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Amending Sand with Isolite and Zeolite under Saline Conditions: Leachate Composition and Salt Deposition

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Abstract. **Understanding the possible influence of inorganic soil amendments on salt leaching and deposition is helpful in selecting soil amendments when salinity is a problem. Greenhouse experiments were conducted to: 1) evaluate the effects of isolite and zeolite on turf quality of Kentucky bluegrass (*Poa pratensis* L.) under three salinity levels; and 2) determine if soil amendments affected leachate composition, salt deposition, and soil sodium absorption ratio (SAR). 'Challenger' Kentucky bluegrass was grown in columns filled with 100% sand, 50 sand : 50 isolite, and 50 sand : 50 zeolite (v/v). Irrigation waters with three levels of salinity [0.25 (control), 3.5, or 6.5 dS·m^{-1}] were applied daily for 3 months in Study I and for 6 months in Study II. Saline water reduced turf quality compared with control. Amendment of sand with isolite increased turf quality only during the third month of treatment with the most saline water in Study I. However, zeolite increased turf quality during both the second and third months at both salinity levels in both studies. The beneficial effects of zeolite on turf quality diminished 5 and 6 months after salinity treatments. Amending sand with zeolite reduced leaching of Na^+ and K^+, but increased the leaching of Ca^{2+} and Mg^{2+}. Amending sand with zeolite increased SAR values by 0.9, 1.6, and 6.3 units in Study I and 0.9, 3.6, and 10.9 units in Study II, under control, 3.5, and 6.5 dS·m^{-1} salinity treatments, respectively. Isolite increased SAR by 1.1–1.6 units with 3.5 dS·m^{-1} and by 2.5–3.5 units with 6.5 dS·m^{-1} salinity treatments. Results indicate that amending with zeolite may buffer soil solution Na^+ concentration in the short- term. In the long-term, however, a substantial amount of Na^+ may be retained concurrent with Ca^{2+} and Mg^{2+} exchange, thereby increasing sodicity and salinity problems.**

Sand is the most widely used root-zone material to reduce compaction; enhance drainage and aeration; and smooth play surfaces in putting greens, tees, and sports fields. However, sand offers little capacity for water and nutrient retention. A wide variety of inorganic soil amendments have been tested for their ability to enhance water and nutrient retention by sand-based root zones (McCoy and Stehouwer, 1998). One of these is isolite, a diatomaceous earth-based porous ceramic aggregate with a bulk density of 0.6 g·cm^{-3}, total porosity of 74%, and cation exchange capacity (CEC) of 1–3 meq/100 g. Isolite reportedly not only reduces compaction, but also increases water-holding capacity and increases air diffusion into the root zone. Another group of amendment includes the zeolites, which are ancient volcano ash-based materials. Clinoptilolitic zeolite is aluminosilicate with three-dimensional framework structures of $(SiAl)O_4$ tetrahedra, which contain pores filled with water molecules and exchangeable cations (Barbarick and Pirela, 1983). Clinoptilolitic zeolite has a particle density of 2.1 (similar to that of sand) and a CEC between 100–300 meq/100 g. Both isolite and zeolite have been investigated for their usefulness as soil amendments for turfgrass (Ferguson and Pepper, 1987; Huang and Petrovic, 1994; Nus and Brauen, 1991; Smalley et al., 1962).

Because of water conservation concerns, turfgrasses are increasingly irrigated with nonpotable water, particularly effluent water or other marginal quality waters (Dean et al., 1998; Hayers et al., 1990a; Mancino and Pepper, 1992). These alternative water sources often contain significant concentrations of dissolved salts. Problems associated with saline soils and saline irrigation waters are increasing as more effluent or poor-quality water is applied to turf sites (Carrow and Duncan, 1998; Harivandi et al., 1992). In situations where salinity is a problem, questions and concerns exist over the selection and use of soil amendments. The major concerns are that soil amendments with high CEC may retain salts, reduce their leaching, and accentuate root-zone salinity problems. Salt leaching has long been recognized as essential in reducing salt hazards and maintaining plant growth under saline conditions. Understanding the possible influences of soil amendments on leaching and deposition of salt and on turfgrass growth will be helpful in selecting soil amendments and developing management approaches.

The objectives of this investigation were to: 1) evaluate the effects of isolite and zeolite on turf quality of Kentucky bluegrass under 0.25, 3.5, and 6.5 dS·m^{-1} salinity treatments; and 2) determine whether soil amendments affect leaching and deposition of salt, thereby altering soil salinity and SAR values.

Materials and Methods

The experiments were conducted in a fiberglass-reinforced plastic greenhouse between Sept. 1998 and Mar. 1999 and repeated between Apr. and Nov. 1999 with new sets of plants and root-zone media. Greenhouse air temperature was maintained at 32 °C day/ 15 °C night. Photosynthetically active radiation (*PAR*) ranged from ≈150 mol·m^{-2}·s^{-1} on cloudy days to 1150 mol·m^{-2}·s^{-1} on sunny days.

Soil treatments and plant materials. Fifty-four polyvinyl chloride (PVC) columns, measuring 10.2 cm in diameter × 50 cm deep, were prepared. Holes were drilled at the bottom of each container to allow drainage. Columns were packed with three different root-zone media: 1) silicon sand (100%) (S); 2) 50 sand : 50 isolite (v/v) (I); and 3) 50 sand : 50 zeolite (Z). The particle-size distribution of silicon sand met U.S. Golf Association putting green specifications, with >70% of sand particles falling in the 0.25–1.0-mm range. Isolite was provided by Sundine Enterprise (Arvada, Colo.), and zeolite, labeled as ZeoPro™, by ZeoponiX (Louisville, Colo.). Fertilizers (6N–1P–0K and 0N–0P–43K) were mixed into 100% sand and I to match the nutrient contribution of the ZeoPro™. Root-zone media were uniformly mixed, added to the columns, and packed. Final bulk densities for S, Z, and I were 1.43, 1.21, and 1.00 g·cm^{-3}, respectively, in Study I, and 1.52, 1.32, and 1.07 g·cm^{-3}, respectively, in Study II.

'Challenger' Kentucky bluegrass sod pieces (10 cm in diameter) were excised from a 5-year-old field plot. They were hand-washed to remove soil and planted in the PVC columns after roots were trimmed to the crown.

Salinity treatments. After a 2–3-month establishment period of turf in the PVC columns, two salinity treatments were imposed by using saline irrigation waters, along with a control, which was watered using tap water with an electrical conductivity (EC) value of 0.25 dS·m^{-1}. Saline irrigation waters were prepared by adding 1 $CaCl_2$: 1 NaCl (w/w) to tap water to obtain EC values of 3.5 and 6.5 dS·m^{-1}. About 65–100 mL of solution was applied daily to each column by hand. This volume was adequate to ensure a >25% leaching fraction. All irrigation treatments were continued for 3 months in Study I, and for 6 months in Study II.

Data collection. Visual turf quality was rated monthly on a 1–9 scale, where 1 = brown,

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thin, dead turf; 6 = acceptable quality; and 9 = dense, uniform, bright-green, nonstressed turf. Leachate was collected by placing a plastic beaker under each column. After volume was determined, the EC of the leachate was measured with an electrical conductivity meter (model RC-16C; Beckman Industrial, Cedar Grove, N.J.). Leachates collected 2 months after initiation of treatment in Study I and 4 months after initiation in Study II were analyzed for K^+, Mg^{2+}, Ca^{2+}, and Na^+ contents using an atomic absorption spectrometer (SpectrAA 40; Varian Analytical Instruments, Palo Alto, Calif.).

At the end of the treatment period, root-zone media at a depth of 20 cm was collected from each column for Na^+, Ca^{2+}, Mg^{2+}, K^+, NO_3^- and NH_4^+ analysis. The Na^+, Ca^{2+}, Mg^{2+}, and K^+ were extracted with 1 M $NH_4C_2H_3O_2$ (2 g root-zone medium in 20-mL solution, 5-min shaking) and measured by atomic absorption spectrometer (Black, 1965). Nitrate and NH_4^+ were extracted with 1 M KCl (2 g root-zone medium in 20 mL solution, 30-min shaking) and measured with a Rapid Flow Analyzer (model 303; Alpkem Corp., Wilsonville, Ore.).

Data analysis. In both studies, the experimental design consisted of three salinity treatments and three root-zone mixes replicated six times in a split-plot design with salinity treatment as main plot factor and amendment type as subplot factor. Analysis of variance (ANOVA) indicated a root-zone mix and study interaction for data on turf quality, leachate Na^+, Ca^{2+}, and Mg^{2+} contents; therefore, data from each study were analyzed separately. Means were separated by Fisher's protected LSD at $P = 0.05$ and ANOVA was applied to the data.

Results and Discussion

Turf quality in study I. Turf quality declined linearly with increasing salinity (Quality = 8.3 – 0.47 × EC, $R^2 = 0.74$) and the declines were magnified with time (Table 1). Mean turf qualities over 3 months were 8.0, 7.0, and 5.0 at salinity levels of 0.25, 3.5, and 6.5 dS·m⁻¹, respectively.

Differences in turf quality were observed among soil amendments 2 and 3 months after salinity treatments began (Table 1). Two months after salinity treatment at 6.5 $dS\cdot m^{-1}$, turf quality in Z was 0.8 units higher than that in S, but quality of turf grown in I did not differ from that grown in either S or Z. Three months after salinity treatment at 3.5 $dS\cdot m^{-1}$, quality of turf grown in Z was higher than that in S. At the 6.5 $dS\cdot m^{-1}$ salinity level, Z and I had increased turf quality by 1.2 and 1.1 units, respectively, compared with sand.

Turf quality in study II. As in Study I, turf quality declined linearly with increasing salinity (Quality = 7.9 – 0.41 × EC, $R^2 = 0.56$). However, quality declined more slowly in Study II than in Study I. Mean turf quality over 6 months was 8.0, 6.1, and 5.5 at salinity levels of 0.25, 3.5, and 6.5 $dS\cdot m^{-1}$, respectively.

On most rating dates in Study II, soil amendments had no effect on turf quality (Table 1). However, 2 months after salinity treatment began, turf grown in Z was of better quality than that in S and I at the 6.5 $dS\cdot m^{-1}$ salinity level. After 4 months, turf in Z was of better quality than that in S, but the quality of turf grown in I did not differ from that grown in Z or S under nonsaline conditions. The beneficial effects of Z on turf quality had diminished after 5 and 6 months of treatment.

Enhanced turf quality in Z during early stages of salinity treatment may have occurred because: 1) Z retained NH_4^+ and K^+ in structural channels of the mineral, which could have improved turf quality and growth (Ferguson and Pepper, 1987; Ferguson et al., 1986; Huang and Petrovic, 1994); 2) Z adsorbed Na^+ and served as a buffering medium to prevent excessive Na^+ uptake, thereby reducing Na^+ toxicity to the plant; or 3) both. However, rising Na^+ levels, as discussed below, might have diminish the long-term beneficial effect of Z as CEC sites became more saturated with Na^+. If the experiments had been continued for a longer period to obtain steady state salt concentration, detrimental effects of salinity may have been observed in Z-amended sand.

Ion composition in the leachates. Soil amendments had no effect on the volume and EC of leachates in both studies (data not shown). However, differences in ion composition of leachates both among salinity treatments and among the types of root-zone media were striking (Tables 2 and 3).

Under control irrigation, the K^+ concen-

Table 1. Effects of amending sand medium with zeolite and isolite on turf quality of 'Challenger' Kentucky bluegrass irrigated with three levels of saline irrigation waters in two greenhouse studies.

Salinity (EC) of irrigation water ($dS\cdot m^{-1}$)	Amendment	Turf quality[z] MAST[y]: 1	2	3	4	5	6
		Study I					
Control (0.25)	Zeolite	8.4	8.0	8.1			
	Isolite	8.2	7.8	8.1			
	None	8.3	7.8	7.8			
3.5	Zeolite	7.1	7.2	7.3 a[x]			
	Isolite	7.1	7.0	6.8 ab			
	None	7.1	6.9	6.3 b			
6.5	Zeolite	6.6	5.1 a	4.4 a			
	Isolite	6.4	4.8 ab	4.3 a			
	None	6.6	4.3 b	3.2 b			
		Study II					
Control (0.25)	Zeolite	7.8	8.5	8.9	8.1 a	7.8	7.7
	Isolite	7.7	8.4	8.7	7.5 ab	7.6	7.7
	None	8.0	8.5	8.9	7.3 b	7.5	7.8
3.5	Zeolite	6.8	6.1	7.6	5.5	5.3	4.8
	Isolite	7.4	6.2	7.4	5.6	4.9	4.9
	None	7.8	5.9	7.4	5.5	5.0	5.0
6.5	Zeolite	6.9	6.0 a	6.3	4.8	4.6	4.4
	Isolite	7.4	5.4 b	5.8	4.8	4.8	4.3
	None	7.5	5.2 b	6.0	5.0	4.8	4.5

[z]Turf quality was rated on a 1–9 scale (9 = best).
[y]Months after initial salinity treatment.
[x]Mean separation within salinity level, columns, and studies by Fisher's LSD test, $P \le 0.05$. No letters indicate no significant differences among means.

Table 2. Effects of amending sand with zeolite and isolite on ion concentrations in leachates collected from PVC columns containing Kentucky bluegrass irrigated with three levels of saline irrigation waters in Study I at 2 months after initiation of salinity treatment.

Salinity (EC) of irrigation water ($dS\cdot m^{-1}$)	Amendment	Ion ($mg\cdot L^{-1}$) K^+	Ca^{2+}	Na^+	Mg^{2+}
Control (0.25)	Zeolite	3.5 b[z]	66.2 a	16.5 a	6.8
	Isolite	46.7 a	64.1 a	14.1 b	5.6
	None	51.5 a	41.2 b	5.2 c	4.3
3.5	Zeolite	8.3 b	755.7 a	51.2 c	86.1 a
	Isolite	129.2 a	353.3 b	405.6 b	17.0 b
	None	105.1 a	305.1 b	525.1 a	11.0 b
6.5	Zeolite	9.9 c	1,609.8 a	64.6 c	101.1 a
	Isolite	128.1 a	781.1 b	1,045.4 b	16.0 b
	None	103.4 b	875.1 b	1,376.5 a	8.0 c
		ANOVA			
Source	df	Mean squares			
Salinity (S)	2	13,135**	4,849,372**	3,054,951**	7,139**
Amendment (A)	2	46,150**	995,392**	1,706,630**	17,845**
S × A	4	2,969*	304,257**	725,297**	4,266**

[z]Mean separation within salinity levels and columns by Fisher's LSD test, $P \le 0.05$. No letters indicate no significant differences among means.
*, **Significant at $P \le 0.01$ and 0.0001, respectively.

tration in leachates from Z in Study I were 92% and 93% lower than in leachates from S and I, respectively. In Study II, control leachate from Z contained 87% lower K^+ than leachate from S. This indicates that Z retains more K^+ than do I and sand, supporting the findings of Ferguson et al. (1986). Sodium concentration of control leachate was highest for Z, intermediate for I, and lowest for S in Study I. In Study II, Na^+ content of leachate was 110% greater for Z than for the average of I and S in the control irrigation treatment, suggesting that zeolite contained a higher Na^+ content. Calcium content was higher in leachate from Z than in that from S.

Concentrations of Na^+ and Ca^{2+} in leachates increased dramatically for all root zones as salinity level increased. This result was expected since the solutions used for all salinity treatments were made by adding equal equivalent weights of Ca^{2+} and Na^+ to the municipal water. However, the magnitude of increases in Na^+ and Ca^{2+} concentrations were strongly influenced by soil-amendment type. Inclusion of Z reduced leaching of Na^+ by 90% to 95%, but increased leaching of Ca^{2+} by 40% to 140% and of Mg^{2+} by 500% to 600% at 3.5 and 6.5 $dS \cdot m^{-1}$. The preferential retention of Na^+ over Ca^{2+} and Mg^{2+} by zeolite occurred even though saline irrigation solutions had a 1 $CaCl_2$: 1 NaCl ratio. Our results suggest that Z is more selective for Na^+ and less selective for Ca^{2+}, which may be related to the size and charge of the cations and the specific crystal structure and distribution of exchange sites in zeolite. Amending sand with I reduced leaching of Na^+ by 23% but increased that of K^+ and Mg^{2+} by 25% and 40% to 100%, respectively, at 6.5 $dS \cdot m^{-1}$. These results suggest that, even though isolite has a lower CEC, it may preferentially retain a small amount of Na^+, and exclude Mg^{2+} and K^+, in highly saline conditions.

Regardless of the root-zone medium, leaching of K^+ from columns irrigated with 3.5 and 6.5 $dS \cdot m^{-1}$ saline waters was more than twice that from those irrigated with potable water in Study I (Table 2). This is in agreement with another study, which indicated that high Na^+ levels depress K^+ uptake, thereby increasing leaching of K^+ (Qian et al., 2000).

Soil analysis. Root-zone mineral concentrations differed among the root-zone mixes (Tables 4 and 5). In the control irrigation treatment, all extractable minerals (K^+, Ca^{2+}, Mg^{2+}, Na^+, and NH_4^+) were higher in Z than in S or I, reflecting zeolite's high CEC. As salinity increased to 3.5 $dS \cdot m^{-1}$, Na^+ concentration in Z increased by 166% to 344% and Ca^{2+} by 29% to 47% in both studies, while Mg^{2+} concentration decreased by 15% in study II only. As salinity level increased again from 3.5 to 6.5 $dS \cdot m^{-1}$, Na^+ concentration in Z increased in both studies by 166% to 172%, but Ca^{2+} concentration decreased by 26% in Study I and remained the same in Study II. The concentration of Na^+ in Z increased linearly, whereas that of Ca^{2+} tended to increase at low salinity, but reached a plateau at high salinity. Mg^{2+} content decreased with increasing salinity.

Amending sand with isolite increased Na^+ and Ca^{2+} concentrations at 3.5 and 6.5 $dS \cdot m^{-1}$. The Na^+ content of the root-zone was 151–162 and 317–355 $mg \cdot L^{-1}$ at 3.5 and 6.5 $dS \cdot m^{-1}$, respectively, which was significantly higher than in sand (42 and 96 $mg \cdot L^{-1}$ at 3.5 and 6.5 $dS \cdot m^{-1}$, respectively) but much lower than in Z (317 and 1317 $mg \cdot L^{-1}$ at 3.5 and 6.5 $dS \cdot m^{-1}$, respectively). Similar trends were observed for Ca^{2+} content.

Sodium absorption ratio of soil increased with increasing level of salinity for all root zones (Tables 4 and 5). Amending sand with zeolite increased SAR values by 0.9, 1.6–3.6, and 6.3–10.9 units under control, 3.5, and 6.5 $dS \cdot m^{-1}$ salinity treatments, respectively, while amending with isolite increased SAR values by 1.1–1.6 units at 3.5 $dS \cdot m^{-1}$ and 2.5–3.5 units at 6.5 $dS \cdot m^{-1}$. This increase in SAR is associated with the preferential retention of Na^+ over Ca^{2+}, Mg^{2+}, or both.

This experiment has provided preliminary information about the leaching and deposition of salts when zeolite and isolite are used as soil amendments. The fact that Z exhibited higher Na^+ in the leachate under nonsaline, but retained more Na^+ under saline conditions, suggests that zeolite can act as both a source and a sink for Na^+. This study clearly shows that zeolite is more selective in retaining Na^+ than

Table 3. Effects of amending sand with zeolite and isolite on ion concentrations in leachates collected from PVC columns containing Kentucky bluegrass irrigated with three levels of saline irrigation waters in Study II at 4 months after initiation of salinity treatment.

Salinity (EC) of irrigation water ($dS \cdot m^{-1}$)	Amendment	Ion ($mg \cdot L^{-1}$) K+	Ca2+	Na+	Mg2+
Control (0.25)	Zeolite	3.3 b [Z]	30.7 a	11.6 a	4.2
	Isolite	14.7 ab	10.7 c	5.8 b	3.8
	None	25.5 a	20.2 b	5.2 b	3.3
3.5	Zeolite	8.3 b	695.3 a	50.1 b	84.1 a
	Isolite	40.2 a	393.3 b	465.0 a	21.1 b
	None	22.8 ab	447.1 b	458.1 a	15.1 b
6.5	Zeolite	12.9 b	1,630.0 a	75.9 c	103.0 a
	Isolite	43.1 a	811.5 c	861.1 b	14.1 b
	None	15.6 b	1,170.1 b	1,190.0 a	10.1 b
ANOVA					
Source	df	Mean squares			
Salinity (S)	2	263^{**}	$3,179,876^{**}$	$1,110,787^{**}$	$4,215^{**}$
Amendment (A)	2	$1,329^{**}$	$333,134^{**}$	$638,562^{**}$	$8,345^{**}$
S × A	4	317^{*}	$125,714^{**}$	$257,370^{**}$	$2,183^{**}$

[z]Mean separation within salinity levels and columns by Fisher's LSD test, $P \le 0.05$. No letters indicate no significant differences among means.
$^{*, **}$Significant at $P \le 0.01$ and 0.0001, respectively.

Table 4. Effects of amending sand medium with zeolite and isolite on ion concentrations of root zone media 3 months after salinity treatments in Study I.

Salinity (EC) of irrigation water ($dS \cdot m^{-1}$)	Amendment	Ion ($mg \cdot L^{-1}$) K+	Ca2+	Mg2+	Na+	NH4+	NO3	SAR2
Control (0.25)	Zeolite	526 aA[Z]	801 aB	107 aA	119 aB	56 aA	24.8 aA	1.1 aB
	Isolite	48 bB	159 bB	43 bA	23 bB	27 abA	33.4 aA	0.4 bC
	None	33 bA	172 bA	42 bA	11 bB	11 bA	14.5 bA	0.2 bB
3.5	Zeolite	696 aA	1,178 aA	98 aA	317 aB	36 aA	33.0 aA	2.4 aB
	Isolite	70 bA	251 bB	26 bA	151 bAB	6 bA	33.2 aA	2.4 aB
	None	32 bA	186 bA	21 bB	42 cA	4 bA	13.0 bA	0.8 bA
6.5	Zeolite	697 aA	871 aB	73 aB	845 aA	71 aA	29.1 aA	7.3 aA
	Isolite	78 bA	409 bA	31 bA	355 abA	5 bA	17.2 bA	4.5 abA
	None	26 bA	206 cA	21 bB	58 bA	2 bA	9.1 bA	1.0 bA
ANOVA								
Source	df	Mean squares						
Salinity (S)	2	$41,132^{*}$	$1,018^{**}$	$74,266^{**}$	$354,742^{***}$	740^{NS}	75^{NS}	36^{***}
Amendment (A)	2	$1,015,435^{***}$	$12,958^{***}$	$1,700,479^{***}$	$336,353^{***}$	$7,456^{***}$	710^{***}	19^{***}
S × A	4	$33,275^{*}$	390^{NS}	$55,579^{**}$	$104,265^{**}$	614^{NS}	121^{NS}	7^{**}

[z]Mean separation within parameters by Fisher's LSD test, $P \le 0.05$. Uppercase letters indicate mean separation among salinity levels for a given root zone; lowercase letters indicate mean separation among root-zone treatments within salinity levels.
$^{NS, *, **, ***}$Nonsignificant, significant at $P \le 0.05$, 0.01, and 0.0001, respectively.

Table 5. Effects of amending sand medium with zeolite and isolite on ion concentrations of root-zone media 5 months after salinity treatments in Study II.

Salinity (EC) of irrigation water ($dS\cdot m^{-1}$)	Amendment	Ion ($mg\cdot L^{-1}$)						
		K^+	Ca^{2+}	Mg^{2+}	Na^+	NH_4^+	NO3	SAR
Control (0.25)	Zeolite	461 aB[z]	572 aB	75 aA	109 aC	29 aB	7.1 aA	1.1 aC
	Isolite	48 bA	191 bC	30 bA	16 bC	4 bA	0.7 bA	0.3 bC
	None	29 bA	168 bB	26 bA	12 bC	4 bA	0.6 bB	0.2 bC
3.5	Zeolite	611 aB	740 aA	64 aB	484 aB	34 aB	3.7 aB	4.6 aB
	Isolite	51 bA	394 bB	23 bB	162 bB	1 bB	1.8 bA	2.1 bB
	None	41 bA	280 cA	21 bA	67 cB	2 bAB	2.7 aA	1.0 cB
6.5	Zeolite	787 aA	763 aA	58 aB	1317 aA	78 aA	1.8 aB	12.4 aA
	Isolite	41 bA	444 bA	17 bC	317 bA	1 bB	0.5 bA	4.0 bA
	None	29 bA	264 cA	15 bA	96 cA	2 bB	0.4 bB	1.5 cA
					ANOVA			
Source	df	Mean squares						
Salinity (S)	2	13,157***	362***	170,762***	1,215,783***	156**	9***	63***
Amendment (A)	2	1,007,308***	5,696***	508,673***	853,038***	4,134***	32***	63***
S × A	4	27,316***	15^{NS}	4,685*	284,466***	223***	9**	22***

[z]Mean separation within parameters by Fisher's LSD, $P \leq 0.05$. Uppercase letters indicate mean separation among salinity levels for a given root-zone; lowercase letters indicate mean separation among root-zone treatments within salinity level.

$^{NS, *, **, ***}$Nonsignificant, significant at $P \leq 0.05$, 0.01, and 0.0001, respectively.

Ca^{2+}, though the concentrations of Ca^{2+} and Na^+ in the irrigation water were equal. Isolite has a low CEC and retained 64% less Na^+ and 22% less Ca^{2+} than did Z. Because of selectivity of cation retention, we observed increases in SAR values for zeolite- and isolite-amended media. The SAR values were highest for Z, intermediate for I, and lowest for S. Beneficial effects of amending sand with zeolite under saline conditions were observed for 2 to 4 months. However, analysis of soil and leachate suggests that, with long-term use of saline irrigation water, zeolite amendments could cause Na^+ to build up in the root zone, increasing the potential for sodicity and salinity problems. In this study, we did not observe a significant effect of isolite on turf performance under nonlimiting soil moisture conditions.

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