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Influence of Gypsum and Wetting Agent on Sand-Based Putting Greens Irrigated with Recycled Wastewater

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ABSTRACT

Recycled wastewater (RW) is a source of irrigation for golf courses in many parts of the world. The objectives of this study were to determine the effects of gypsum and wetting agent applications on the turfgrass quality, clipping yield, root zone chemical and physical properties, and leachate of a sand-based putting green irrigated with secondary and tertiary RW. Our results showed that gypsum amendment produced better turfgrass quality under summer heat stress than the wetting agent and the control. Soil water infiltration was impeded by secondary and tertiary RW but was improved by the gypsum treatments. When compared with topdressing with straight sand, the wetting agent application did not improve turfgrass quality or soil properties when irrigated with RW. Monthly applications of a wetting agent resulted in lower water infiltration rates, but the values remained within the U.S. Golf Association recommendations for putting green construction. Golf course superintendents are encouraged to use gypsum when managing sand-based putting greens with RW as the primary source of irrigation water.

Potable water shortages are becoming a global issue as the human population continues to increase and urban areas expand. Community leaders often view turfgrass management as a low priority in areas with potable water shortages. Recycled wastewater has been identified as an alternative water source for golf course irrigation because of its abundance (Harivandi, 2007). After secondary treatment, most RW sources contain plant essential nutrients that can be used to supplement fertilization (Harivandi, 2011); however, some RW sources contain elevated salts and other potentially toxic ions. Using RW for irrigation can result in salt accumulation in turfgrass root zones (Qian and Mecham, 2005; Slavens et al., 2009) and can damage the soil structure. The agronomic impacts are physiological stress, turfgrass toxicity, and poor water infiltration and percolation (Harivandi, 2007). Another potential problem associated with the use of RW is surface and groundwater pollution caused by leaching and runoff of RW (Thomas et al., 2006). Soil amendments, such as calcined clay and peat (Letey et al., 1966; Morgan et al., 1966; Valoras et al., 1966) and wetting agents (Karnok and Tucker, 2001), have long been used to improve water movement in turfgrass soils adversely affected by compaction, salinity, and other factors. For example, gypsum has been used to decrease P leaching and runoff (Torbert et al., 2005; Watts and Torbert, 2009) as well as to aid in the reclamation of calcareous saline-sodic soils (Gharaibeh et al., 2009).

Limited information is available regarding the effects of gypsum or wetting agents on turfgrass quality, soil health, and the environment when RW is used as a primary source of irrigation for sand-based putting greens. This knowledge would be especially useful when RW is used for irrigation in a semiarid region receiving 70% of the annual precipitation from July to September. The objectives were to determine the effects of gypsum and wetting agent applications on turfgrass quality, clipping yield, root zone chemical and physical properties, and the leachate of a sand-based putting green irrigated with secondary and tertiary RW.

MATERIALS AND METHODS

Research Putting Green Construction

The study was conducted on a sand-based putting green at the turfgrass research station of Beijing Forestry University located in the northern suburb area (40°22′ N, 116°21′ E). The putting green was constructed according to U.S. Golf Association (USGA) recommendations, with drain lines spaced 3 m apart in a herringbone pattern (U.S. Golf Association, 1993). The 30-cm-deep root zone medium was a mixture of 90% sand and 10% peat (v/v), with the sand size conforming to the USGA recommendation for particle size distribution. The root zone mixture had 28% aeration porosity, 22% capillary porosity, and a saturated water conductivity of 46 cm h^{-1} determined following the method described by Hummel (1993). A 10-cm layer of pea gravel conforming to the USGA recommendation for particle size distribution was constructed for the entire subgrade. Thirty polyvinyl chloride lysimeters, 45 cm in diameter and 30 cm deep, were installed in the root zone during construction. Three lysimeters were placed on top of the pea gravel over each lateral drain line on 0.8-m centers. Each lysimeter was connected from the bottom to a 2-cm polyethylene (PE) pipe buried alongside the drain tiles. All of the PE

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Abbreviations: EC, electrical conductivity; PE, polyethylene; RW, recycled wastewater; TKN, total Kjeldahl nitrogen; USGA, United States Golf Association.

Table 1. Study site weather data from 2009 through 2011.

	2009				2010				2011			
		Air temperature				Air temperature				Air temperature		
Month	Precipitation	Avg.	Max.	Min.	Precipitation	Avg.	Max.	Min.	Precipitation	Avg.	Max.	Min.
	mm	°C			mm	°C			mm	°C		
April	53.9	15.7	21.8	8.4	0.0	9.6	17.5	3.7	16.3	14.7	21.1	7.0
May	15.2	25.4	29.2	14.6	29.0	20.9	31.1	13.3	18.0	21.2	29.1	14.1
June	144.0	25.7	31.8	18.7	45.4	25.6	32.8	18.7	88.4	26.1	33.1	21.3
July	233.2	26.3	31.7	21.7	31.2	29.0	38.3	22.9	213.8	27.0	33.6	22.9
Aug.	74.7	24.8	30.4	20.5	105	27.2	35.7	21.7	55.4	26.5	31.1	22.5
Sept.	29.0	21.4	27.1	16.4	82	21.8	31.5	12.6	18.2	21.8	30.3	15.2
Oct.	15.0	14.6	22.5	9.0	41.4	12.8	20.2	5.4	28.5	13.3	19.7	7.3
Nov.	28.2	3.0	11.0	0.3	28.2	3.0	11.0	0.3	21.1	5.9	11.6	0.1

lines were installed to provide drainage in the same direction as the drain lines, which connected to a sump well 10 m from the green. The configuration allowed separate collection of leaching solutions from each lysimeter. The root zone mixtures in the lysimeters were compacted using a concrete hammer in 10-cm increments to a bulk density of 1.4 g cm^{-3}, similar to that of the putting green.

The putting green was seeded with Penn A4 creeping bentgrass (*Agrostis stolonifera* L.) in August 2009 at a rate of 100 kg ha^{-1}. A 16–6–12 N–P–K fertilizer (Best, J.R. Simplot Co.), containing 4.2% highly water soluble N and 11.8% slow-release N, was applied before seeding at a rate of 50 kg ha^{-1} of N. At the end of October 2009, the green was fertilized again at a rate of 50 kg ha^{-1} of N using the same fertilizer and topdressed with sand at 20 m^3 ha^{-1}. The grass was mowed at 3.2 mm and watered as needed to maintain active plant growth.

Experiment Design and Treatment Applications

The experiment commenced in April 2010 following the same management practices in 2010 and 2011. The mowing height remained at 3.2 mm throughout the study. The green was fertilized with 50 kg ha^{-1} of N in the middle of April, May, June, August, and September using a 19–6–12 N–P–K fertilizer (Best, J.R. Simplot Co.) (9.1% highly water-soluble N and 9.9% slow-release N). At the end of September, a 4–0–1 N–P–K fertilizer (Cytozorb, The Andersons) containing selected macronutrients (4% NO_3–N, 1% K, 0.53% Mg, and 1% S) and micronutrients (2% Fe, 0.25% Mn, and 0.2% Zn) was applied to supply 25 kg ha^{-1} of N. Soil aeration was provided in April and early October each year using an AERCORE800 solid-tine aerator (Greenman Machinery Co.) at 40-mm tine spacing. The diameter of the tines was 13 mm and the penetration depth was 80 mm. Following the October aeration, all plots were topdressed with sand at 20 m^3 ha^{-1}. A winter-protective blanket (Covermaster) was used to cover the green from mid-November to mid-March. Greens had recovered from the aeration before being covered with the blanket.

The experiment was arranged in a split-plot design. Main plots were those turf areas (2 by 2.4 m) irrigated with the three water sources (potable, secondary RW, and tertiary RW). Main plots were arranged in randomized complete blocks with three replicates and blocked by the distance from the primary drain outlet. Each main plot was assigned to one lateral drain. Main plots were separated by a 1-m turf border. Within each main plot, there were three 2- by 0.8-m subplots. The subplot factors included a monthly application of gypsum ($CaSO_4 \cdot 2H_2O$, Beijing Chemistry Works) in the topdressing sand, a wetting agent (Aqueduct nonionic polyols, Aquatrols) applied after sand topdressing, and a control.

Irrigation water was applied every other day at 120% of evapotranspiration calculated by the Penman–Monteith equation (Allen et al., 1998), using the weather data from an on-site weather station. Monthly precipitation and temperature data were collected throughout the study and summarized (Table 1). The amount of irrigation water for each main plot was calculated based on the area of the main plots plus half of the border area separating the plots. Irrigation water was applied using a hand-held spray wand with a breaker that delivered water slowly enough to avoid runoff. Recycled water (Beijing Drainage Group Co., LTD, Jiu Xian Qiao sewage treatment plant, Beijing) was stocked weekly and analyzed for water quality (Table 2). Although >90% of the solids were removed from the secondary water at the treatment facility, it remained slightly odoriferous. The tertiary water contained no solids and was odor free.

Gypsum and the wetting agent were applied monthly from April to September. Gypsum was applied along with a sand topdressing to deliver a sand volume of 20 m^3 ha^{-1} and a gypsum rate of 2500 kg ha^{-1}. Sand and gypsum were thoroughly mixed using a blender (JY-160, Jianyue Equipment). The same sand used for root zone construction was used for topdressing. A push broom was used to uniformly brush the sand into the turf after application using a 36H13 drop spreader (Greenman Machinery Co.). The wetting agent was applied at 13.25 L ha^{-1} after sand topdressing using a CO_2–pressurized sprayer at 250 kPa equipped with a flat-fan nozzle (TeeJet 8002VS, TeeJet Spray Systems Co.) calibrated to deliver a spray volume of 360 L ha^{-1}.

Irrigation Water Quality

Irrigation water electrical conductivity (EC) was measured with an EC meter (DDSJ-308A), and the pH was measured using a pH meter (PHS-25). Total water K, Na, Ca, Mg, and Fe contents were analyzed using an AA7000w flame atomic absorption spectrophotometer (Beijing East and West Electronic Co.). Total water N was analyzed following the persulfate digestion method (D'Elia et al., 1977). Water NH_4–N was determined following the modified Nessler reagent method (Demutskaya and Kalinichenko, 2010). The total water P was analyzed following the method described by Murphy and Riley (1962).

Table 2. Water quality of irrigation sources used on sand-based creeping bentgrass (*Agrostis stolonifera* L.) putting greens during 2010 and 2011.

Water source	Statistic	pH		EC†		Na		Ca		Mg		K		Total N		Total P		NH_3–N	
		2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
				— dS m^{-1} —		mg L^{-1}													
Portable	Avg.	7.5	7.7	0.64	0.70	143	143	25	24	21	20	1.7	1.8	2.8	4.1	0.03	0.09	0.2	0.6
	SD	0.3	0.2	0.06	0.08	4.5	8.0	4.0	4.0	3.4	3.6	0.2	0.3	1.0	2.0	0.01	0.04	0.1	0.2
	Min.	7.0	7.5	0.57	0.57	139	130	18	19	16	16	1.4	1.5	1.1	2.9	0.02	0.04	0.1	0.1
	Max.	7.8	7.9	0.70	0.79	150	151	28	30	251	26	1.9	2.2	3.9	8.1	0.04	0.17	0.3	0.8
Secondary	Avg.	7.7	7.8	1.03	5.43	578	690	59	60	24	26	21.6	23.2	5.7	6.4	0.37	0.36	0.3	2.0
	SD	0.4	0.1	0.04	1.21	11.5	61	6.8	8.1	3.2	4.7	3.6	4.5	1.9	2.5	0.59	0.27	0.1	0.5
	Min.	7.3	7.7	0.95	3.30	262	610	49	52	21	19	16.2	18.5	2.6	2.6	0.05	0.13	0.1	1.3
	Max.	8.3	7.9	1.07	7.03	590	763	68	70	29	32	24.3	30.0	7.2	9.1	1.42	0.87	0.5	2.6
Tertiary	Avg.	7.7	7.7	1.04	1.08	183	197	33	30	22	24	16.1	18.2	5.0	4.3	0.55	0.16	0.9	1.1
	SD	0.3	0.2	0.06	0.14	8.5	9.3	4.2	1.8	2.8	5.4	1.3	2.7	1.6	2.0	0.63	0.04	1.1	0.2
	Min.	7.2	7.6	0.98	0.93	170	184	29	28	20	16	14.2	15.5	2.1	2.3	0.04	0.11	0.1	0.9
	Max.	8.0	8.0	1.11	1.33	190	210	37	32	26	31	17.8	22.8	6.0	8.1	1.39	0.21	2.7	1.4

† Electrical conductivity.

Turfgrass Quality, Soil Properties, and Leachate Measurement

Turf quality was assessed monthly from April through September using the National Turfgrass Evaluation Program (www.ntep.org/) guidelines: scale of 1 to 9, with 1 representing dead grass, 6 representing a minimum acceptable level, and 9 representing the best quality. Clippings were collected from each subplot monthly April through September using a greens mower (Model 552, Shanghai Barroness Lawn Machinery Co.), with a cutting width of 43 cm. Turf borders of the main plots were mowed first and then each subplot was mowed in two passes with the basket attached. The collected clippings were immediately transferred to a laboratory and dried at 68°C for 48 h before determining the dry yield (Mills and Jones, 1996). The dry clippings from October were ground to pass through a 0.178-mm sieve for tissue analysis. The K, Na, Ca, Mg, and Fe shoot contents were determined using an AA7000w flame atomic absorption spectrophotometer following dry ashing in a muffle furnace at 490°C for 8 h and digestion with 5 mol L^{-1} aqua regia (Greweling, 1976; Jones et al., 1991). Total shoot tissue P content was determined following the vanadomolybdophosphoric yellow color method of dry ashing solution (Jones et al., 1991). Total shoot tissue N content was determined using the micro-Kjeldahl digestion method (Bremner, 1996).

Soil samples were taken in October each year to analyze the pH, EC, and K, Na, Ca, Mg, Fe, N, and P contents. The pH was determined in a suspension containing 1 part medium in two parts water according to McLean (1982), and the EC was determined in a 1:5 medium/water extract following the method described by Rhoades (1982). The modified NH_4OAc method was used to extract K, Na, Ca, Mg, and Fe. Soil total Kjeldahl N (TKN) was determined using the micro-Kjeldahl digestion method (Bremner, 1996). Soil total P was determined using the alkaline oxidation method (Dick and Tabatabai, 1977). The water infiltration rate in each subplot was measured using potable water and a double-ring infiltrometer under unsaturated conditions (Turf-Tec International). The rate of water infiltration was determined after reaching a constant rate (<5% change in 5 min) following the methodology of Bouwer (1986).

Water leachates were collected monthly from July to September by providing suction from an SHB-III vacuum pump (Zhenzhou Greatwall Scientific Industrial and Trade Co.) to a filter and collection bottle connected to the PE pipe. The EC, pH, and K, Na, Ca, Mg, Fe, P, total N, and NH_4^+–N contents of the leachates were determined following the same methods used for water quality analysis described above.

Statistical Analysis

The experiment was conducted in 2010 and repeated in 2011 on the same plots, and the final data were subjected to analysis of variance (ANOVA) using mixed model procedures (SAS version 9.2, SAS Institute), with replication as the random factor. There were no significant yearly interactions. Because year was not a replicated treatment and the data from 2 yr showed homogenous variability, the data from both years were combined for statistical analysis. Main effects are only presented whenever interactions between water source and soil amendments were not significant. Treatment means were separated using Fisher's protected least significant difference (LSD) at the 0.05 probability level.

RESULTS AND DISCUSSION

Turfgrass Quality and Clipping Yield

Turfgrass quality was differentially affected by irrigation water in June only, with potable water providing the highest turf quality, followed by tertiary RW and secondary RW (Table 3). Topdressing amendments affected turf quality in July, with the gypsum treatment providing higher turf quality than the wetting agent and sand topdressing alone (Table 3); however, significant interaction effects between water source and soil amendment existed. In the secondary water treatments, the gypsum treatment resulted in higher turf quality (7.5) than the wetting agent (7.0) or control (7.2), while in the potable and tertiary water treatments, gypsum and wetting agent were higher (7.5) than the control (7.2) (data not shown). This suggests that using secondary RW posed more problems for creeping bentgrass combined with hot weather. Similar results were reported by Neylan et al. (2005) and Slavens et al.

Table 3. Creeping bentgrass (*Agrostis stolonifera* L.) turf quality, using the National Turfgrass Evaluation Program (www.ntep.org/) guidelines: scale of 1 to 9, with 1 representing dead grass, 6 representing a minimum acceptable level, and 9 representing the best quality, on sand-based putting greens as affected by soil amendments and irrigation source from 2010 and 2011, with the data combined for the 2 yr.

Treatment	df	Apr.	May	June	July	Aug.	Sept.
Water source							
Potable		6.1 a†	6.3 a	6.8 a	6.3 a	6.4 a	6.2 a
Secondary		6.1 a	5.7 a	5.7 c	5.9 a	6.3 a	6.6 a
Tertiary		6.4 a	6.2 a	6.3 b	6.0 a	6.4 a	6.3 a
Soil amendment							
Gypsum		6.5 a	6.5 a	6.2 a	6.8 a	6.4 a	6.3 a
Wetting agent		6.3 a	6.1 a	6.1 a	6.2 b	6.1 a	6.1 a
Control		6.2 a	5.9 a	5.7 a	6.2 b	6.3 a	6.0 a
	ANOVA, Pr > *F*						
Source of variance							
Water (W)	2	0.2042	0.0756	0.0034	0.0634	0.7984	0.0947
Soil (S)	2	0.8720	0.2201	0.5917	0.0216	0.4120	0.5739
W ´ S	4	0.8471	0.7810	0.2928	0.0030	0.7699	0.3953
CV, %		7.8	9.7	6.3	4.0	5.9	5.8

† Means within a column of the same treatment factor followed by the same letter are not significantly different at the 0.05 probability level.

Table 4. Creeping bentgrass (*Agrostis stolonifera* L.) clipping yield on sand-based putting greens as affected by soil amendments and irrigation sources during the growing seasons of 2010 and 2011 with data combined for both years.

		Clipping yield					
Treatment	df	Apr.	May	June	July	Aug.	Sept.
		g m^{-2}					
Water source							
Potable		8.91 c†	29.98 c	87.47 c	63.07 c	52.99 c	51.11 b
Secondary		12.11 a	40.41 a	120.05 a	72.37 a	66.25 a	66.99 a
Tertiary		10.56 b	34.25 b	106.47 b	68.93 b	58.78 b	53.54 b
Soil amendment							
Gypsum		10.87 a	37.61 a	115.27 a	69.95 a	58.95 a	58.65 a
Wetting agent		10.47 a	34.94 a	105.76 ab	70.41 a	61.14 a	58.32 a
Control		10.23 a	32.10 a	92.96 b	64.01 a	57.92 a	54.67 a
	ANOVA, Pr > *F*						
Source of variance							
Water (W)	2	0.0320	0.0419	0.0045	0.0142	0.0399	0.0437
Soil (S)	2	0.8397	0.3944	0.0500	0.2099	0.7865	0.8053
W ´ S	4	0.9057	0.5339	0.5868	0.6832	0.7630	0.9228
CV, %		20.96	23.86	16.89	11.12	16.88	24.74

† Means within a column of the same treatment factor followed by the same letter are not significantly different at the 0.05 probability level.

(2009) for creeping bentgrass, annual bluegrass (*Poa annua* L.), and Kentucky bluegrass (*Poa pratensis* L.), which showed a reduction in quality when RW was used during periods of heat stress. The clipping yield was higher in the plots receiving RW than the plots irrigated with potable water throughout the entire growing season (Table 4). This was probably due to the higher N, P, and K content in the RW used for irrigation (Table 2). The increased shoot growth did not coincide with higher turf quality, however, indicating that extra nutrients in the RW did not compensate for the detrimental effects of the high salt content of the RW or that the plants had enough of

Table 5. Turfgrass tissue analysis of creeping bentgrass (*Agrostis stolonifera* L.) as affected by soil amendments and irrigation source during 2010 and 2011, with data combined for the 2 yr.

		Turf tissue content		
Treatment	df	Na	Ca	P
		mg kg^{-1}		%
Water source				
Potable		559 b†	7545 a	0.38 b
Secondary		764 a	5682 b	0.38 b
Tertiary		630 ab	5720 b	0.41 a
Soil amendment				
Gypsum		636 a	6984 a	0.39 a
Wetting agent		656 a	5750 b	0.39 a
Control		661 a	6215 b	0.40 a
		ANOVA, Pr > *F*		
Source of variance				
Water (W)	2	0.0487	0.0038	0.0339
Soil (S)	2	0.3901	0.0500	0.7895
W ´ S	4	0.1592	0.1251	0.3382
CV, %		13.93	28.34	7.79

† Means within a column of the same treatment factor followed by the same letter are not significantly different at the 0.05 probability level.

the nutrients so that the extra amount provided with the RW was not necessary. Gypsum application affected the clipping yield in June only, with plants having a higher yield in plots receiving gypsum than topdressing only. Appling gypsum was beneficial when irrigated with potable water that contained a significant amount of Na (Table 2).

Nutrient Content of Shoot Tissues

Creeping bentgrass receiving secondary RW for irrigation produced shoot tissues with a higher Na (secondary RW only) and lower Ca (secondary and tertiary RW) content compared with the potable water treatment (Table 5). A higher P content in shoot tissues was also detected in the creeping bentgrass irrigated with tertiary RW. Tissue analysis showed no significant difference in TKN, K, or Mg content among all irrigation treatments (data not shown). Creeping bentgrass shoot tissues from plants receiving gypsum had a higher Ca content than control plots or plots treated with the wetting agent (Table 5).

Root Zone Chemical Properties and Water Infiltration

Irrigation with secondary RW resulted in higher soil Na and K contents and EC than plots receiving potable water (Table 6). Increased soil Na, K, and EC in soil-based turfgrass plots was reported by Qian and Mecham (2005) and Thomas et al. (2006). Root-zone K, Ca, and Mg increased as a result of the gypsum treatment. Root-zone TKN, P, and pH were not affected by topdressing amendment or irrigation water source (data not shown) (Table 6).

Irrigation with secondary RW lowered soil water infiltration rates compared with irrigation with potable water (Table 6). This was probably the result of the higher sodium adsorption ratio (SAR) (13.2) in the secondary RW compared with the SAR of the potable water (5.1) and tertiary RW (4.4) (data not shown). There was a significant interaction between the effects of irrigation water source and treatments on soil water

Table 6. Soil chemical properties of sand-based putting greens as affected by soil amendments and irrigation source sampled in October 2010 and 2011, with data combined for the 2 yr.

Treatment	df	Na	Ca	Mg	K	EC†	Infiltration rate
		mg kg^{-1}				dS m^{-1}	cm h^{-1}
Water source							
Potable		449 b‡	14,157 a	1236 a	10,921 b	0.15 b	112.8 a
Secondary		574 a	13,800 a	1345 a	13,117 a	0.29 a	79.9 b
Tertiary		501 b	12,893 a	1237 a	11,903 ab	0.17 b	94.6 b
Soil amendment							
Gypsum		508 a	15,381 a	1405 a	13,786 a	0.22 a	110.2 a
Wetting agent		495 a	13,052 b	1254 ab	11,520 b	0.20 a	74.9 b
Control		522 a	12,428 b	1160 b	10,635 b	0.18a	102.3 a
	ANOVA, Pr > F						
Source of variance							
Water (W)	2	0.0026	0.1326	0.3372	0.0427	0.0044	0.0003
Soil (S)	2	0.7354	<0.0001	0.0192	0.0025	0.6100	<0.0001
W × S	4	0.9589	0.3833	0.8036	0.9164	0.7674	0.0430
CV, %		24.3	13.9	19.8	21.9	35.4	23.4

† Electrical conductivity.

‡ Means within a column of the same treatment factor followed by the same letter are not significantly different at the 0.05 probability level.

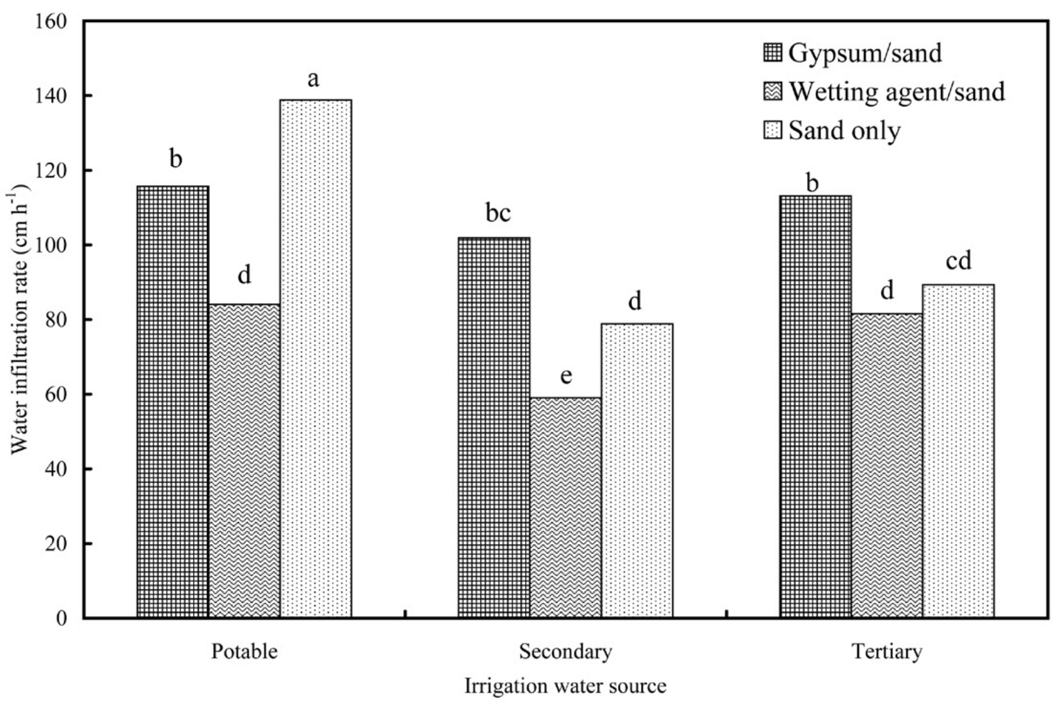

Fig. 1. Soil water infiltration rate of sand-based putting greens as affected by soil amendments and irrigation water sources from measurements taken in October 2010 and 2011. Data were combined for statistical analysis. Bars with the same letter are not significantly different according to Fisher's least significant difference at the 0.05 probability level.

infiltration (Table 6). Gypsum treatment yielded a higher water infiltration rate than the wetting agent or sand topdressing control treatment when irrigated with RW. When irrigated with potable water, however, the sand topdressing control treatment yielded a higher water infiltration rate than gypsum or sand topdressing treatments (Fig. 1). The cause of this effect is not clear and requires further study. Results from the gypsum treatment irrigated with RW were comparable to those of Gharaibeh et al. (2009), who reported improved water infiltration as a result of using gypsum and irrigation water with a moderate SAR to reclaim saline soil.

Mobbs et al. (2012) noted inconsistent effects on water infiltration among wetting agents applied after topdressing with sand. Morgan et al. (1966) reported that the infiltration rate was lower in soil treated with a wetting agent than untreated soil. Also, no differences were observed between wetting agent treatments and soils amended with peat and calcined clay (Morgan et al., 1966). Additional research is necessary to investigate the interactions among soil types, wetting agents, and SAR levels of irrigation water. Although the water infiltration rate was decreased by the wetting agent in this study, the infiltration rate in plots treated with the wetting agent was higher than the USGA root-zone specification for putting green construction (U.S. Golf Association, 1993).

Chemical Properties of Leachate

Plots irrigated with secondary RW produced higher EC and K, Na, Ca, and Mg levels in leachate samples than those irrigated with potable and tertiary RW (Table 7). These results are similar to those observed by Thomas et al. (2006), who also reported increased EC, K, Na, and Mg in leachate samples following the application of RW. Leachate samples collected from plots receiving tertiary RW irrigation had a higher K content than samples taken from plots receiving potable water in August and September (Table 7). Additionally, the tertiary RW treatments had higher K than the potable water treatments in July. Nutrient differences in leachates were in proportion to the content in the water used for irrigation. Total N and P in leachates were no higher than those found in the potable water, indicating that no extra N or P load to the groundwater would occur as a result of using RW for irrigation (data not shown). Higher Ca and Mg levels in leachate samples were caused by the application of gypsum (Table 7).

In conclusion, this study illustrates that gypsum application is beneficial for creeping bentgrass when secondary RW, which contains elevated salts, is used to irrigate sand-based putting greens during hot weather. Water infiltration was impeded by secondary and tertiary RW irrigation, but adding gypsum to the topdressing sand before application helped to alleviate the adverse effects. Application of a wetting agent did not improve turfgrass quality or soil properties when irrigated with RW compared with topdressing with sand alone. Wetting agent applications actually decreased infiltration rates regardless of water source; however, the values were still well within the USGA specifications. The magnitude of the decrease in water infiltration rates from the use of a wetting agent may not be great enough to cause significant management problems. Despite the higher N and P content of RW for irrigation, leachate samples collected during monsoon months did not show increased N or P. Our results suggest that using RW as the primary source of irrigation water in a semiarid region combined with appropriate cultural practices does not pose significant environmental problems.

Table 7. Chemical properties of water leachate from sand-based putting greens as affected by soil amendments and irrigation source sampled in July, August, and September of 2010 and 2011, with data combined for the 2 yr.

Treatment	df	EC†			Na			Ca			Mg			K		
		July	Aug.	Sept.	July	Aug.	Sept.	July	Aug.	Sept.	July	Aug.	Sept.	July	Aug.	Sept.
		ds m^{-1}			mg L^{-1}											
Water source																
Potable		1.07 b‡	1.10 b	1.36 b	34.7 b	40.5 b	41.8 b	67.8 b	72.5 b	72.9 b	45.4 c	46.86 b	41.4 b	3.5 b	4.3 c	4.3 c
Secondary		2.58 a	2.82 a	3.11 a	197.1 a	264.9 a	248.3 a	107.9 a	114.2 a	113.5 a	68.4 a	68.64 a	72.4 a	4.5 a	6.5 a	7.0 a
Tertiary		1.22 b	1.29 b	1.44 b	86.2 b	69.1 b	62.6 b	63.9 b	72.8 b	77.8 b	55.9 b	54.40 b	40.4 b	3.7 b	5.5 b	5.9 b
Soil amendment																
Gypsum		2.08 a	2.04 a	2.21 a	111.8 a	129.9 a	125.1 a	102.4 a	104.5 a	119.5 a	60.0 a	60.95 a	57.7 a	4.1 a	5.8 a	5.7 a
Wetting agent		1.42 a	1.62 a	1.86 a	91.7 a	128.4 a	115.1 a	70.4 b	79.9 b	77.3 b	54.8 a	57.07 a	47.8 b	3.8 a	5.3 a	5.7 a
Control		1.37 a	1.54 a	1.84 a	86.2 a	116.1 a	112.5 a	67.0 b	75.2 b	67.5 b	54.8 a	51.86 a	48.6 b	3.8 a	5.3 a	5.8 a
		ANOVA, Pr > *F*														
Source of variance																
Water (W)	2	0.0013	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	0.0012	<0.0001	<0.0001	0.0002	0.0002	<0.0001	0.0089	<0.0001	<0.0001
Soil (S)	2	0.1818	0.4978	0.5707	0.6676	0.9406	0.9440	0.0109	0.0079	<0.0001	0.4982	0.1753	0.0023	0.6320	0.1452	0.9716
W × S	4	0.9819	0.9988	0.9560	0.9869	0.9967	0.9777	0.4059	0.5708	0.8652	0.5678	0.2942	0.7568	0.6992	0.2999	0.2834
CV, %		27.81	27.48	28.70	45.76	42.77	44.28	36.95	33.13	31.36	26.84	25.37	17.13	24.21	17.11	17.94

† Electrical conductivity.
‡ Means within a column of the same treatment factor followed by the same letter are not significantly different at the 0.05 probability level.

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