cation exchange capacity (CEC). Low CEC rootzones are commonly associated with potassium (K) deficiencies (Carrow et al., 2001). The abundance of calcium (Ca) in calcareous sands can also complicate K

management (Peech and Bradfield, 1943; Stanford et al., 1941).

Potassium is the most abundant cation in the cytoplasm (Marschner, 1995) and is an important macronutrient for turfgrass (Carrow et al., 2001). Potassium makes up 1 to 3% of turfgrass leaf tissue on a dry weight basis; it is second only to nitrogen (N) in quantity among the nutrients applied as fertilizer (Carrow et al., 2001).

In order to ensure K availability in sands, turfgrass managers are directed to fertilize with equal amounts of K and N (Carrow et al., 2001), although in practice many turfgrass managers apply more K than N (Ervin et al., 2004; Snyder

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and Cisar, 2000). However, some recent research now suggests that K fertilization of sands may have little influence on turfgrass quality (Dest and Guillard, 2001; Johnson et al., 2003; Nikolai, 2002). Published values for the K extracted by various methods in turfgrass sand rootzones are conspicuously absent. An investigation of the ability of different soil tests to predict tissue K concentrations could be the first step in a more effective and science-based approach to K nutrition of sand rootzones.

Different extractants have been used to assess the K status of soils. The method used most often is 1 N ammonium acetate (NH_4OAc) buffered at pH 7 (Haby et al., 1990). Common universal extractants used in soil testing include the Mehlich 3 extraction (Mehlich, 1984) and the Morgan extraction (Morgan, 1941). Less common methods used for K extraction are the 1:5 soil-water extraction (Soil and Plant Analysis Council, 1999) and the 0.01 M calcium chloride (CaCl_2) extraction (Van Erp et al., 1998). Direct measurement of extractable Ca is complicated by the presence of Ca in the CaCl_2 solution. Because of chemical similarities between strontium (Sr) and Ca (Brescia et al., 1988), strontium chloride (SrCl_2) is expected to have an extraction efficiency equaling that of CaCl_2 while allowing for the determination of Ca in the extract.

Soil K consists of solution, exchangeable, fixed, and structural K (Sparks and Huang, 1985). The amounts of K extracted can be affected by the pH, ionic strength, and ionic composition of the extraction solution as well as the soil-to-solution ratio and shaking time. Because the extraction methods mentioned above vary widely in these characteristics, it is to be expected that extractable K concentrations vary with extraction procedure. The 1:5 water procedure extracts soluble K (Bower and Wilcox, 1965). Although the amount of soluble K is known to vary with the soil:water ratio (Reitemeier, 1946) and extraction time, soluble K is highly correlated with soil solution K (Gillman and Bell, 1978). Extraction methods for the soil solution vary in the quantity of K extracted (Dahlgren, 1993), but a measurement of water soluble K is both highly correlated with soil solution K and simple to reproduce.

A solution containing CaCl_2 or SrCl_2 may extract the solution K and a portion of the adsorbed K, but it should extract less of the adsorbed K than methods that attempt to measure exchangeable K (McLean and Watson, 1985). The NH_4OAc , Mehlich 3, and Morgan procedures extract all of the soluble K, most of the ex-

changeable K, and small but varying proportions of the fixed and structural K (Haby et al., 1990; McLean and Watson, 1985).

The objectives of this study were (i) to evaluate six extraction methods (1 N NH_4OAc , Mehlich 3, Morgan, 0.01 M CaCl_2 , 0.01 M SrCl_2 , and water) for their ability to extract soil K in a calcareous sand; and (ii) to investigate whether soil extractable K could be used to manage tissue K concentrations of a creeping bentgrass putting green.

MATERIALS AND METHODS

A field experiment was conducted on an L-93 creeping bentgrass putting green at the Cornell University Turfgrass and Landscape Center in Ithaca, New York. The putting green was established in 1997 with 4.54-g seed m^{-2} planted on a 30-cm-deep rootzone using a calcareous sand (320 g CaCO_3 equivalent kg^{-1} soil) mined from glacial deposits at RMS Gravel (Dryden, NY). Sand properties are shown in Table 1.

Potassium was applied as K_2SO_4 to 3- m^2 plots, using a completely randomized design, with six K application rates (0, 3, 6, 13, 19, and 25 g K m^{-2} 56 days $^{-1}$ divided into four equal applications at 14-day intervals during June and July of 2002). Rates were selected to include a control and to cover and exceed the range (5–10 g K m^{-2} 56 days $^{-1}$) frequently applied by turfgrass managers. Each treatment was replicated four times. The K was applied with a CO_2 -powered backpack sprayer calibrated to deliver 167 mL of solution m^{-2} at 345 kPa. Nitrogen (N) was applied at a rate of 2 g N m^{-2} on June 5, June 17, July 1, and September 9, 2001, whereas 1 g N m^{-2} was applied at 2-week intervals between July 15 and August 26. Phosphorus was applied to all plots at the rate of 1 g P_2O_5 m^{-2} on June 5, July 1, July 29, and August 26.

Sufficient irrigation was applied immediately after fertilization to wash the fertilizer solution from the leaves. Irrigation water contained 5.1×10^{-2} mmol K L^{-1} , and application of 370 mm irrigation in 2002 was equal to the addition of 4.1×10^{-2} mmol K kg^{-1} soil (an insignificant amount compared with the background level in the soil and the amount applied as fertilizer).

Soil samples (0–10 cm depth), here referred to as the July 28 samples, were collected 13 days after the fourth fertilizer application. After verdure and thatch were removed, the samples were initially stored in a freezer at -12°C ; they were then thawed, dried, and ground to pass 2-mm prior to laboratory analyses.

TABLE 1
Physical and chemical properties of 0–10-cm RMS sand-based putting green soil
prior to K application and irrigation treatments

Parameter	Mean	N	Standard Error
pH (1:1 H ₂ O)	8.3	24	
Sand (g kg ⁻¹) [†]	948	1	
Silt (g kg ⁻¹) [†]	35	1	
Clay (g kg ⁻¹) [†]	17	1	
Organic matter (g kg ⁻¹)	4.0	24	0.01
Bulk density (g cm ⁻³)	1.5	4	0.03
Total porosity (%)	43	4	1.0
Total Ca [‡] (mol kg ⁻¹)	2.39	8	0.057
Total Mg [‡] (mmol kg ⁻¹)	453	8	12.9
Total K [‡] (mmol kg ⁻¹)	262	8	5.2
Total Na [‡] (mmol kg ⁻¹)	176	8	2.8
Nonexchangeable K [§] (mmol kg ⁻¹)	4.40	3	0.145
Exchangeable K [¶] (mmol kg ⁻¹)	0.91	24	0.025
Water soluble K (mmol kg ⁻¹)	0.20	24	0.006
Cation exchange capacity [#] (mmol _c kg ⁻¹)	12.0	24	0.07

[†]Particle size analysis by ASTM F-1632-03 (ASTM International, 2003) without destruction of organic matter or carbonates

[‡]Total digestion by EPA Method 3052 (USEPA, 1999)

[§]Nonexchangeable K by boiling HNO₃ (Pratt, 1965)

[¶]Exchangeable K by NH₄OAc (NCR-13, 1988)

^{||}Water soluble K by 1:5 H₂O extraction (Soil and Plant Analysis Council, 1999)

[#]Cation exchange capacity by BaCl₂ compulsive exchange (Gillman and Sumpter, 1986)

The green was mowed 6 times weekly at a height of 3.2 mm, and clippings were removed. Leaf tissue samples were collected on the same day that soil samples were taken. Tissue samples were analyzed for total K using the dry ash method of Greweling (1976), and tissue N was determined using a C/N analyzer (Thermo-Quest Italia, Milan, Italy).

Potassium was extracted from the soil samples using 1 N NH₄OAc (NCR-13, 1988), Mehlich 3 (Wolf and Beegle, 1995), Morgan (Morgan, 1941), 1:5 H₂O (Soil and Plant Analysis Council, 1999), 0.01 M SrCl₂, and 0.01 M CaCl₂ (Houba et al., 2000). The Mehlich 3 extraction is an unbuffered dilute double acid extraction containing acetic acid, ammonium nitrate, ammonium fluoride, nitric acid, and ethylenediaminetetraacetic acid (EDTA) with an initial pH of 2.5. The Morgan solution contains sodium acetate buffered at pH 4.8. Because NH₄OAc is the most commonly used extractant for exchangeable K (Haby et al., 1990), K extraction efficiencies for all other methods were correlated with the K extracted by NH₄OAc.

The 0.01 M SrCl₂ and 0.01 M CaCl₂ methods have a 1:10 soil-water ratio and a shaking time of 2 h compared with a 30-min shaking time for the 1:5 H₂O extraction method. To determine if differences between K extraction using the 1:5 H₂O method and extraction using the

0.01 M CaCl₂ method were caused by the electrolyte or the soil:solution ratio and shaking time, all July 28 samples were also analyzed using a 1:10 H₂O extraction and a 2-h shaking time. The pH of the 1:5 H₂O, 0.01 M SrCl₂, NH₄OAc, Morgan, and Mehlich 3 solutions were measured both before mixing with soil and at the end of the extraction procedure (Table 2). This was done to determine the final pH of the extracting solution after shaking with the calcareous sand.

During June and July, the precipitation to evapotranspiration ratio (P:ET) was 1.2. The entire experiment was repeated on the same experimental units under a more intense irrigation scheme (P:ET = 2.0) in August and September of 2002. Soil samples were taken on September 22, 2002, 13 days after the fourth fertilizer application under more intense irrigation. These samples will be referred to as the September 22 samples.

All statistical analyses were performed using the REG procedure in SAS/STAT software, version 8.02 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Extraction Methods for Potassium

Under both P:ET regimes, all soil extraction methods gave results that were correlated with the NH₄OAc extractable K. The correlations for

TABLE 2

Mean pH of extracting solutions before and after extraction of 0–10-cm RMS sand-based putting green soil.

Measurements were done in six replicates

Extractant	pH before extraction	pH after extraction
1 N NH ₄ OAc	7.0	7.4
Mehlich 3	2.6	5.2
Morgan	5.0	5.5
1:5 H ₂ O	5.7	8.2
0.01 M SrCl ₂	5.5	8.2

the July 28 samples are shown in Fig. 1. However, the absolute quantities of K extracted were method and time dependent (Fig. 2 and Table 3). For the July 28 samples, the Mehlich 3 extraction method removed 1.3 mmol nonexchangeable and structural K kg⁻¹ soil in addition to the soluble and NH₄OAc extractable K. Morgan extracted 0.3 mmol K kg⁻¹ less than the NH₄OAc.

The relationship between 0.01 M SrCl₂ and 0.01 M CaCl₂ extractable K was nearly 1:1 (data not shown). This indicates that 0.01 M SrCl₂ is a suitable analog for 0.01 M CaCl₂ in K extraction of the RMS sand. As mentioned in the introduction, the 0.01 M SrCl₂ has an advantage in that Ca can be measured easily in the extract. The 0.01 M SrCl₂ and 0.01 M CaCl₂ extracted 0.3 mmol K kg⁻¹ soil less than the NH₄OAc extraction method. Averaged across all K treatments, 0.01 M SrCl₂ extracted 82% of the K that was extracted by NH₄OAc. These results compare well with those of Vogeler et al. (1997), who found that only 85% of exchange sites, as measured by NH₄OAc, were actively exchangeable after leaching with MgCl₂ for 13 days. Schneider (1997) suggested that the K extracted by NH₄OAc, but not by 0.01 M CaCl₂, was not readily exchangeable with ions in the soil solution and, hence, was largely unavailable to plants. Given the 2-h shaking time, unbuffered solution, and an ionic strength similar to the soil solution ionic strength, our results suggest that the 0.01 M SrCl₂ and 0.01 M CaCl₂ extractable K pools may better represent actively exchangeable K, while the 1 N NH₄OAc method also extracts part of a less readily exchangeable K pool.

The 1:5 H₂O method extracted the least K of any of the methods tested. The 1:10 H₂O method, with a 2-h shaking time, extracted slightly more K than the 1:5 H₂O method with a 30-min shaking time. There was also more Ca and Mg extracted by the 1:10 H₂O and 2-h shaking time than the 1:5 H₂O extraction with a 30-

min shaking time. Similar results were obtained by Reitemeier (1946), who attributed the differences to an increased dissolution of carbonates upon dilution, prompting a small amount of ion exchange of Mg and/or Ca for K, thus increasing the K concentration of the 1:10 H₂O extract compared with the 1:5 H₂O extract. Inasmuch as both extraction ratio and shaking time differed between the methods, we cannot attribute the differences to either one.

Because the ionic strengths of the 1:5 and 1:10 H₂O solutions are less than that of the soil solution, an overestimation of monovalent cations and an underestimation of divalent cations is expected as a result of the concentration charge effect (McBride, 1994). The 0.01 M SrCl₂ solution, with an ionic strength approximating that of soil solution, seemed to be unaffected by this shift between monovalent and divalent cations.

Most soil test extractants used for measurement of sand rootzone K status do not adjust to the pH of the sand (Table 2). Because the pH-dependent charge of organic matter is the source of most cation exchange sites in sand rootzones, unbuffered extracting solutions may provide a more accurate measurement of the exchangeable K (Sumner and Miller, 1996). Although Morgan extractable K was very similar to that of 0.01 M SrCl₂ (Fig. 2 and Table 3), the pH of the Morgan solution after shaking with the RMS sand was well below the soil pH (Table 2). The ionic strength of the Morgan extractant is also well above that of the soil solution, which may increase the dissociation of organic acids at a given pH (McBride, 1994). Both the pH and ionic strength effects of the NH₄OAc, Morgan, and Mehlich 3 extraction methods make it difficult both to predict and to interpret the source of the K extracted from sand rootzones with a pH-dependent charge.

Effect of Potassium Application on Extractable Potassium

The four sequential K applications increased extractable K for each method under both irrigation regimes (Fig. 2). Figure 2 and Table 3 show that while the NH₄OAc, Mehlich 3, Morgan, and 0.01 M SrCl₂ methods all extracted roughly the same amount of K with the increase in K application in the July 28 samples (slopes varying from 0.066 to 0.075 mmol K kg⁻¹ soil per gram of K applied per m²), the 1:5 H₂O method extracted proportionally less K as the K application rate was increased (slope equaled 0.029 mmol K kg⁻¹ soil per gram of K applied per m²). These results sug-

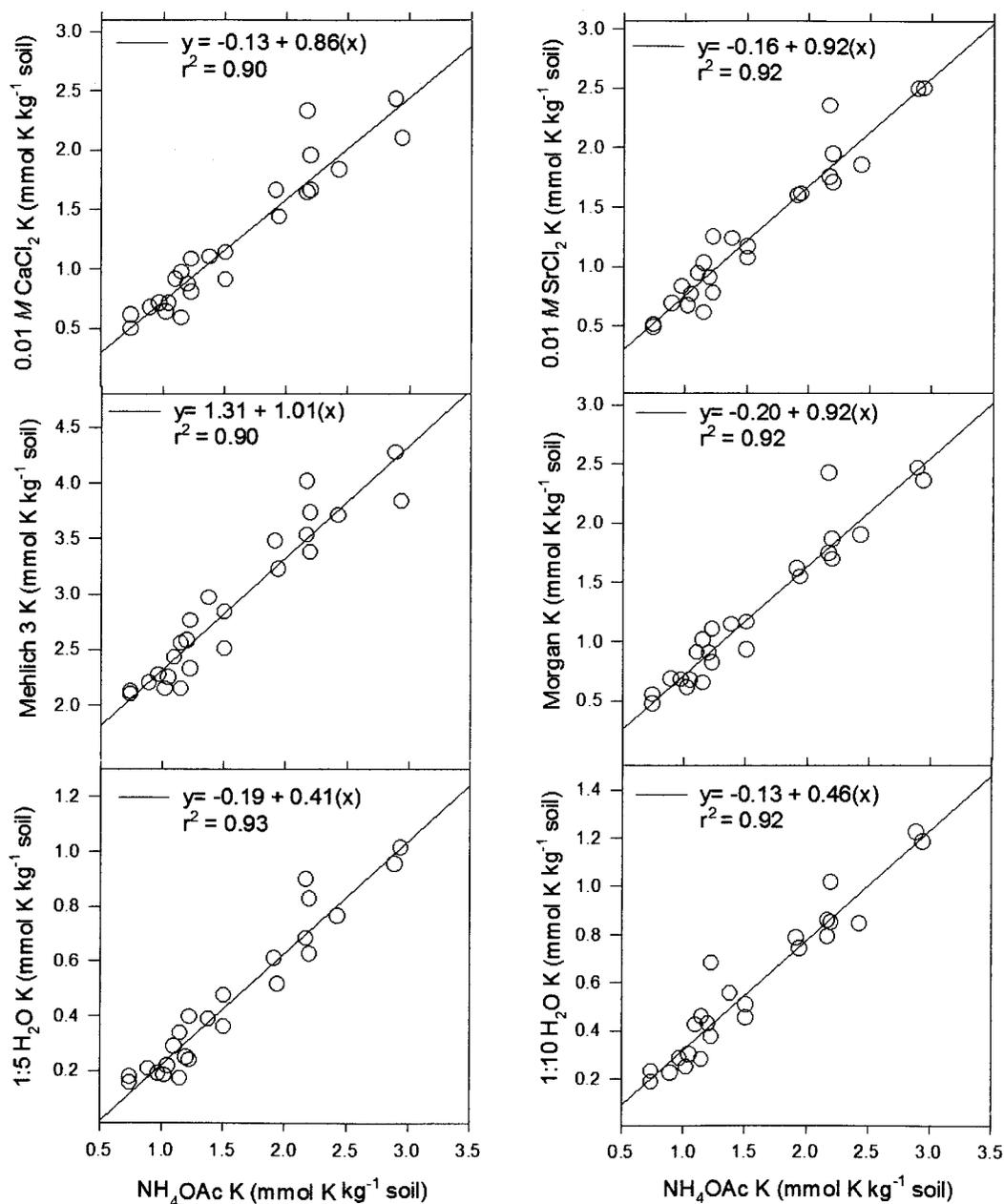


Fig. 1. Correlation of K extracted by 0.01 M CaCl₂, 0.01 M SrCl₂, Mehlich 3, Morgan, 1:5 H₂O, and 1:10 H₂O, with the K extracted by 1 N NH₄OAc from 24 soil samples from a calcareous sand putting green.

gest that K application increased the exchangeable K (in addition to soluble K) and that the 1:5 H₂O does not extract K from this exchangeable pool.

Similar results were obtained for the September 22 samples (Fig. 2 and Table 3). However, there was a net loss in extractable K for all meth-

ods under a more intensive irrigation regime (Fig. 3), most likely caused by K leaching from the rootzone's upper 10 cm. In Fig. 3, the dashed line represents the amount of K we would expect to extract on each date if all the applied K was extracted, which for comparison purposes has been calculated for even dispersion of K through the

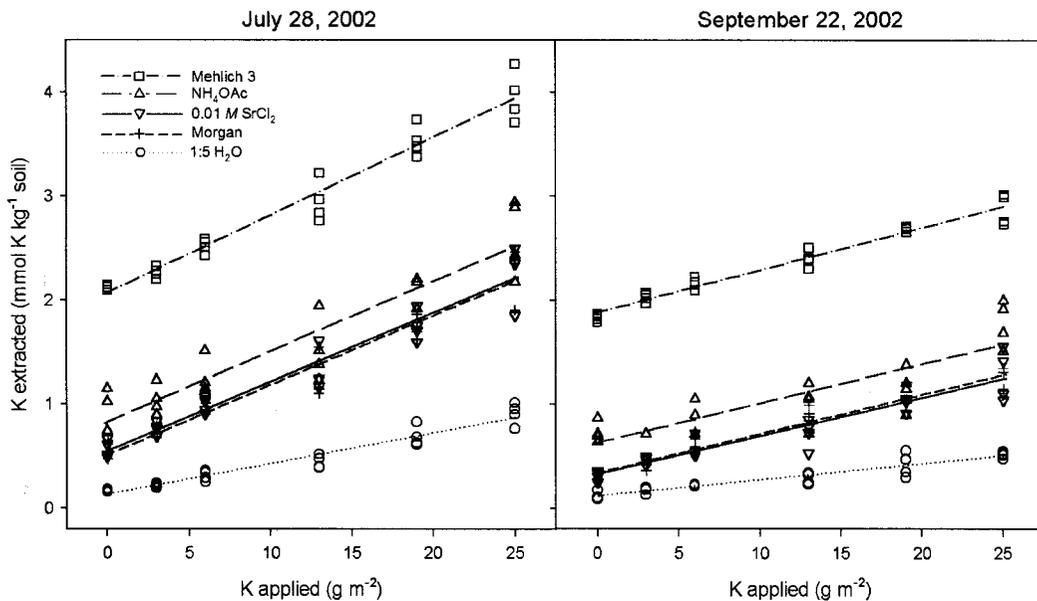


Fig. 2. Extractable K using five soil extraction methods following four consecutive K fertilizer applications to a calcareous sand creeping bentgrass putting green. Samples were taken 13 days after the last of the four applications.

rootzone's 30-cm depth with no leaching and no plant uptake of K. The K extracted by the various methods, shown on the Y-axis of each plot, was determined by taking the K extracted after four fertilizer applications and subtracting the amount of K measured by the same extractant in that plot prior to the first of the four fertilizer applications. The result is the net change in K from the beginning to the end of the experimental period for each of the 24 experimental plots. Ex-

tractable soil K increased in June and July under the low irrigation regime (Fig. 2), and, thus, the soil K concentrations were higher at the beginning of the high irrigation regime than they were at the beginning of the low irrigation regime. However, net extractable K decreased with K application under high irrigation (Fig. 3), regardless of the method used to extract K from the soil and despite the fact that the same amount of K was added under both irrigation regimes. These re-

TABLE 3

Intercepts (β_0), slopes (β_1), and coefficients of determination (r^2) for K extracted from the surface 0-10 cm of a RMS sand-based putting green on July 28 (precipitation to evapotranspiration ratio = 1.2) and September 22 (precipitation to evapotranspiration ratio = 2.0) following previous K applications of 0, 3, 6, 13, 19, and 25 g K m⁻² 56 days⁻¹

Extractant	β_0	β_1	r^2	P value
<u>July 28 samples</u>				
0.01 M SrCl ₂	0.55	0.066	0.93	< 0.0001
1 N NH ₄ OAc	0.83	0.067	0.87	< 0.0001
Mehlich 3	2.07	0.075	0.95	< 0.0001
Morgan	0.51	0.067	0.93	< 0.0001
1:5 H ₂ O	0.13	0.029	0.93	< 0.0001
<u>September 22 samples</u>				
0.01 M SrCl ₂	0.33	0.037	0.88	< 0.0001
1 N NH ₄ OAc	0.63	0.038	0.75	< 0.0001
Mehlich 3	1.88	0.041	0.96	< 0.0001
Morgan	0.34	0.038	0.93	< 0.0001
1:5 H ₂ O	0.11	0.016	0.87	< 0.0001

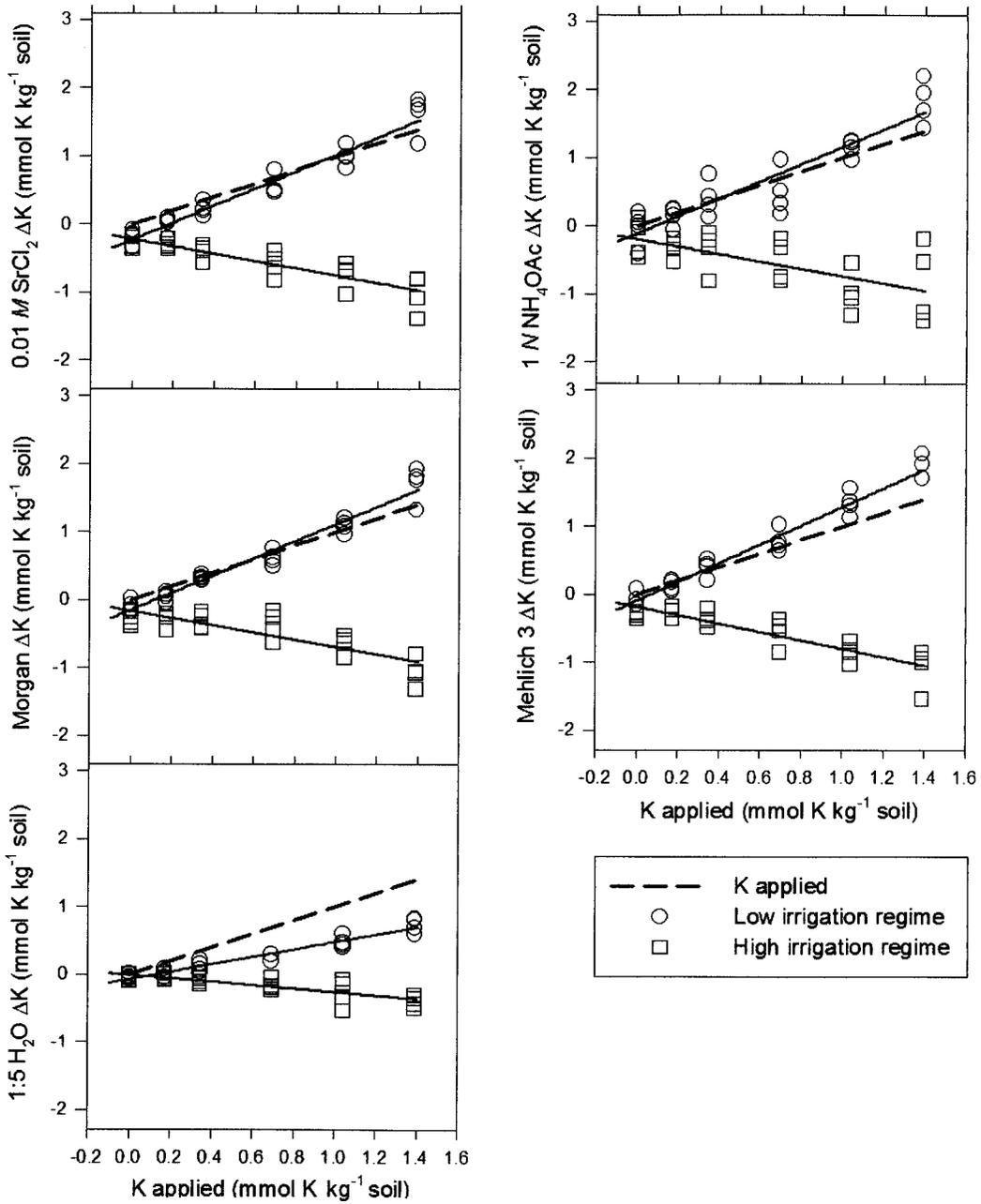


Fig. 3. Net change in 0.01 M SrCl₂, NH₄OAc, Morgan, Mehlich 3, and 1:5 H₂O extractable K under low irrigation (○) and high irrigation (□) following four fertilizer K applications to a calcareous sand creeping bentgrass putting green. The precipitation to evapotranspiration ratio for the low and high irrigation rates were 1.2 and 2.0, respectively.

sults are similar to the decrease in extractable soil K observed under conditions of increased irrigation by Lodge and Lawson (1993). If extractable soil K can be readily influenced by regular turf-

grass management practices such as irrigation, it may be difficult to rely upon infrequent assessment of extractable soil K as the only means of monitoring K availability in sand rootzones.

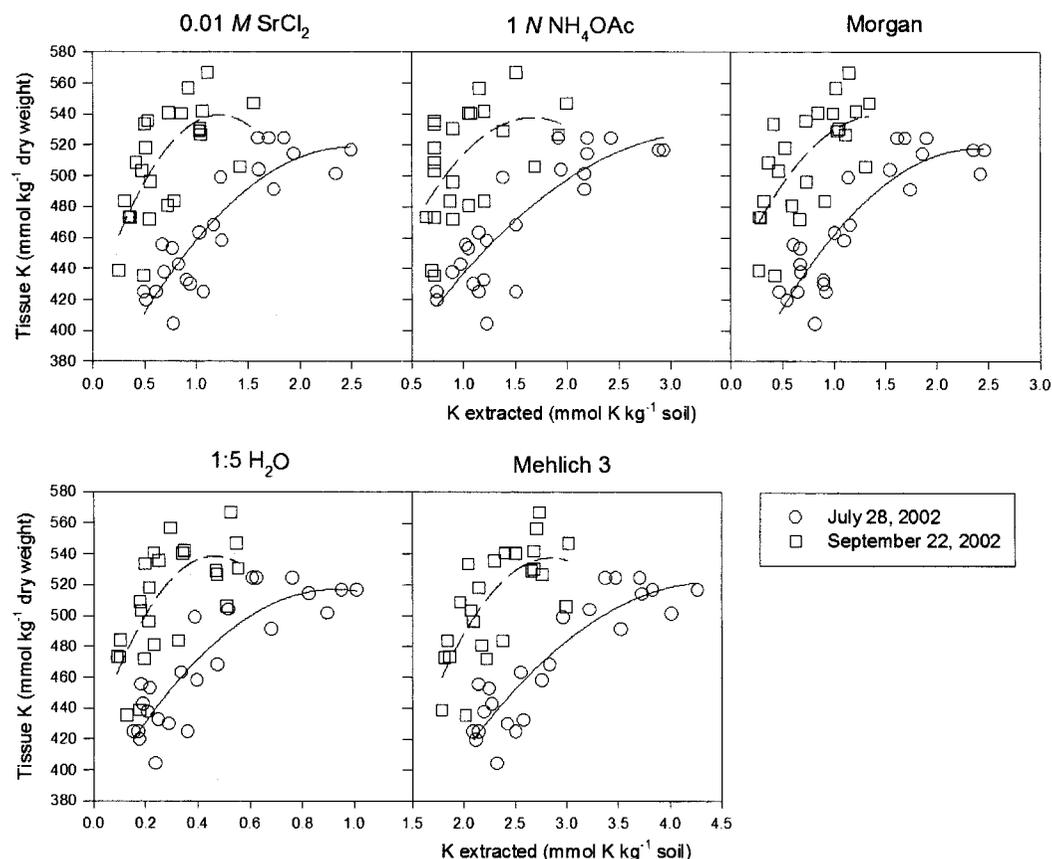


Fig. 4. Relationships between extractable soil K and creeping bentgrass tissue K on July 28 (precipitation to evapotranspiration ratio = 1.2) and September 22 (precipitation to evapotranspiration ratio = 2.0) as determined by the 0.01 M SrCl_2 , NH_4OAc , Mehlich 3, Morgan, and 1:5 H_2O extraction methods.

Soil Test Potassium as a Predictor of Creeping Bentgrass Tissue K Content

The increase in soil test K for all tests was reflected in an increase in creeping bentgrass tissue K content (Fig. 4). Thus, on individual sampling dates, soil test K levels were predictive of tissue K content. However, maximum tissue K content was obtained at a lower soil test K level on September 22 compared with the samples taken on July 28 (Table 4). These results indicate that tissue K content could be related to soil test K on individual sampling dates, but factors other than extractable soil K can also influence tissue K concentrations. Such factors could include N fertilization, variations in root activity, seasonal variations in plant requirements for K, changes in soil activity of Ca and Mg, plant growth rate, age of the sampled leaves, and varied soil moisture levels. In our study, the mean N content of tissue

samples collected on July 28, 2002, was 46 g kg^{-1} ; the September 22 samples had a mean N content of 54 g kg^{-1} . It is possible that higher nitrogen fertilization prior to the September 22 sample collection caused this increase in overall tissue K content.

Tissue K contents represent the actual K status of a plant, whereas soil analysis is used to assess potential availability of K to the plant roots (Marschner, 1995). Waddington et al. (1994) stated that the nutrient status of a turfgrass stand grown in a sand rootzone can be better assessed using tissue nutrient analyses than by soil nutrient analyses. Barraclough and Leigh (1993a and b) have demonstrated that variability in tissue K content can be caused by factors other than soil K concentration. Our results support this finding: soil extractable K levels were not consistently predictive of tissue K from July to September, 2002. Where no K was added, standard soil test K

TABLE 4

Maximum predicted tissue K content (quadratic model) with associated soil K, coefficient of determination (R^2), and P value for creeping bentgrass tissue K concentration as predicted by extractable soil K from five different soil extraction methods on July 28 (precipitation to evapotranspiration ratio = 1.2) and September 22 (precipitation to evapotranspiration ratio = 2.0) in 2002

Soil K extraction method	R^2	P value	Maximum predicted tissue K mmol K kg ⁻¹ dry matter	Soil test K at maximum predicted tissue K mmol K kg ⁻¹ soil
<u>July 28 samples</u>				
0.01 M SrCl ₂	0.78	< 0.0001	519	2.5
1 N NH ₄ OAc	0.73	< 0.0001	525	2.9
Mehlich 3	0.81	< 0.0001	521	4.3
Morgan	0.78	< 0.0001	518	2.4
1:5 H ₂ O	0.78	< 0.0001	516	1.0
<u>September 22 samples</u>				
0.01 M SrCl ₂	0.47	0.0012	538	1.1
1 N NH ₄ OAc	0.28	0.0309	532	2.0
Mehlich 3	0.54	0.0003	536	3.0
Morgan	0.48	0.0010	539	1.3
1:5 H ₂ O	0.45	0.0017	535	0.6

results suggested K deficiency, whereas tissue contents were in the reported sufficiency ranges. These results suggest that current soil K interpretations for sand putting greens may need to be adjusted; they also indicate limited usefulness of one-time soil sampling for predicting K needs.

SUMMARY AND CONCLUSION

Application of K fertilizer caused an increase in extractable K from a calcareous sand rootzone for all extraction methods evaluated in this study. All extraction methods exhibited a positive correlation with NH₄OAc for extractable K. Methods differed in the absolute amounts of K extracted, possibly because of differences in extraction pH, ionic strength, and saturating ion. The 1:5 H₂O method did not seem to extract K from the exchangeable pool, indicating that this method may underestimate plant available K. The Morgan and SrCl₂ procedures extracted equal amounts of K. Averaged across all K treatments, 0.01 M SrCl₂ extracted 82% of the K that was extracted by NH₄OAc. Under high irrigation intensity, extractable K decreased when the extractable K at the onset of the high irrigation regime was accounted for. More K was lost from the soil that contained a higher amount of extractable K at the beginning of the high irrigation regime. Furthermore, maximum tissue K concentrations were reached at lower soil test K levels (for all methods) for the samples collected on September 22 com-

pared with those collected on July 28. We conclude that each of the methods investigated in this study can identify an increase in extractable K after K application, but extractable K cannot consistently predict tissue K content, indicating that it may be difficult to diagnose K deficiencies in sand rootzones solely with soil tests.

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