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# Bentgrass response to K fertilization and K release rates from eight sand rootzone sources used in putting green construction.

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# BENTGRASS RESPONSE TO K FERTILIZATION AND K RELEASE RATES FROM EIGHT SAND ROOTZONE SOURCES USED IN PUTTING GREEN CONSTRUCTION

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## ABSTRACT

There is a lack of plant response to fertilizer K in some sandy soils even though routine soil tests for soil available K are shown to be low. This lack of plant response to K fertilization may be explained by K release from nonexchangeable forms. Greenhouse and laboratory experiments were conducted to evaluate a) response of 'Penncross' bentgrass (*Agrostis palustris* Huds.) grown in rootzones with different sand sources to K fertilization and b) K release from nonexchangeable forms from the different sand sources as an index to K availability. Experimental variables in the greenhouse were two K levels (0 and 250 mg K $kg^{-1}$ soil) and eight sand rootzone sources. Rootzone soils were sub-irrigated to ensure no K loss from leaching. Two laboratory methods (boiling 1 *M* $HNO_3$ extraction and continuous leaching with 0.01 *M* HCl) and total K uptake by the bentgrass were employed to index K release from nonexchangeable forms for each rootzone source. Potassium fertilization significantly increased bentgrass yield growing in one rootzone source and root weight in three rootzone sources. Potassium uptake by bentgrass and the two laboratory methods showed important differences in K release from the sand rootzones. The K removed by the two laboratory methods was closely related to leaf tissue K and K uptake, with the 1 *M* $HNO_3$ extraction method providing the closest fit. The study suggests that release of K from primary minerals in some rootzones with high sand content is proceeding at rates to satisfy bentgrass requirements for K. The 1 *M* $HNO_3$ extraction method may provide an alternative to the routine laboratory procedures presently being used to measure the extractable K in sand-based constructed putting greens by measuring K contributed by nonexchangeable forms.

**Keywords**

Clipping yield; leaf tissue potassium; nonexchangeable potassium; potassium extracting solutions; potassium uptake; root weights

## INTRODUCTION

The effect of K fertilization on turfgrass response has varied from a positive growth response [Holt and Davis, 1948; Goss, 1965; Markland and Roberts, 1967] to a limited or total lack of plant response [Davis, 1969; Waddington et al., 1978; Turner, 1980; Canaway et al., 1987]. Also turfgrass response to K or a lack thereof has been shown to be related to N fertilization levels [Monroe et al., 1969; Christian et al., 1979]. Creeping bentgrass did not respond to K fertilization in which yield, turfgrass quality, shoot and root growth were measured in field experiments conducted by Dest [1980; and unpublished data, Storrs Agric. Experiment Station] even though available soil K tested low. One of the experiments was carried out for 8 years in a putting green rootzone media containing 98% sand in which tissue K never fell below 16.8 g $kg^{-1}$ in plots receiving no fertilizer K. The soil available K level measured by the modified Morgan extractant was 53 kg K $ha^{-1}$ which is considered very low [Griffin and Washko, 1983]. In the same study by Dest [1980], correlations relating extractable soil K by several chemical solutions with plant response were not significant.

Several investigators [Liebhardt et al., 1976; Woodruff and Parks, 1980; Rehm and Sorensen, 1985] reported a lack of corn (*Zea mays L.*) response to K fertilization on sand and loamy sand soils. It was postulated that the release of nonexchangeable K was supplying a portion of the corn's requirement for K. Studies have shown that K release from nonexchangeable forms differs among soils [Garman, 1957; Sadusky et al., 1987]. There was no yield response of reed canarygrass (*Phalaris arundinacea* L.) grown on a fine sandy loam to increasing K fertilization rates when fertilized at 112 kg N $ha^{-1}$ [Allinson et al., 1992]. A review of the literature by Mengel [1985] clearly shows the capacity of grasses to exploit nonexchangeable soil K to satisfy their K requirements. Bentgrass has been found to have an unusual ability to utilize K from mineral sources in the soil [Colby and Bredakis, 1966] which has been related to the large surface area of its roots.

The absence of some plants to respond to fertilizer K in sandy soils that are low in soil test extractable K by routine laboratory tests may be explained by the

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release of K from nonexchangeable forms at rates which satisfy the plant's requirement for K. Knowing the difference in K release from nonexchangeable forms among sand rootzones used to construct putting greens could provide an index to K availability over an extended period of time. The objectives of the study were to a) determine the response of bentgrass grown on different high sand rootzones to K fertilization and b) evaluate K release from nonexchangeable forms as an index of K availability in sand rootzones.

## MATERIALS AND METHODS

The soils used in the study are rootzone mixes with high sand content used in putting green construction. The rootzones used were from eight different sources, two within Connecticut and six from outside Connecticut. Sources of sand and some of their chemical and physical properties are shown in Table 1. Soil pH was measured in a soil-to-water ratio of 1:1 with a glass electrode. The cation exchange capacity and exchangeable K were determined by the neutral 1*M* ammonium acetate method described by Chapman [1965]. Organic matter content was determined using the wet oxidation method by Walkley and Black [1934]. Silt and clay were determined by the pipette method after the removal of the sand.

### Greenhouse experiment

A greenhouse experiment was conducted to determine bentgrass response to K fertilization among sand rootzone sources and to determine K release rates by measuring K uptake by bentgrass in those rootzones with no K added. Plastic pots with a 15.2-cm diameter and 17.8-cm depth were filled with 2400 g of each rootzone source. Phosphorus was applied as calcium phosphate ($CaHPO_4$) to all treatments to supply 90 mg P $kg^{-1}$ of rootzone soil, mixed throughout the rootzone source, and the rootzones allowed to equilibrate for one month. Ten seeds of Penncross creeping bentgrass were sown into each container and thinned to 5 plants per pot after 8 weeks. The 5 plants were then permitted to grow for an additional 8 weeks after which 4 consecutive clipping harvests, designated Harvest 1, Harvest 2, Harvest 3 and Harvest 4, were taken at 22 day intervals. Nitrogen was applied as urea at 50 mg N $kg^{-1}$ to all rootzone sources at planting and after each of the first three harvests. Potassium was applied as KCl at planting, after thinning to 5 plants, and after the first three harvests for a total of 250 mg K $kg^{-1}$ of rootzone mix. Potassium treatments are designated as $K_0$ and $K_1$ (0 and 50 mg K $kg^{-1}$). The rootzone soils were sub-irrigated to insure no K loss from leaching. The 2 (K rate) × 8 (sand source) factorial experiment was set out in a randomized complete block design with five replications.

Oven dry weights of clippings were used to assess yield at each harvest and the combined yield of the four harvests as a result of fertilization. Roots were harvested at the completion of the experiment. Soil was washed gently from the roots with a fine spray of water, oven dried at 70°C, the oven dry weight determined, and then the roots ashed at 600°C for two hours. The ash weight was subtracted from the oven dry weight to determine the root ash-free dry weight. Clippings from the four harvests were analyzed for leaf tissue K after drying. Tissue was ground in a Wiley mill to pass a 20-mesh screen. Tissue was digested in a nitric-perchloric acid mixture and the K content was analyzed using the procedure outlined by Steckel and Flannery [1965]. Total uptake of K over the four harvests was used as an index to K release from nonexchangeable forms. Sub irrigation was discontinued after the last harvest and the rootzones allowed to dry. When the plants in the pots developed moisture stress to the point of permanent wilting, soil samples were collected and the gravimetric moisture content of each pot determined in order to ascertain the effect of fertilizer K on moisture stress of the bentgrass as a function of K fertilization. Visual observation of K deficiency on the foliage was noted at the first sign of the symptom occurring. Potassium deficiency symptoms are described by Lawton and Cook [1954].

### Laboratory study

Two laboratory methods (1 *M* $HNO_3$ and continuous leaching with (0.01 N HCl)) were employed to index K release from nonexchangeable forms for each rootzone and to relate the K extracted by each method with K uptake, K content in the leaf tissue, total yield

**Table 1. Chemical and physical properties of rootzone sources.**

| Rootzone source | pH | CEC | Exchangeable K | Organic matter | Particle size | | |
|---|---|---|---|---|---|---|---|
| | | | | | Sand | Silt | Clay |
| | | cmol $kg^{-1}$ | mg $kg^{-1}$ | g $kg^{-1}$ | % | | |
| Florida | 7.5 | 0.85 | 4.0 | 4.2 | 98.3 | 0.8 | 0.9 |
| Kansas | 8.1 | 0.55 | 15.7 | 0.1 | 99.3 | 0.4 | 0.3 |
| Maryland | 6.8 | 2.28 | 2.4 | 14.6 | 98.0 | 1.2 | 0.5 |
| Oklahoma | 7.8 | 3.95 | 12.3 | 16.7 | 96.3 | 3.0 | 0.7 |
| Redding | 7.3 | 3.88 | 8.8 | 13.4 | 95.4 | 3.0 | 1.6 |
| Rockledge | 6.6 | 3.96 | 6.1 | 13.2 | 97.9 | 2.1 | 0 |
| Shorehaven | 6.1 | 4.37 | 4.3 | 21.2 | 98.4 | 1.6 | 0.2 |
| Woodway | 6.5 | 3.83 | 9.8 | 13.2 | 94.8 | 3.4 | 1.8 |

**Table 2. Analysis of variance summary for creeping bentgrass clipping yield, leaf tissue K concentration, root weight, and soil moisture content at the point of permanament wiliting to rootzone source and applied K.**

| Source | Clipping yield | | | | | Leaf K concentration | | | | | Soil |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Harv. 1 | Harv. 2 | Harv. 3 | Harv. 4 | Total Harv. | Harv. 1 | Harv. 2 | Harv. 3 | Harv. 4 | Root weight | moisture content |
| Soil | ** | ** | NS | ** | ** | ** | ** | ** | ** | ** | ** |
| K | NS | NS | NS | NS | * | ** | ** | ** | ** | ** | NS |
| Soil ´ K | NS | NS | NS | ** | ** | ** | ** | ** | ** | ** | NS |

*, ** Significant at P <0.05 and <0.01, respectively. NS, not significant

and root growth. Potassium in each rootzone was extracted by a) boiling in 1 *M* $HNO_3$ as outlined by Pratt [1965] and b) removed by continuous leaching with 0.01 *M* HCl as described by Garman [1957]. Potassium removed was determined in the continuous leaching study after 1, 3, 5, 7 and 9 liters were leached through 25 g of soil at a rate of flow of 1 liter per 6 hours. Potassium accumulation curves were plotted for each soil.

Data were subjected to the ANOVA procedure of SAS [The SAS Institute, 1990] and results are shown in Table 2. Duncan's multiple range test was used to compare rootzone source means of K removed in the $K_0$ treatment from K uptake by bentgrass and the two chemical procedures. Fisher's LSD was used to compare means between the $K_0$ and $K_1$ treatments within a rootzone. Correlation coefficients relating the two chemical methods used to characterize K release to clipping yield, root growth, tissue K and K uptake were calculated to determine their effectiveness as indices to K release from nonexchangeable forms from the rootzone sources.

## RESULTS AND DISCUSSION

### Yields and Moisture Stress

Potassium fertilization significantly increased clipping yield of bentgrass grown in the Florida rootzone source at the last harvest (Table 3) and for total clipping yield, (Table 4) compared with the K treatment in which no fertilizer K was applied. Potassium fertilization on the other seven rootzone sources did not affect bentgrass yields significantly except for total clipping yield on the Redding rootzone source (Table 4) in which the total yield was significantly less where K was applied compared with the $K_0$ treatment. Monroe et al. [1969] reported a reduction in Kentucky bluegrass (*Poa pratensis* L.) weights grown in a white quartz sand in the greenhouse over four harvest dates and for total clippings when fertilizer K levels exceeded 100 mg $kg^{-1}$ at a 65 mg $kg^{-1}$ treatment with N. However, this was not the case when N rates were increased.

There also was a significant rootzone × K interaction for root growth. Potassium fertilization significantly increased root weights in the Woodway, Shorehaven, and Florida rootzone sources (Table 4). Bentgrass root weight was unaffected by K fertilization growing in the other five rootzone sources. The effect of K fertilization on the increase in root weights in the Woodway, Shorehaven, and Florida rootzone sources compared with the no K treatment may be accounted for by the lower K supplying power from the nonexchangeable forms of K in these sources (Table 6 and Fig. 1). Holt and Davis [1948] found a reduction of root growth in two creeping bentgrass cultivars when K was withheld from plants growing in a white quartz sand. Structural forms of K are absent in quartz sand.

Potassium fertilization has been shown to de-

**Table 3. Rootzone sources ´ K fertilization effects on clipping yields of Penncross creeping bentgrass at four harvests.**

| | Harvest 1 | | Harvest 2 | | Harvest 3 | | Harvest 4 | |
|---|---|---|---|---|---|---|---|---|
| Rootzone source | $K_0$ | $K_1$ | $K_0$ | $K_1$ | $K_0$ | $K_1$ | $K_0$ | $K_1$ |
| | | | | g/pot † | | | | |
| Florida | 0.31 | 0.71 | 1.13 | 1.45 | 1.93 | 2.09 | 2.09 | 3.09 |
| Kansas | 0.81 | 0.36 | 1.07 | 0.94 | 1.69 | 3.13 | 3.13 | 3.18 |
| Maryland | 0.81 | 1.03 | 1.53 | 1.67 | 1.74 | 2.93 | 2.93 | 3.12 |
| Oklahoma | 1.07 | 1.16 | 1.43 | 1.60 | 1.76 | 3.44 | 3.44 | 3.26 |
| Redding | 1.58 | 1.38 | 1.93 | 1.64 | 1.53 | 3.57 | 3.57 | 3.37 |
| Rockledge | 1.46 | 1.24 | 1.75 | 1.69 | 1.76 | 3.54 | 3.54 | 3.67 |
| Shorehaven | 1.85 | 1.32 | 1.38 | 1.66 | 1.49 | 3.17 | 3.17 | 3.25 |
| Woodway | 1.51 | 1.87 | 1.80 | 1.85 | 1.57 | 3.50 | 3.50 | 3.48 |
| LSD | NS | | NS | | NS | | 0.36 | |
| CV % | 28.9 | | 20.6 | | 28.8 | | 8.8 | |

**Means between K treatments within a rootzone source compared using Fisher's LSD,**
*** Significant difference at P = 0.05, NS not significant.**
**† Average of 5 replications.**

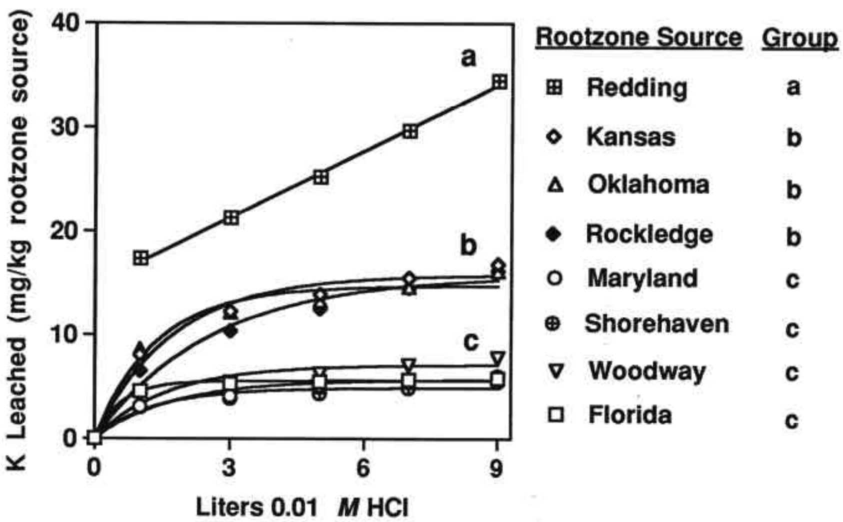


Figure 1. Cumulative K release rate curves for the eight rootzone sources produced from continuous leaching with the 0.01 *M* HCl solution.

crease the incidence of wilting in Penncross creeping bentgrass [Waddington et al., 1978, Carrow, 1994]. However, the results of our study showed that K fertilization compared with no fertilizer K within a rootzone source did not significantly delay the onset of wilting as soil moisture content was depleted (Table 4). DiPaola and Engel [1976] reported that the first day of wilting of a 'Seaside' and Penncross creeping bentgrass blend was not significantly influenced by K fertilization.

**Leaf tissue K**

Leaf tissue deficiency symptoms for K were noted on plants growing in the Florida rootzone source at the $K_0$ treatment just prior to Harvest 2 with leaf tissue K continuing to decrease over the last two harvests. Leaf tips turned yellow followed by a yellowing along the margins. The content of leaf tissue K taken at this harvest was 8.1 g $kg^{-1}$ of dry tissue weight, (Table 5). This was below the sufficiency range of 10 g $kg^{-1}$ of tissue K suggested by Jones [1980]. Lunt et al. [1974] also reported a minimum tissue level of K of 10 g $kg^{-1}$ of dry tissue weight in 'Newport' Kentucky bluegrass associated with maximum yield. It was not until the last harvest that the bentgrass tissue concentration of K fell below 10 g $kg^{-1}$ in all the other rootzones except for the plants growing in the Redding and Rockledge sources (Table 4). Also noted just prior to the last harvest were leaf K deficiency symptoms occurring on plants growing in the Maryland, Shorehaven, and Woodway rootzone sources. No deficiency symptoms were noted on the Kansas, Oklahoma, Redding, and Rockledge rootzone sources. These were also the rootzone sources that had the greatest K supplying power from the nonexchangeable form shown in Fig. 1 and Table 6.

Potassium fertilization significantly increased leaf tissue K concentration within a rootzone source at all four harvests (Table 5). The exception was plants growing in the Kansas rootzone source at Harvest 1 and in the Redding rootzone source in Harvests 3 and 4. The continued rapid release of K from the nonexchangeable K form from the Redding rootzone source with no applied K is a reflection of the continued release of K shown

**Table 4. Rootzone sources ´ K fertilization effects on total clipping yield from four harvests, root weight, and rootzone moisture content at point of permanent wilting of Penncross creeping bentgrass.**

| | Total clipping yield | | Root weight | | Soil moisture | |
|---|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_0$ | $K_1$ | $K_0$ | $K_1$ |
| | g/pot | | | | g $kg^{-1}$ | |
| **Redding** | 8.67 | 7.92 * | 4.43 | 4.47 NS | 14.5 | 17.9 |
| **Woodway** | 8.41 | 8.78 NS | 5.4 | 7.04 * | 12.8 | 11.5 |
| **Rockledge** | 8.07 | 8.34 NS | 5.64 | 5.47 NS | 11.8 | 11.0 |
| **Shorehaven** | 7.77 | 7.72 NS | 5.03 | 8.04 * | 12.4 | 9.3 |
| **Oklahoma** | 7.67 | 7.78 NS | 4.57 | 4.86 NS | 11.5 | 12.0 |
| **Maryland** | 7.42 | 7.61 NS | 3.02 | 3.88 NS | 7.5 | 7.4 |
| **Kansas** | 6.23 | 6.17 NS | 2.44 | 2.67 NS | 2.5 | 2.3 |
| **Florida** | 5.25 | 7.18 * | 1.52 | 4.14 * | 5.6 | 3.5 |
| **LSD†** | 0.59 | | 2.03 | | NS | |
| **CV%** | 6.2 | | 17.9 | | 23.3 | |

**† LSD to compare means between K treatments within a rootzone source.**
***significant difference at P < 0.05; NS, not significant**

**Table 5. Rootzone source ´ fertilizer K effect on the K concentration of Penncross creeping bentgrass leaf tissue at each clipping harvest.**

| | Harvest 1 | | Harvest 2 | | Harvest 3 | | Harvest 4 | |
|---|---|---|---|---|---|---|---|---|
| Rootzone source | $K_0$ | $K_1$ | $K_0$ | $K_1$ | $K_0$ | $K_1$ | $K_0$ | $K_1$ |
| | | | | $g\ kg^{-1}$ † | | | | |
| Florida | 21.9 | 43.1 * | 8.1 | 38.4 * | 5.9 | 30.2 * | 3.3 | 28.3 * |
| Kansas | 37.7 | 41.0 NS | 21.1 | 38.9 * | 14.7 | 35.4 * | 8.1 | 25.6 * |
| Maryland | 29.7 | 42.0 * | 16.1 | 37.4 * | 12.2 | 30.1 * | 6.9 | 27.2 * |
| Oklahoma | 34.1 | 43.5 * | 22.1 | 37.8 * | 21.0 | 35.1 * | 9.2 | 25.8 * |
| Redding | 35.0 | 41.0 * | 32.1 | 37.1 * | 31.5 | 31.8 NS | 25.2 | 26.6 NS |
| Rockledge | 36.0 | 44.2 * | 21.9 | 39.1 * | 25.8 | 33.3 * | 15.7 | 27.5 * |
| Shorehaven | 29.2 | 46.5 * | 13.4 | 40.3 * | 12.7 | 33.2 * | 5.7 | 30.3 * |
| Woodway | 30.3 | 44.1 * | 15.9 | 40.0 * | 16.4 | 32.1 * | 7.5 | 29.6 * |
| LSD | 3.7 | | 4.3 | | 2.9 | | 1.8 | |
| CV % | 7.9 | | 12.1 | | 9.4 | | 7.5 | |

**Means between K treatments within a rootzone source compared using Fisher's LSD,**
*** Significant difference at P < 0.05, NS not significant.**
**† Average of 5 replications.**

by the accumulated release curve (Fig. 1). This probably accounts for the lack of difference in leaf tissue content between the $K_0$ and $K_1$ treatments. Leaf tissue K of bentgrass growing in the Redding rootzone source was 31.5 and 31.8 $g\ kg^{-1}$ in the $K_0$ and $K_1$ treatments, respectively, at Harvest 4. Although leaf tissue K of bentgrass in the $K_0$ treatment in the last harvest of plants growing in the Rockledge rootzone source was significantly less than in the $K_1$ treatment, leaf tissue K was 15.7 $g\ kg^{-1}$, which is well above the 10 $g\ kg^{-1}$ sufficiency value set by Jones [1980].

## K uptake

Table 6 shows K uptake from each rootzone source. The amount of K taken up by the bentgrass over the four month period was 13.0, 10.6, 22.0, 38.0, 81.6, 60.3, 47.0 and 43.6 $mg\ kg^{-1}$ of tissue dry weight from the Florida, Kansas, Maryland, Oklahoma, Redding, Rockledge, Shorehaven, and Woodway rootzone sources, respectively. There was a significantly greater uptake of K by bentgrass growing in the Redding rootzone source compared to all other rootzone sources followed by the bentgrass growing on the Rockledge rootzone source. The bentgrass growing on the Florida, Kansas, and Maryland rootzone sources removed significantly less K than the other five rootzone sources. The amount of K removed by the bentgrass (Table 6, column one) was greater than the available K on the cation exchange sites (Table 1, column three) on all rootzone sources except for the Kansas rootzone source. This indicates that a substantial amount of K uptake by the bentgrass is coming from structural forms with as much as 9 times the K taken up by bentgrass than on the exchange sites in the Maryland, Redding, Rockledge, and Shorehaven rootzone sources. Highly significant correlations were obtained when K uptake was compared to total clipping yield, root weight, and tissue K at each of the last 3 harvests (Table 7). Correlation coefficients to K uptake were 0.75 and 0.64 for total clipping yields and root weights, respectively, and 0.64, 0.83 and 0.92 for leaf tissue K for Harvest 2, 3, and 4, respectively.

**Table 6. Potassium removed from the rootzone sources by Penncross creeping bentgrass, 1.0 M HNO3, and continuous leaching with 0.01 M HCl from the K0 treatment.**

| | Source of K removal | | |
|---|---|---|---|
| | Bentgrass ‡ | 1.0 M HNO3 | 0 .01 M HCl § |
| | | $mg\ kg^{-1}$ | |
| Florida | 13.0 d† | 19.7 e | 5.8 c |
| Kansas | 10.6 d | 174.3 c | 16.8 b |
| Maryland | 22.0 d | 33.5 e | 6.0 c |
| Oklahoma | 38.0 c | 189.1 bc | 16.2 b |
| Redding | 81.6 a | 2984.8 a | 34.5 a |
| Rockledge | 60.3 b | 230.3 b | 16.2 b |
| Shorehaven | 47.0 c | 61.6 e | 5.5 c |
| Woodway | 43.6 c | 127.5 d | 7.8 c |

**† Means within columns with the same letter are not significantly different (P< 0.05) using Duncan's multiple range test.**
**‡ Total from four harvests.**
**§ K accumulated after 9 liters.**

## K release from chemical solutions

Potassium accumulation removed by continuous leaching with 0.01 *M* HCl for the eight rootzones were plotted to produce K release curves for each

**Table 7. Correlation coefficients (r) relating total K uptake from the K0 treatment with total clipping yield, root weights, and leaf tissue K.**

| | Clipping yield | | Root weights. | |
|---|---|---|---|---|
| K uptake (total) | 0.75** | | 0.64** | |
| | Leaf tissue K | | | |
| | Harvest 1 | Harvest 2 | Harvest 3 | Harvest 4 |
| K uptake 1 | 0.15 NS | | | |
| K uptake 2 | | 0.64** | | |
| K uptake 3 | | | 0.83** | |
| K uptake 4 | | | | 0.92** |

**** Correlation coefficients significant at P < 0.01.**

**Table 8. Correlation coefficients (r) relating the two K extraction methods with clipping yield, root weights, tissue K and K uptake.**

| Extraction method | Correlation coefficients (r) | |
|---|---|---|
| 1 M HNO3 | total yield | 0.47** |
| | root weight | 0.14 |
| | tissue K | 0.90** |
| | K uptake | 0.73** |
| 0.01 M HCl | total yield | - 0.32 |
| | root weight | 0.19 |
| | tissue K | 0.74** |
| | K uptake | 0.56** |

** Correlation coefficients significant at P < 0.01.

rootzone source (Fig. 1). The average K concentration in the last 9 liters of solution is shown in the last column in Table 6. Extracting with 0.01 *M* HCl solution produced three distinct families of curves in which there was a significant difference in K release among the families. The Redding rootzone source still had a steep gradient after 9 liters of leaching solution compared with the other curves, indicating that it was still releasing K at a very rapid rate (Fig. 1). The next family of curves is represented by the Kansas, Oklahoma, and Rockledge rootzone sources which released significantly more K than the last family of curves represented by Florida, Maryland, Shorehaven, and Woodway rootzone sources.

A close study of the curves for all rootzone sources other than the Redding rootzone source show that exchangeable K extracted by 1 *M* NHOAc (pH 7.0) (Table 1) makes up different portions of the curves in Fig. 1 depending on the rootzone source. Exchangeable K is represented by the steep portion of the curves in the Kansas, Oklahoma, Rockledge, Florida, and Maryland rootzone sources. The more uniform portion of these curves, out to K accumulated at 9 liters of leaching solution, represents K released from nonexchangeable forms. It should be further noted that the curve for the Rockledge rootzone source is still continuing to rise at a steeper gradient than the Oklahoma and Kansas rootzone sources of the same family at the end of 9 liters of leaching solution, indicating that it is releasing K at a faster rate. This is probably the reason that leaf tissue K on plants growing in the Rockledge rootzone source at Harvest 4 contain 15.7 g K $kg^{-1}$ of dry tissue weight (Table 5), within the sufficiency range suggested by Jones [1980]. The curve for the Woodway rootzone source indicates that the K, out to the 9 liters of leaching solution, came from the exchangeable form in which exchangeable K is 9.8 mg $kg^{-1}$ in the rootzone compared to 7.8 mg $kg^{-1}$ leached with by the 0.01 *M* HCl solution (Table 6).

When K removed by the 0.01 *M* HCl solution was compared with K uptake and leaf tissue K for the last harvest (Table 8), highly significant positive correlations of 0.56 and 0.74 were found, respectively. However, no relationship was found between the 0.01 *M* HCl solution with root weights and total clipping yields. The K extracted by the boiling 1 *M* $HNO_3$ extraction procedure was considerably higher than the 0.01 *M* HCl leaching solution and that removed by bentgrass (Table 6). However. the order of relative ranking of K removed by all three methods was similar. Correlation coefficients between the 1 *M* $NHO_3$ extractable K with K uptake by the bentgrass and tissue K were correlated with *r* values of 0.73 and 0.90, respectively (Table 8). Also the *r* value between clipping yield and K extracted by the 1 *M* $HNO_3$ solution was significant at the 1% level of probability. The relationship between root weights and the 1 *M* $HNO_3$ extractant was nonsignificant.

## SUMMARY AND CONCLUSIONS

Potassium is a highly mobile nutrient in sand putting greens because of their inherently low cation exchange capacity. Therefore, the use of routine soil tests which measure most of the K on cation exchange sites do not properly predict plant available K for sand putting greens containing nonexchangeable K sources. Those sands that contain nonexchangeable forms of K-bearing minerals can contribute K to plants as they weather, and could be a reason for the lack of plant response to K fertilization. The lack of response to K fertilization found in sand putting greens reported by Colclough and Lawson [1989] has been attributed to K derived from the sand. A large amount of K has been shown to be contained in the sand fraction of some loamy sand soils by Sadusky et al. [1987] which becomes available to plants from mineral weathering and is a reason that some crops do not respond to K fertilization, even though conventional soil tests indicate low K availability.

Our results show that K fertilization generally had little effect on clipping yield of bentgrass grown on sand rootzones, even though they tested low in exchangeable K. However, root weight was significantly increased by K fertilization on those rootzone sources with a low K supplying capability, whereas K fertilization had no effect on root weight in the other rootzone sources where K release from nonexchangeable forms was greater. In our study, K fertilization did not influence moisture stress tolerance as soil moisture content was depleted. Inconsistent results with K fertilization on clipping yield and moisture stress tolerance have been shown by others [Waddington et al., 1978; DiPaola and Engel, 1976]. Other factors such as N fertilization are probably playing a greater role.

Two laboratory methods, one using 1 *M* $NHO_3$ and the other using 0.01 *M* HCl have shown differences in K release rates from the different sand rootzones and were significantly related to tissue K and K uptake, with the 1 *M* $HNO_3$ providing the closest fit. The results of the study suggest that release of K from primary minerals contained in some sands used in rootzone mixes is occurring at rates which satisfy bentgrass requirements for K. The two laboratory procedures show promise for predicting the ability of different sand sources in contributing K to plants. The uptake of K by bentgrass also revealed differences in K release rates from nonexchangeable forms of K among the sand rootzone sources. Although this method provides an index to K availability and has been a standard method used in the past, it is nevertheless time consuming. The two laboratory methods presented in this study provide a quicker means to assess K release rates from nonexchangeable K sources. Because of its simplicity, the 1 *M* $HNO_3$ extraction method may provide an alternate to the routine laboratory procedures presently being used to measure the exchangeable K in sand-based constructed putting greens by measuring K contributed by nonexchangeable forms.

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