FERTILIZER MANAGEMENT

Nitrogen, Phosphorus, and Potassium Responses and Requirements in Calcareous Sand Greens

P. G. Johnson,* R. T. Koenig, and K. L. Kopp

ABSTRACT

Calcareous sands are widely used in the construction of putting greens in the western USA. Plants growing on these sands frequently exhibit nutrient deficiencies and rapidly changing nutrient levels due to the low nutrient-holding capacity of this medium. Our objectives were to determine the effects of N, P, K, and N × K and P × K interactions on the growth of creeping bentgrass (Agrostis stolonifera Huds.) in calcarceous sand greens. Measurements included visual ratings of turfgrass quality, soil and tissue nutrient levels, and golf ball roll distance. Creeping bentgrass plots receiving 5.5 kg P ha⁻¹ yr⁻¹ had lower quality than the remainder of the treatments (27.5–110 kg P ha⁻¹ yr⁻¹). Interactions between P and K were not observed. Ball roll was negatively correlated with soil test P. According to linear plateau regression analysis, soil test P level was 3.0 mg kg⁻¹ soil, and tissue test P was 0.4% for maximum quality. Nitrogen fertilizer treatments increased turfgrass quality and with each successively higher treatment. No N × K interactions were observed. No significant effect of K on turfgrass quality was observed; however, K rates increased soil test K, and tissue K showed a weak correlation ($R^2 = 0.13$) with turfgrass quality. Potassium levels within the soil profile indicated leaching of K through the root zone. Alternative K fertilization methods (foliar, increased frequency, and slow-release forms) may be needed to improve K nutrition of bentgrass growing on calcareous sands.

M OST GOLF COURSES and athletic fields in the Intermountain West use local materials in their construction. This is especially true for sands used in the construction of United States Golf Association (USGA) specification putting greens or athletic fields with modified root zones. Unfortunately, many sources of sand in the Intermountain West are calcareous with slightly alkaline pH.

Calcareous soils arise from parent material such as limestone or seashells and contain more than 1% calcium carbonate equivalent (CCE) but can be as high as 100% CCE (Carrow et al., 2001). Low-CCE sands (<10%) consist of silica sand particles with surface deposits or coatings of CaCO₃. High-CCE sands (>30%) have sand-sized grains of calcite mixed with grains of silica particles (E.D. Miltner, personal communication).

Plants growing on calcareous media commonly exhibit P and micronutrient deficiencies (Carrow et al., 2001) because the alkaline pH of these soils renders these nutrients unavailable. Nutritional problems are magnified when calcareous sands are used as the primary ingredient in sand root zones. Due to these nutritional problems, turfgrass managers often have difficulty growing satisfactory turf on calcareous sands. Nutrient levels also change rapidly due to the low cation exchange capacity (CEC) and high leaching potential of these media.

Fry et al. (1989) investigated P and K effects in similar sands in Colorado and only observed significant P effects on turfgrass quality. Potassium effects were not observed, due in part to an inherently high K content of the sands. Christians et al. (1981) investigated N, P, and K and their interactions in sand greens of Ohio and observed N × K interactions where more K was needed as N fertilization rates increased. No influence of P was observed, however. Both of these studies used turfgrass quality data and soil test data for measurements. Our objectives were to determine the effects of N, P, and K and the interactions of N × K and P × K on the growth of creeping bentgrass on calcareous sands in the Intermountain West. Similar to previous studies, we used turf quality ratings and soil test measurements but also included tissue tests and determinations of ball roll.

MATERIALS AND METHODS

This study was conducted on a research putting green constructed in 1995 to modified USGA specifications (USGA, 1993) in North Logan, UT. The sand used in the green differed from USGA specifications by having a greater percentage of fine sands, with 23.1% of the mix in the 0.15- to 0.25-mm particle size range and 12.1% in the 0.05- to 0.15-mm size range. The root zone mix was specified at 95% calcareous sand (Brigham Sand and Gravel, Brigham City, UT) and 5% peat to a depth of approximately 31 cm. The actual mix was tested in 1998 and contained 95% sand, 3% silt, 2% clay, and 0.5% organic matter. The putting green turf consisted of a ‘Providence’ creeping bentgrass.

Initial soil tests using a 0.5 M sodium bicarbonate solution (Olsen and Sommers, 1982; Haby et al., 1990) indicated low P and K levels (Table 1). Diethylenetriaminepentaacetic acid (DTPA)—extractable Zn and SO₄²⁻—S levels were also low and were amended in fall 1998 and spring 1999 with S (98 kg/ha) and a micronutrient fertilizer that applied 8.1 kg Mg ha⁻¹, 6.1 kg S ha⁻¹, 0.5 kg Cu ha⁻¹, 5.4 kg Fe ha⁻¹, 2.0 kg Mn ha⁻¹, and 0.7 kg Zn ha⁻¹ (Scotts Trace Element Package, The Scotts Co., Marysville, OH). In general, the turfgrass quality of the putting green was relatively poor and would not have been acceptable for a typical golf course at the time these studies were conducted."

Abbreviations: CCE, calcium carbonate equivalent; CEC, cation exchange capacity; DTPA, diethylenetriaminepentaacetic acid; USGA, United States Golf Association.
Table 1. Initial chemical and physical characteristics of the root zone sand (September 1998).

<table>
<thead>
<tr>
<th>Soil test parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.7</td>
</tr>
<tr>
<td>Salinity, dS m⁻¹</td>
<td>0.2</td>
</tr>
<tr>
<td>Organic matter, %</td>
<td>0.5</td>
</tr>
<tr>
<td>Sand, %</td>
<td>95</td>
</tr>
<tr>
<td>Silt, %</td>
<td>3</td>
</tr>
<tr>
<td>Clay, %</td>
<td>2</td>
</tr>
<tr>
<td>CaCO₃ equivalent, %</td>
<td>3.2</td>
</tr>
<tr>
<td>P, mg kg⁻¹</td>
<td>2.5</td>
</tr>
<tr>
<td>K, mg kg⁻¹</td>
<td>16</td>
</tr>
<tr>
<td>NO₃⁻ N, mg kg⁻¹</td>
<td>2.1</td>
</tr>
<tr>
<td>Zn, mg kg⁻¹</td>
<td>0.15</td>
</tr>
<tr>
<td>Fe, mg kg⁻¹</td>
<td>3.52</td>
</tr>
<tr>
<td>Cu, mg kg⁻¹</td>
<td>0.3</td>
</tr>
<tr>
<td>Mn, mg kg⁻¹</td>
<td>1.45</td>
</tr>
<tr>
<td>SO₄²⁻, mg kg⁻¹</td>
<td>2.02</td>
</tr>
<tr>
<td>CEC, cmol kg⁻¹</td>
<td>1.3</td>
</tr>
</tbody>
</table>

† Olsen and Sommers, 1982.
‡ Habey et al., 1990.
§ 2 M KCl extract.
¶ DTPA extractable.
# CaCl₂ extract.
†† CEC, cation exchange capacity.

Two separate, but related, experiments were initiated in April 1999 and continued through September 2001. In Exp. 1, P and K rates were varied while N was held constant. Experiment 2 involved varied rates of N and K with constant levels of added P. In 1999, the fertilizer treatments (Table 2) were divided among six applications between April and November. Fertilizer solutions (500 mL/plot) were applied using a pressurized plot sprayer. Some burning of the turf was observed due to the high rates and high salt content of the fertilizer solution. In 2000 and 2001, the same yearly nutrient amounts were divided among 12 applications to more closely simulate fertilization intervals on putting greens using soluble fertilizer sources and to prevent burning of the turf. Fertilizer solution volume was also increased to 1500 mL and applied with a watering can. The plots were irrigated with 2.5 mm of water immediately after the treatments were applied in all 3 yr. Regular irrigations were scheduled to replace approximately 80% of the reference evaporation every 2 d. turf was mowed at 4 mm four times each week with clippings removed at each mowing. The summer growing seasons of 1999, 2000, and 2001 were nearly rain-free, so the water applied to the experiment was highly controlled.

Visual ratings of turfgrass quality were made at least once each month using a scale of 1 to 9 where 1 represents brown, dormant turf and 9 represents the best quality (Skogley and Sawyer, 1992). Shoot density and color were also rated in a similar manner at least once each year.

Soil samples from each plot were collected five times each year using a soil probe to extract a core to a 15-cm depth. Soil test P and K were measured using a sodium bicarbonate extract (Olsen and Sommers, 1982). Tissue samples were collected and analyzed yearly in early August. A random sampling of the plots was made yearly to monitor DTPA-extractable micronutrient levels. Golf ball roll distance was measured using a modified Stimpmeter with the ball release notch at 19 cm from the beveled end (Gaussoin et al., 1995).

In Year 3, a separate test was conducted on selected plots in both experiments to measure soil test K at depths within the soil profile down to the gravel drainage layer. All replicates of the plots receiving the highest and lowest rate combinations of P and K in Exp. 1 and N and K in Exp. 2 were sampled using a soil probe. The core was divided into sections representing depths of 0 to 7.5, 7.5 to 15, 15 to 22.5, and 22.5 to 30 cm. Each section was analyzed separately for K concentration using a sodium bicarbonate extract (Haby et al., 1990).

The design of each experiment was a randomized complete block with three replications. Within each block, P and K nutrient combinations in Exp. 1 and N and K nutrient combinations in Exp. 2 were completely randomized. Individual plot size was 1.5 by 1.5 m. Data were analyzed using analysis of variance (PROC GLM) and correlation analysis (PROC CORR). Mean separation was done using Fischer’s protected LSD at a 0.05 significance level. The relationships between turfgrass quality and soil test P and tissue P were determined using linear plateau analysis (PROC NLIN). All statistical analyses were performed by SAS (SAS Inst., 2000).

**RESULTS AND DISCUSSION**

**Phosphorus**

Creeping bentgrass turf responded to P treatments soon after the experiment began. Before the experiments, the turf was lacking density, and leaves exhibited characteristic purple deficiency symptoms. Plots receiving 5.5 kg P ha⁻¹ yr⁻¹ had significantly reduced quality (3.0 out of 9 on the turf quality scale) and were deficient as evidenced by the purple leaf coloration. The remainder of the P treatments produced statistically similar results ranging from 5.3 to 5.5 on the turfgrass quality

Table 2. Nitrogen, P, and K fertilizer rates used in Exp. 1 and 2.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>244</td>
<td>98, 147, 244, 342</td>
<td>Urea</td>
</tr>
<tr>
<td>P</td>
<td>5.5, 27.5, 55.0, 110</td>
<td>66.2</td>
<td>Phosphoric acid</td>
</tr>
<tr>
<td>K</td>
<td>0, 101, 203, 304</td>
<td>0, 101, 203, 304, 406</td>
<td>Potassium chloride</td>
</tr>
</tbody>
</table>

Urea

Monoammonium phosphate

Potassium chloride
scale. No interactions between P and K rates were observed.

Phosphorus fertilization increased soil (Fig. 1) and tissue (Fig. 2) P. Soil (Fig. 3) and tissue P (Fig. 4) were also related to turfgrass quality. According to linear plateau regression analysis, soil test levels beyond 3 mg P kg$^{-1}$ soil and tissue levels above 0.4% did not result in increased turfgrass quality.

Ball roll was negatively correlated with soil test P ($R = -0.57; p < 0.0001$). The lowest P application rate (5.5 kg P ha$^{-1}$) resulted in significantly longer ball roll (56 cm) compared with the higher P rate treatments. This was due to the relatively thin stand of turf. Ball roll was 52 cm on bentgrass receiving 27.5 kg P ha$^{-1}$ and 50 and 49 cm on turf receiving 55 and 110 kg P ha$^{-1}$, respectively. While these ball roll distances are significantly different, the actual difference on a putting green as experienced by a golfer may not be as large.

Karcher et al. (2001) reported that the minimum ball roll distance detected by players is approximately 15 cm using an unmodified Stimpmeter. Using regression equations reported by Gaussoin et al. (1995), we calculated that 4-cm ball roll from the modified Stimpmeter, as used in this work, is equal to 15 cm on the unmodified Stimpmeter instrument. Using this 4 cm as the noticeable difference in ball roll distance, the 5.5 kg P ha$^{-1}$ gave longer ball rolls than all other treatments; however, noticeable differences are not present between the 27.5 to 110 kg P ha$^{-1}$ treatments.

This work indicates that relatively low levels of soil test P are needed by creeping bentgrass. Previously, levels greater than 7 to 12 mg P kg$^{-1}$ soil (Olsen method) were recommended (Carrow et al., 2001). These data show that P levels can be kept very low, possibly discouraging annual bluegrass (Poa annua L.) (Waddington et al., 1978; Turner and Hummel, 1992) and reducing P pollution concerns.

**Nitrogen**

Nitrogen is the nutrient that guides most putting green fertilization programs. The 98 kg N ha$^{-1}$ yr$^{-1}$ rate did not provide acceptable turf quality (Fig. 5). The 147 kg

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**Fig. 2.** Tissue P response to P fertilization rate. Data are combined over 3 yr (1999–2001).

**Fig. 3.** Mean turfgrass quality response to soil test P. Data are combined over 3 yr (1999–2001). Mean turfgrass quality is the mean of six to seven turfgrass quality evaluations on each plot each year.

**Fig. 4.** Mean turfgrass quality response to tissue P. Data are combined over 3 yr (1999–2001). Mean turfgrass quality is the mean of six to seven turfgrass quality evaluations on each plot each year.

**Fig. 5.** Mean turfgrass quality response from yearly N fertilizer rate: Exp. 2. Mean turfgrass quality is the mean of six to seven turfgrass quality evaluations on each plot each year. Means within each group marked by the same letter are not significantly different at $P = 0.05$ according to Tukey’s test.
N ha\(^{-1}\) yr\(^{-1}\) rate was of marginal quality while the 244 and 342 kg N ha\(^{-1}\) yr\(^{-1}\) rates were ranked best in turfgrass quality for nearly all evaluations, with the 342 rate being consistently higher in 2000 and 2001. Similar bentgrass response patterns occurred in all 3 yr. These trends with bentgrass turf in response to N applications (Fig. 5) are similar to other N fertilization research (Waddington et al., 1972; Christians et al., 1979; Christians et al., 1981).

Nitrogen fertilization rates influenced tissue N concentrations; however, tissue N did not plateau, even at 342 kg N ha\(^{-1}\) yr\(^{-1}\) (Fig. 6). In work by Christians et al. (1981), chlorophyll content of bentgrass was observed to increase even up to 586 kg N ha\(^{-1}\) yr\(^{-1}\). Uptake may plateau at rates higher than those tested here (Carrow et al., 2001), but higher rates could also be detrimental to overall turfgrass quality. Although the highest N fertilization level gave the highest quality in these evaluations, this amount of N is excessive for most golf course turf in a cool-arid environment like northern Utah because of excessive growth and thatch production.

The lowest N rate plots exhibited the longest ball roll (67 cm) compared with the higher N rates. Each N rate treatment was significantly different than the other treatments, with 62.5, 57.8, and 54.4 cm for the 147, 244, and 342 kg N ha\(^{-1}\) yr\(^{-1}\) treatments, respectively. These results are similar to other studies of N effects on putting green speed or ball roll (Throssell, 1981; Rist and Gaussoin, 1997). The lowest N rate, while fast, offered unacceptable visual quality, so a compromise between visual appearance and ball roll would be needed.

High rates of K did not reduce the need for N in Exp. 2 as indicated by the lack of an N \(\times\) K interaction on turfgrass quality, opposite of the trends observed by Christians et al. (1979). Tissue K was positively correlated with N fertilization rate \((r = 0.49; p < 0.0001)\) and even had a stronger relationship than K fertilization rate and tissue K \((r = 0.13; p = 0.09)\). These trends are similar to the response reported by Christians et al. (1981) where at low N rates, tissue production increased with increased K fertilization rates. The response might be explained by K uptake being limited at low N rates because of reduced growth. The lack of N \(\times\) K interactions may have been affected by the generally low soil test K levels in these sands, even at the highest K fertilization rates. This will be discussed in the following section.
Table 3. Soil test K at depths within the root zone: Exp. 2. LSD(0.05) = 11.3 for all comparisons.†

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>98 kg N; 0 kg K</th>
<th>98 kg N; 406 kg K</th>
<th>342 kg N; 0 kg K</th>
<th>342 kg N; 406 kg K</th>
<th>No nutrient control§</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–7.5</td>
<td>35.7</td>
<td>69.3</td>
<td>27.0</td>
<td>62.7</td>
<td>17</td>
</tr>
<tr>
<td>7.5–15</td>
<td>16.7</td>
<td>42.7</td>
<td>14.3</td>
<td>39.7</td>
<td>10</td>
</tr>
<tr>
<td>15–22.5</td>
<td>14.3</td>
<td>29.0</td>
<td>12.7</td>
<td>29.0</td>
<td>7</td>
</tr>
<tr>
<td>22.5–30</td>
<td>15.3</td>
<td>29.0</td>
<td>15.3</td>
<td>29.3</td>
<td>15</td>
</tr>
</tbody>
</table>

† Data from Exp. 1 were nearly identical in response patterns.
‡ Column headings are simplified for clarity. All treatments are in kg nutrient ha⁻¹ yr⁻¹.
§ Not replicated. For observational comparison only.

Potassium

Potassium is the nutrient usually needed in the second largest quantity by turf; however, no positive effect of K fertilization rates was observed on turf quality (data not presented). No significant differences among K levels were observed in 2000 or 2001. Higher rates of K reduced quality in 1999, but this was due to foliar burning caused by the high concentration of fertilizer salts.

The lack of response was unexpected, considering the very low levels of soil test K at the start of the experiment (Table 1). Soil test K was increased slightly by K application rates but not in proportion to the amount applied (Fig. 7). Tissue K showed a weak positive correlation with turfgrass quality (Fig. 8). Tissue K negatively influenced ball roll distance, but a significant relationship was observed only in Year 1 (Fig. 9).

Lack of turf quality response to K has been observed in other research and was explained by the lack of stress on the turfgrass and inherently high amounts of K present in the sands (Christians et al., 1981; Fry et al., 1989). Potassium is known to increase tolerance to heat, drought, and traffic stresses (Turner and Hummel, 1992; Carrow et al., 2001), so future work should include the effects of traffic and water stress with K treatments.

Another explanation for the lack of a K response is the inability of the sand to absorb K due to low CEC and subsequent leaching of K through the root zone. Soil test K at various depths in the root zone indicated that K was moving below the root zone (typically 15–20 cm deep) and leaching out of the green (Table 3). Potassium levels were highest in the surface layer of all treatments and decreased with depth in the profile. Higher levels were observed at all depths for the higher K rates. More K at the surface is likely related to greater amounts of organic matter and a corresponding higher CEC. The higher K concentrations at depth with the higher K rate treatments indicates some leaching was occurring.

Mean soil test K ranged from 28 to 46 mg K kg⁻¹ soil (Fig. 7). If the K fertilizer had remained in the root zone, much higher K concentrations would be detected in the soil test. For example, in a calcareous soil system (silt loam texture and 37% CCE), soil test K increased 1 mg K kg⁻¹ soil for each 5 kg K ha⁻¹ applied (Koenig et al., 2001). In the present study, a similar response would have increased soil test K approximately 240 mg K kg⁻¹ soil for the highest K fertilizer rate at the end of 3 yr. Potassium removal in clippings would reduce
the amount of K measured in the soil test. However, the low soil test response coupled with elevated soil test K measured below the root zone (Table 3) does indicate that K was leaching through the root zone.

Potassium levels in the green changed throughout the year. Levels generally started low in spring and increased throughout the year, even in the 0 kg K ha\(^{-1}\) control (Fig. 10). The low levels of K early in spring provide further evidence for leaching of K overwinter. The cause of the gradual increase throughout the year in the control plots is not known. Potassium is not being supplied from irrigation water. This increase may be caused by the occasional deposition of clippings from adjacent, fertilized plots or the release of K during mineral weathering.

The lack of a positive quality response and low soil test response to K suggest that careful K management is needed on sand root zone putting greens. Unlike in finer-textured soils, K cannot be banked or applied in excess of plant needs in one year. Instead, on calcareous sand greens, K must be applied or made available to plants on a more regular basis to maintain adequate tissue levels.

Nutrient responses in the calcareous sand used in this study were similar to those in noncalcareous sands described elsewhere (Turner and Hummel, 1992; Carrow et al., 2001). Calcareous sands, and sand greens in general, may not require higher levels of applied nutrients but more careful management of form and application timing. This could be achieved by making more frequent, lower-rate applications of dry or foliar (liquid) forms of K or using a slow-release form.

ACKNOWLEDGMENTS

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