Australian Journal of Crop Science AJCS
AJCS 8(1):80-90 (2014) ISSN:1835-2707

Spatial and temporal salinity accumulation patterns on golf course fairway soils under effluent water irrigation

David J. Skiles[1], Saad F. Alshammary[2], and Yaling Qian[1]*

[1]Deptartment of Horticulture and Landscape Architecture, Colorado State University, Fort Collins, CO 80523-1173, USA
[2]National Center of Agriculture Technology, King Abdulaziz City for Science & Technology, Riyadh, Saudi Arabia

*__Corresponding author:Yaling.Qian@colostate.edu__

Abstract

In this study, salinity accumulation patterns on 4 fairways of two golf courses irrigated with effluent water were investigated using two different types of sensors. Spatial and temporal salt accumulation patterns were measured using a network of *in-situ* soil sensors located at two depths (15 and 30 cm for 5TE sensor and 8 and 19cm for Turf Guard sensor TG2). A positive correlation was observed between 5TE sensor-measured soil salinity and saturated paste extracted soil salinity (r = 0.77). In addition, a significant exponential relationship was observed between the values of soil salinity, measured by TG2 sensor, and those measured in saturated paste extraction ($R^2 = 0.97$). Moreover, a strong correlation between the average values of soil salinity and soil water content (r = 0.76), as well as the percentage of sand in the soil (r = - 0.63) for Heritage fairway 1 were found. Overall, the highest salinity was pronounced for fairway 19 at Common Ground Golf Course. However, the salinity level as high as 10.6 dS m^{-1} is not a result of water reuse, but a historical geological contribution. The data of this study suggest that an adequate drainage network in predominantly clay soils irrigated with effluent water could better manage salinity accumulation associated with poor drainage.

Keywords: Effluent water irrigation, Golf Courses, Perennial ryegrass, Salinity Sensors.
Abbreviations: 5TE_Decagon's 5TE sensor is designed to measure the water content, electrical conductivity, and temperature of soil and growing media. TG2_Toro Turf Guard Dual Level (TG2) sensors use principles of soil permittivity and frequency response to measure soil water content and soil salinity.

Introduction

Global demand for water increases proportional to population growth and global precipitation pattern changes. Water demand is greatest in arid regions, where high quality water is typically allocated for drinking water purposes (Devitt et al., 2004). The use of water for irrigation of landscapes and turfgrass is often viewed as a low priority use for high quality fresh water resources (Marcum, 2006). Traditional usage of poor quality water for irrigation has left large areas of land unproductive for plant growth (Marcum, 2006; Ghassemi et al., 1995; Pessarakli and Szabolics, 1999).

Facing the water demands of present day in the arid and semi-arid regions, high quality water is limited, and sometimes restricted for landscape irrigation (Devitt et al., 2004). To maintain high quality turf in arid regions, where annual precipitation is a limiting factor, irrigation is required (Carrow, 2006). In these geographic regions, conventional irrigation consumes surface and ground water resources, and has a negative impact on the availability, accessibility and reliability of water resources (Pereira et al., 2002). Saline water resources include poor quality groundwater aquifers, municipal effluent and agricultural drainage (Miyamoto and Chacon, 2006).

The use of non-potable water sometimes has been mandated in arid areas for turfgrass irrigation (Marcum, 2006 and Lockett et al., 2008). Effluent water is the product of modern wastewater treatment systems. Some of the main constituents include: salts of different types, nutrient elements, and organic compounds (Toze, 2006). The contribution of effluent water irrigation to water conservation varies by location. Water reuse satisfied 25% of the water demand in Israel, where 66% of total treated sewage is reused (Lazarova and Asano, 2004). Water reuse is expected to reach 10% to 13% of water demand in Australia and California (Lazarova and Asano, 2004).

In the Denver area, effluent water irrigation can free up enough fresh water to supply 40000 to 50000 households. Effluent water contains a range of micro-elements at levels sufficient to satisfy the need of most turfgrasses for these substances. It may also contain enough macro-nutrients, nitrogen (N), phosphorus (P), and potassium (K) to significantly figure in a fertilization program. The economic value of these nutrients can be substantial. Water reuse for irrigation in urban landscapes is a powerful means of water conservation, water reclamation, and nutrient recycling.

Due to the dense plant canopy and active root systems, turfgrass landscapes are increasingly viewed as environmentally desirable disposal sites for wastewater. In fact, dense, well-managed turfgrass areas are among the best bio-filtration systems available for removal of excess nutrients and further reclamation of treated wastewater. Effluent water contains high levels of soluble salts that are undesirable as irrigation water (U.S.G.A., 1994).

Effluent water has relatively high sodium concentrations relative to calcium and magnesium (Qian and Mecham, 2005). Turfgrass systems can be successfully irrigated with effluent water (Thomas et al., 2006), although there are some limiting effects. Effluent water composition is dependent on source and prior uses (Asano, 1987). An approximate inorganic salt load of 300 ppm may result from each single cycle of residential water use (Bishop, 1990). The potential for long-term changes to soil chemistry is attributable to increased salt and other specific element contents of effluent water (Asano, 1987). Golf course managers are often concerned about salinity and sodicity issues associated with effluent water irrigation. Eighty percent of golf course managers have little or no experience managing golf courses under effluent irrigation (Devitt et al., 2004).

A concern is how to maintain soil health and turf quality. Long-term and continued use of effluent water may lead to increased soil sodicity, and the eventual reduction of soil infiltration, permeability, and aeration in clayey soils that exacerbate salinity problems (Qian and Mecham, 2005). Sometimes, changes in soil chemistry can be accompanied by changes in the physical properties of soil with effluent irrigation. Coppola et al., 2004 evaluated the hydrological response of soils under effluent irrigation. Distinct changes were observed; surface soil bulk densities increased and hydraulic conductivity decreased. The observed changes in soil hydraulic conductivity under effluent water irrigation could lessen the ability of a soil to be effectively leached for excess salts. Effective leaching of soil salts achieves a reduction of soil salinity specifically in a root zone (Carrow et al., 2000). Changes in soil chemistry were observed when effluent irrigation was used. Mancino and Pepper, 1992 found that increases in ion load and pH did not harm the functional quality of a sandy loam soil. It remained viable for turf growth. Devitt et al. (2007) and Miyamoto and Chacon (2006) examined salinity accumulation variability along with spatial and temporal patterns of accumulation in effluent irrigated sites.

Spatial variability of salinity accumulation was found to be greatest over Aridisol soil types at various depths. The deep sandy soils have minimal salt accumulation (Miyamoto and Chacon, 2006). For a golf course, transitions to effluent irrigation and the variation of salinity from year to year can be quantified by an equation, accounting for the total number of days under effluent irrigation, irrigation system uniformity and the leaching fraction applied (Devitt et al., 2007). Salinization potential can be approximated using an empirical formula accounting for the salinity of irrigation water and soil texture classification (Miyamoto and Chacon, 2006). Effluent water irrigation along the Front Range of Colorado (Denver metropolitan region) has been studied using conventional methods, including soil sampling at various depths followed by lab analysis. Qian and Mecham (2005) found significant differences in SAR, EC, ESP along with extractable(s) sodium, calcium, phosphorus, boron and magnesium and pH between sites using effluent irrigation and those with surface water for irrigation. Furthermore, it is suggested that persistent management practices (such as calcium additions) may be helpful in mitigating some of the negative impacts associated with effluent irrigation. Temporal and spatial salinity accumulation patterns have also been examined in other regions of the U.S., using *in situ* sensors to measure soil salinity of putting greens and fairways. Salinity variation observed across 1600 days was nearly twice as great for the fairways when compared to putting greens (Devitt et al., 2007). Fairway soils are natural, unlike the engineered soil system that comprises the United States Golf Association (U.S.G.A.) sand based putting green. Putting greens were found to have less salt accumulation (Devitt et al., 2007).

Our study was conducted on Heritage Golf Course (an established effluent irrigated golf course) and Common Ground Golf Course (a course that has recently transitioned to effluent irrigation) between 2008 and 2009. The findings of this study will help the managers to maintain sustainable irrigated golf courses receiving effluent water. The objectives of this study were (1) to determine temporal and spatial salinity accumulation patterns in fairway soils irrigated with effluent water and (2) to determine the relationship of soil salinity with multiple variables including soil texture, soil water content, and compaction for the established effluent water irrigated course.

Results and Discussion

Heritage Golf Course

Spatial and temporal salinity patterns on fairways

Spatial changes of fairway soil salinity are presented along with descriptive statistics in (Tables 1 A-D). Our results showed that elevated salinity was not pronounced for most plots. Specifically, plots 3, 4, 5, and 6 of fairway 1 and plots 2, 3, 4 and 5 of fairway 10 had salinity levels less than 3 dS m^{-1}. However, soil salinity varied from plot to plot on each fairway. When daily salinity data were averaged over the season for individual sensors, higher salinity levels were found at the cart path side of fairways edges, i.e., plot 2 for Fairway 1 and plots 1 and 6 for Fairway 10 (Tables 1 A-D). The salinity levels of these plots exceeded 3-4 dSm^{-1}. In a previous studies by Kotuby et al. (2000), and Brown and Berstein (1953), the salinity threshold of perennial ryegrass was reached to 5.6 dS m^{-1}, with a 50% yield reduction observed at 12 dSm^{-1}. Moreover, Qian et al. (2001) reported that the salinity levels of 3.2 dS m^{-1} caused 25% shoot growth reduction for a salt-sensitive Kentucky bluegrass cultivar and 4.7 dS m^{-1} for a salt-tolerant Kentucky bluegrass cultivar. In this study, turfgrass grown on fairways was perennial ryegrass (*Lolium perenne* L.). Perennial ryegrass can tolerate soil salinity better than Kentucky bluegrass. It is interesting that plots exhibiting low and high salinities presented opposite seasonal trends, especially from the summer 2008 to the spring of 2009. In early August to September when the weather was relatively dry, under routine irrigation practice, the mean soil salinity of low salinity plots was less than 2 dS m^{-1}, whereas for the high salinity plots, the mean soil salinity was about 4 dS m^{-1}. As the golf course caused a gradually reduction in water input from September to November, a further increases in soil salinity were observed in plots with high salinity. In contrast, soil salinity was reduced below 1.5 dSm^{-1} in plots with low salinity.

It was observed that these patterns continued into the spring of 2009. After reinstallation of the data logger in March, the mean soil salinity of low salinity plots was less than 1.5 dS m^{-1}. However, the restart of routine irrigation in late March increased salinity by about 0.5 units in these plots. By contrast, the restart of routine irrigation in March reduced soil

Table 1. Basic descriptive statistics of soil salinity at Heritage fairway 1 at the 15 and 30 cm depths (labeled as A and B, respectively) and fairway 10 at the 15 and 30 cm depths (labeled as C and D, respectively).

A						
Plot	1	2	3	4	5	6
Mean (dS m^{-1})	2.30	4.40	1.91	2.08	2.63	2.08
Standard Deviation,	0.46	0.64	0.18	0.19	0.32	0.22
Coefficient of Variation	0.20	0.14	0.10	0.09	0.12	0.11

B						
Plot	1	2	3	4	5	6
Mean (dS m^{-1})	3.70	0.76	1.83	1.89	2.43	1.8408
Standard Deviation,	0.76	0.79	0.14	0.14	0.35	0.1291
Coefficient of Variation	0.76	1.04	0.08	0.07	0.14	0.07

C						
Plot	1	2	3	4	5	6
Mean (dS m^{-1})	3.98	1.77	2.54	1.72	2.40	3.32
Standard Deviation,	0.26	0.41	0.23	0.33	0.40	0.27
Coefficient of Variation	0.06	0.23	0.09	0.19	0.17	0.08

D						
Plot	1	2	3	4	5	6
Mean (dS m^{-1})	1.88	2.38	2.48	2.73	3.02	2.55
Standard Deviation,	0.13	0.43	0.43	0.40	0.36	0.44
Coefficient of Variation	0.07	0.18	0.17	0.15	0.12	0.18

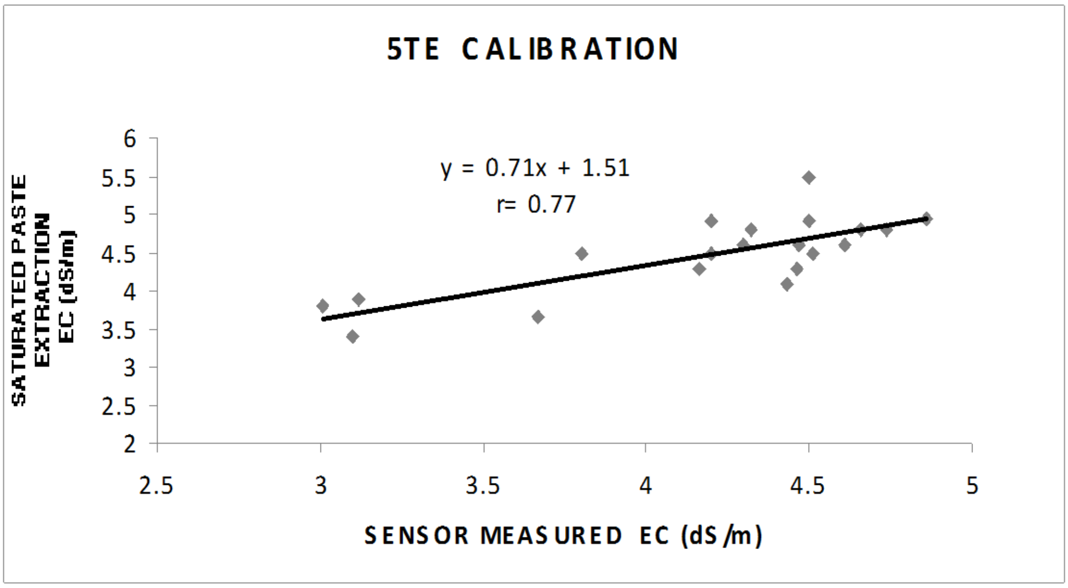


Fig 1. Sensor measured electrical conductivity (EC) was linearly regressed against conventional saturated paste extract electrical conductivity (EC).

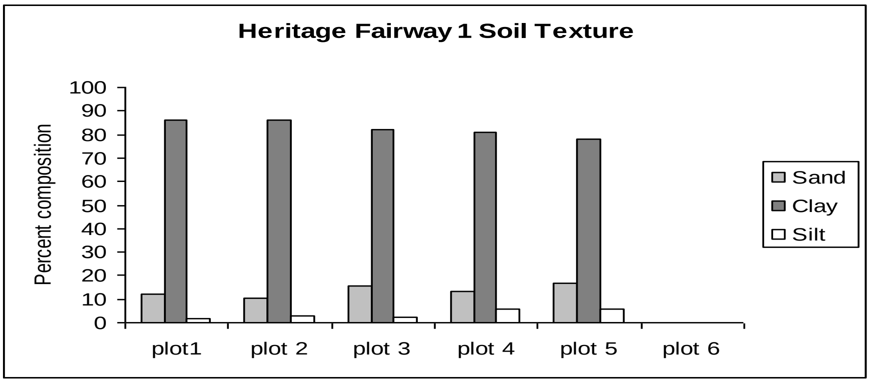
salinity about one unit to around 4 dSm^{-1} on Fairway 1 and 3-4 dSm^{-1} on Fairway 10 for the plots having high salinity (Table 1 A-D and Table 2A-D). In April and October 2009, the rainfall was more than the average precipitation in Colorado State (Fig. 3). Soil salinity of the high salinity plots was gradually reduced with each significant rainfall event. A majority (67 %) of Heritage plots possessed higher mean values of soil salinity at the 15 cm depth than those at 30 cm depth of soil.

Soil water content

Spatial changes of soil water content (SWC) are presented in Table 2 A-D. Though the irrigation distribution uniformity ranged from 90 to 92%, there were significant differences in SWC between the investigated plots. The SWC of plots 1 and 2 on Fairway 1 ranged between 40-50 %, which were significantly higher than other plots (25-35 %). The SWC patterns of The Heritage Golf Course fairway 1's individual plots showed that majority of plots contained high SWC at the shallow depths (Table 2A-D). This result was expected, mainly due to location of Fairway 1 on a slope. In fact, water runoff might occur during precipitation and irrigation, resulting in reducing the amount of water penetrating deeper into the soil profile. Though seasonal variations existed, the general trend of SWC among plots persisted throughout the season. For both fairways, plot 1 exhibited the highest SWC levels. The SWC levels of fairway 1 appeared to be decreased with each consecutive plot position further away in proximity from the cart path, in which plot 5 and 6 had the lowest SWC with little seasonal fluctuation. Although these plots were not adjacent to the central drainage system, the drainage pattern of water from these plots was similar to those plots close to the drainage system due to subterranean sand layers. Overall, the SWC was higher in fairway 10 when compared with fairway 1. Generally, the SWC levels showed reductions as plot positions became further away from cart path side of fairway as was seen in fairway 1. This variation

Table 2. Basic descriptive statistics of soil water content (SWC) at Heritage fairway 1 at the 15 and 30 cm depths (labeled as A and B, respectively) and fairway 10 at the 15 and 30 cm depths (labeled as C and D, respectively). (Percentage expressed in decimal format).

			A			
Plot	1	2	3	4	5	6
Mean	0.47	0.46	0.36	0.37	0.29	0.31
Standard Deviation,	0.20	0.06	0.05	0.05	0.05	0.05
Coefficient of Variation	2.85	0.13	0.15	0.14	0.18	0.15
			B			
Plot	1	2	3	4	5	6
Mean	0.46	0.41	0.28	0.28	0.30	0.27
Standard Deviation,	0.10	0.05	0.06	0.04	0.04	0.04
Coefficient of Variation	0.21	0.11	0.20	0.15	0.13	0.15
			C			
Plot	1	2	3	4	5	6
Mean	0.49	0.39	0.37	0.38	0.39	0.43
Standard Deviation,	0.07	0.06	0.06	0.07	0.06	0.05
Coefficient of Variation	0.15	0.17	0.17	0.19	0.15	0.11
			D			
Plot	1	2	3	4	5	6
Mean	0.20	0.36	0.40	0.39	0.38	0.44
Standard Deviation,	0.21	0.05	0.05	0.06	0.05	0.07
Coefficient of Variation	1.08	0.14	0.13	0.16	0.12	0.15



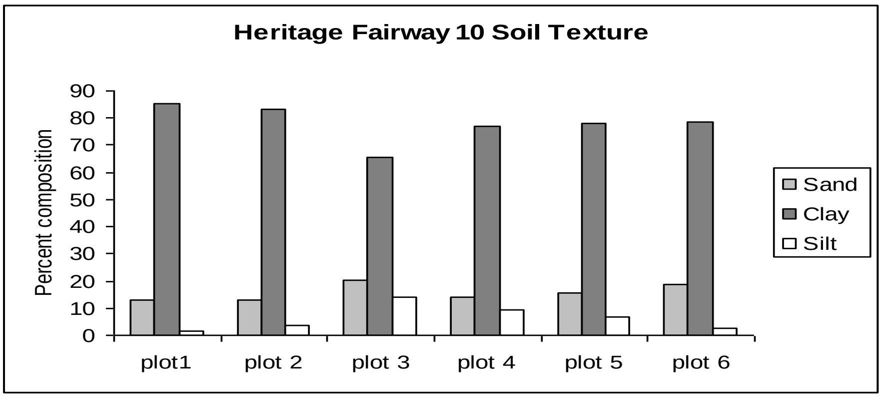


Fig 2. The Heritage fairway 1 and 10 soil texture data. Texture analysis by rudimentary jar tests.

in soil water contents could be attributed to the difference in the clay contents of plots (Fig. 2). The high SWC could be a reflection of poor drainage. In April and October of 2009, the study site experienced higher than average precipitation (Fig. 3). The study results agree with those of Qian and Mecham (2005) who reported that changes in soil chemistry might be accompanied by changes in soil physical properties; thus, affecting the soil water contents.

Turf Quality

In this study, the turf quality was measured visually on a scale of 1 to 10, accounting for color, density and uniformity. The results of this study indicated that turf quality was higher in plots with high SWC than those with low SWC for fairway 1 (Fig. 4). The low turf quality rating within plots with low SWC may be explained by the negative impacts resulted from of the deficiency of soil water content.

Table 3. SAS Pearson Correlation of measured variables for (A) Heritage fairway 1 and (B) Heritage fairway 10. Correlation variables examined were electrical conductivity, soil water content, compaction, percentage of sand, percentage of silt and percentage of clay.

(A)	Heritage Fairway 1 Pearson Correlations					
	Salinity (EC)	SWC	Comp.	% Sand	% Silt	% Clay
Salinity (EC)		0.76**	-0.35	-0.63*	-0.18	0.57
SWC			-0.32	-0.76**	-0.51	0.82**
Comp.				0.38	0.31	-0.40
% Sand					0.32	-0.85**
% Silt						-0.76**

(B)	Heritage Fairway 10 Pearson Correlations					
	Salinity (EC)	SWC	Comp.	% Sand	% Silt	% Clay
Salinity (EC)		0.73**	-0.25	0.02	-0.32	0.22
SWC			-0.38	0.05	-0.41	0.27
Comp.				-0.22	0.25	-0.05
% Sand					0.51	-0.78**
% Silt						-0.94***

*, ** And *** Significance level at <0.05, 0.01 and 0.001, respectively.

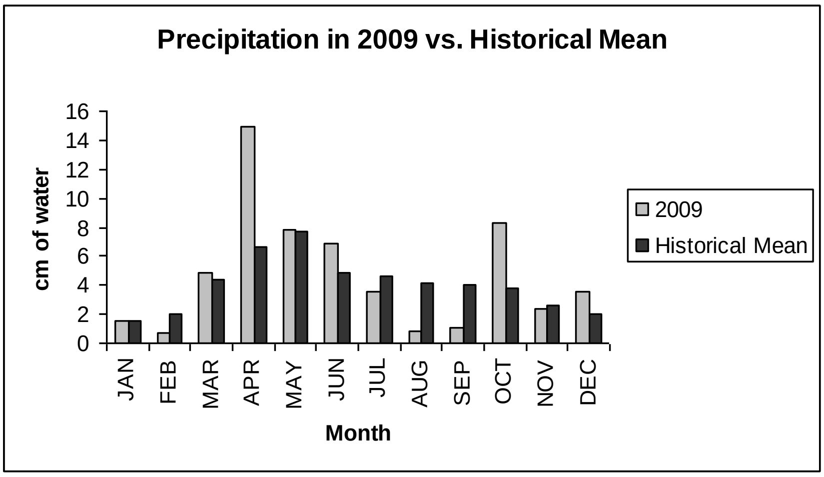


Fig 3. Monthly 2009 precipitation amounts versus historical monthly mean precipitations. Data compiled from National Oceanic and Atmospheric Administration Lab (NOAA) in Boulder Colorado. Historical Mean for years 1893-2008.

Because application of less irrigation water will allow more salt accumulation in soil profile; thus, it adversely affect the growth and turf quality due to high salt stress. Those plots with lower average quality within fairway 10 (Fig. 4) did not have significantly lower SWC in comparison to those with higher quality (plots 1-3 and 6).

Soil moisture data from fairway 10 indicates that SWC across all plots rarely dropped to 20-25%. Only in pre- and post- season SWC reached levels as low as 20-25%. Poor drainage and low hydraulic conductivity are most likely the cause of limited SWC fluctuation.

Soil compaction

Average compaction values appeared to be greater at 30 cm depth than 15 cm below soil surface for both fairways (Fig. 5). The plots at the far edge of fairway 1 showed the greatest compaction at the 30 cm depth. Overall, there were no significant differences in soil compaction between the studied plots of fairway 10.

In addition, the relationship between compaction and salinity accumulation was not significant in this study. The poor relationship might be due to the application of less irrigation water and the soil compaction did not affect the soil infiltration. In contrast to our findings, other researchers reported that upward movement of water increased as surface layer bulk densities became greater (Affleck, 1980). Miyamoto and Chacon (2006) also found that compacted soil was more prone to salinity accumulation due to reduced leaching effectiveness.

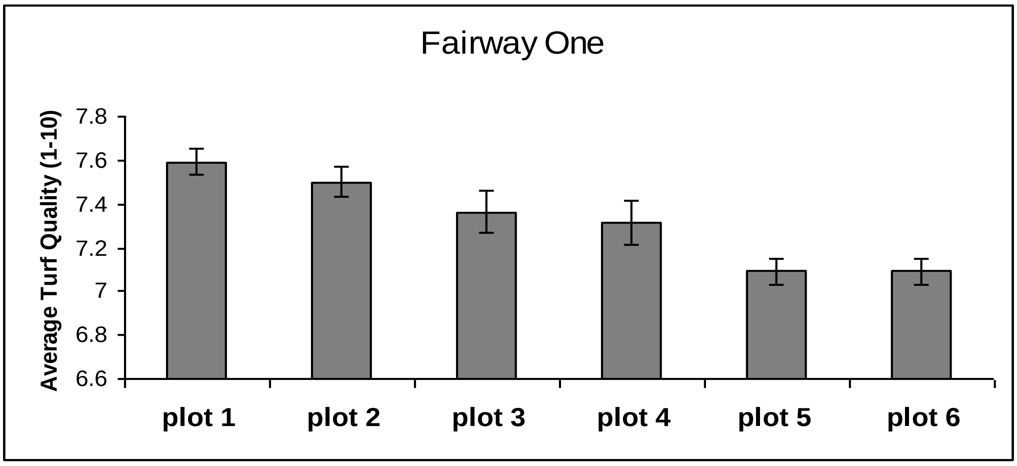
Pearson correlation

Strong correlation was found between soil salinity and soil water content (SWC) for both fairways (Table 3 A and B). The plots with high soil salinity showed high SWC. Soil with higher clay content would result in greater soil water retention, exhibiting higher soil water content. This relationship was only observed in fairway 1.

In fact, the degree of difference in soil texture is much smaller than the degree of difference in soil water content in Fairway 10 (Table 1 A-D and Table 2A-D). Based on the obtained data, it can be suggested that poorly drained sites are less effectively leached, maintained high soil water content, and are prone to long-term soil salinity build up. Salinity can vary widely across a seemingly homogenous golf course fairway in a manner reflective of the underlying soil physical characteristics. Our data indicated that the level

Table 4. Basic descriptive statistics of soil salinity at the 8 (A) and 19 (B) cm depths at Common Ground Golf Course.

A						
Sensor	1	2	3	4	5	6
Fairway	1	1	1	19	19	19
Mean	2.1276	3.2627	0.4442	8.4765	6.3185	4.8810
Standard Deviation,	0.5901	0.9556	0.0521	2.0367	1.4635	0.8961
Coefficient of Variation	0.2773	0.2929	0.1172	0.2403	0.2316	0.1836
B						
Sensor	1	2	3	4	5	6
Fairway	1	1	1	19	19	19
Mean	1.3451	1.9686	0.3825	2.7879	3.4253	5.4114
Standard Deviation,	0.3344	0.3148	0.0303	0.5272	0.2358	0.4481
Coefficient of Variation	0.2486	0.1599	0.0793	0.1891	0.0688	0.0828



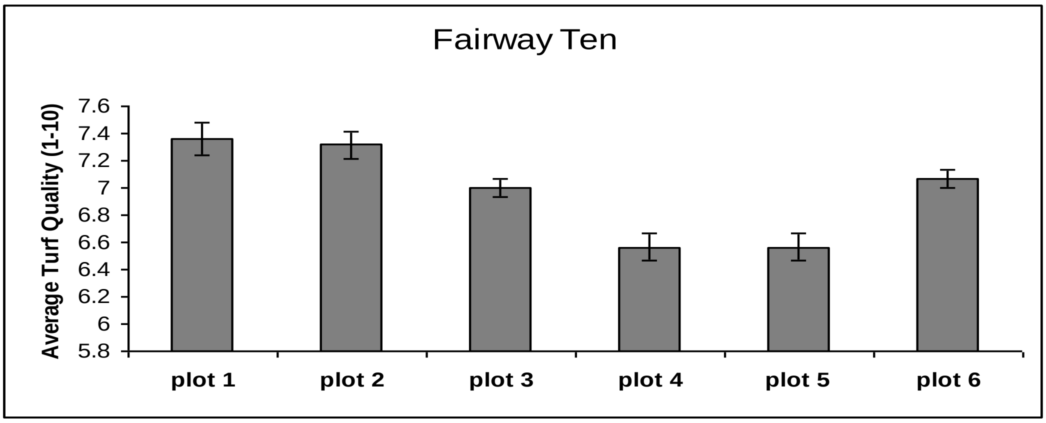


Fig 4. Turf quality data for The Heritage Golf Course sensor equipped plots. Turf quality was measured visually on a scale of 1-10 accounting for color, density and uniformity. Readings were recorded every two weeks from June through September 2009. Bars indicate standard error for each plot position.

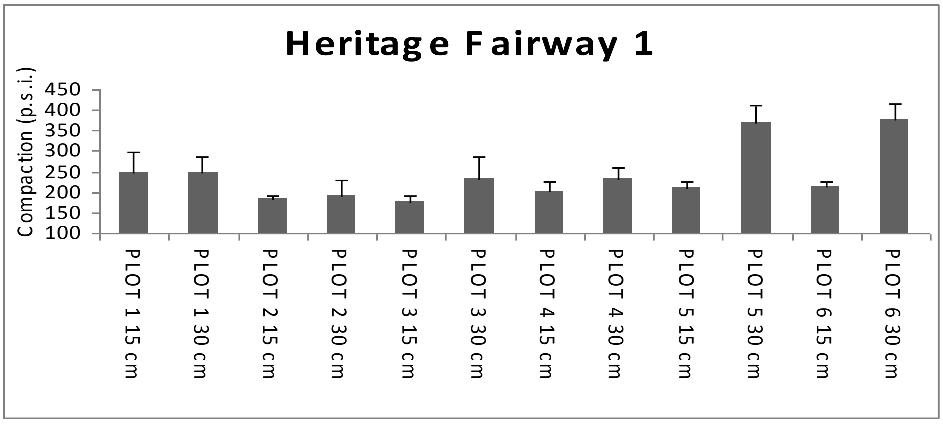
of soil salinity appears to be related to soil texture and soil water content (drainage effectiveness).

Common ground golf course spatial and temporal salinity patterns on fairways

Soil salinity at 8 cm depth ranged from 2 to 6 dS m^{-1} for Fairway 1 and from 4.5 to 10.6 dS m^{-1} for Fairway 19 (Table 4 A). Fairway 1 exhibited change of soil salinity in response to irrigation events at both depths. High soil salinity was observed at shallow depths (8 cm) than at deeper depths (19 cm) for Fairway1 (Table 4 B).The reason for high soil salinities at Common Ground when compared to Heritage is mainly due to the sensors being installed at shallow soil depths (8 and 19 cm vs. 15 and 30 cm). The study findings agree with those of Devitt et al. (2007) who reported that surface soil layers are dynamic, transient and complex in nature especially with regards to salinity. High salinity was found on Fairway 19. Fairway 19 is located at a corner of the property, in an area known to be salt prone prior to renovation. Soil texture analysis (Jar-test) showed that the clay contents were 79 % and 82 %, respectively in fairway No 1 and 19 as shown in (Fig. 7). Common Ground Golf Course

Table 5. Basic descriptive statistics of SWC at the 8 (A) and 19 (B) cm depths at Common Ground Golf Course.

A						
Sensor	1	2	3	4	5	6
Fairway	1	1	1	19	19	19
Mean	29.3486	31.5412	41.2464	30.4650	31.1516	29.1816
Standard Deviation,	4.0982	3.4713	2.0996	0.7326	1.8750	0.8002
Coefficient of Variation	0.1396	0.1101	0.0509	0.0240	0.0602	0.027
B						
Sensor	1	2	3	4	5	6
Fairway	1	1	1	19	19	19
Mean	24.7879	28.9071	10.4934	29.2948	29.8895	N/A
Standard Deviation,	3.6313	1.1560	7.5570	1.6487	0.5999	N/A
Coefficient of Variation	0.1465	0.0400	0.7202	0.0563	0.0201	N/A



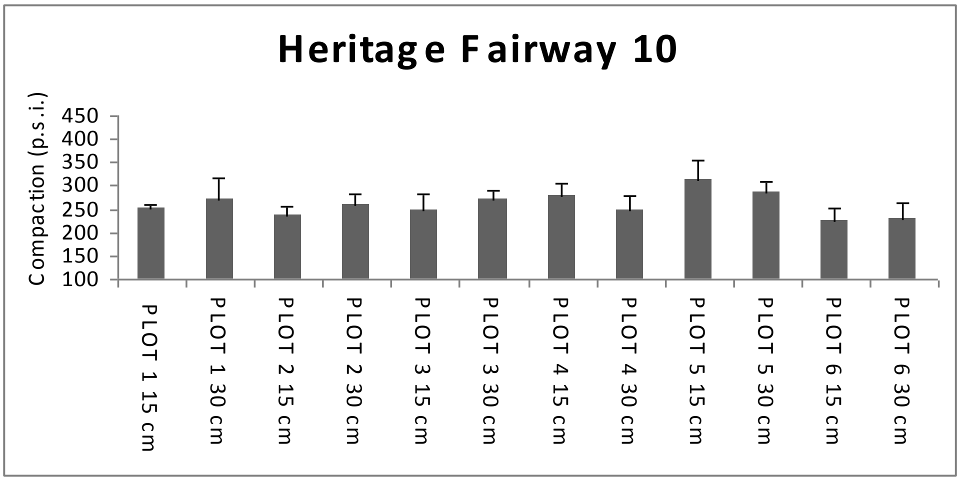


Fig 5. Average soil compaction (ASC) data for sensor equipped plots at Heritage. Bars indicate standard error for each plot position over two depths.

was transitioned to use recycled wastewater in 2009. Depression areas and areas lacking natural subsurface drainage to the underground water are more prone to salinity degradation. Salinity accumulation patterns from the transitional course reflect changes in response to irrigation application events. The majority (83 %) of Common Ground plots had higher soil salinity at the 8 cm depth than at the 19 cm depth (Table 4 A and B). Field mapping of soil moisture, salinity, compaction and turf grass quality has been explored in an attempt to quantify the variability of field conditions and its inventory (Carrow et al., 2009). The mapping efforts were aimed to identify management zones within a single golf course that would warrant variable precision management strategies, specifically precision salinity and irrigation management.

The Center for Advanced Turf Technology of Toro has developed precision tools and technologies to better manage substantial variations in salinity. Salinity of fairway soils is of particular importance with regard to effluent water irrigated golf courses because salinity levels can become elevated enough during peak summer months (Carrow et al., 2009). The pattern of salinity accumulation from both the established effluent irrigated course and the newly effluent irrigated course have similarities. Salinity trends from both sites show an ebb and flow type of pattern over time as effluent water irrigation is applied in staggered applications. The dynamic nature of these salinity accumulations under

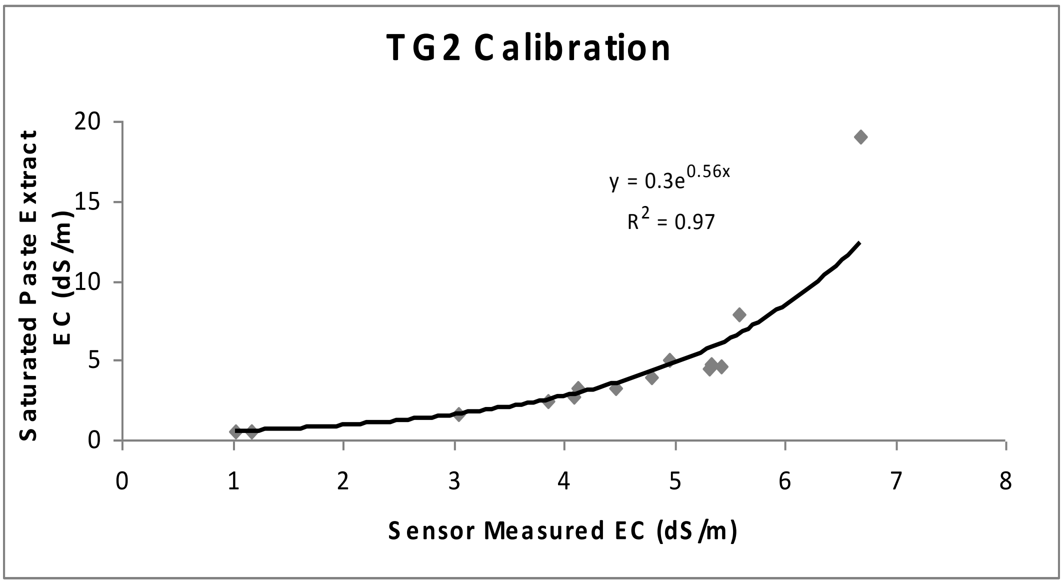
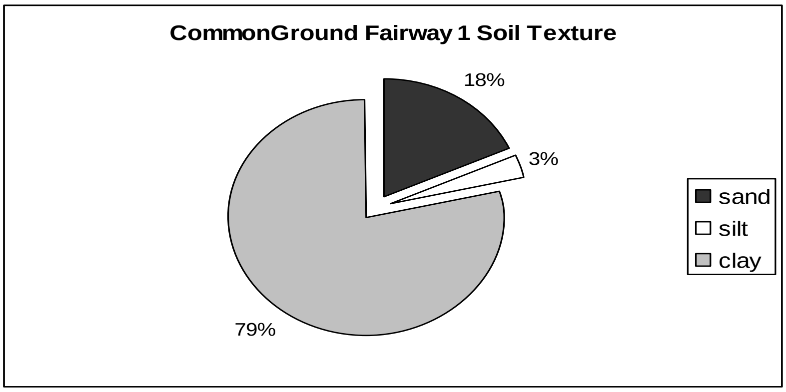


Fig 6. Non-linear regression of sensor measured electrical conductivity (EC) and conventional saturated paste extract electrical conductivity (EC).



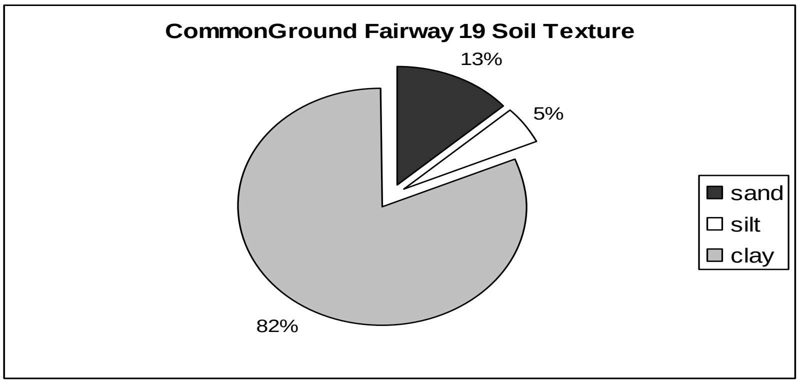


Fig 7. Common Ground fairway 1 and 19 soil texture data. Texture analysis by rudimentary jar tests.

effluent water irrigation complicates the management strategy for maintaining turf health. Clay soil's resistance to effective leaching is partially attributed to poor drainage characteristics.

Soil water content

Soil water content (SWC) data from Fairway 1 indicated that SWC at 8 cm fluctuates in response to staggered irrigation applications (Table 5 A and B). Soil water content at the 20cm depth showed a seasonal reduction. The SWC of Fairway 19 had less fluctuation between the sensors until around September-October when reduced irrigation inputs significantly reduced soil water content (Table 5 A and B). Fairway 19's soil moisture data lacking any fluctuation may indicate significant differences of the hydrological characteristics between fairways 1 and 19.

The fluctuation of the SWC helps in the gas exchange process of the soil with the addition of fresh oxygen (O_2) and the expulsion of carbon dioxide (CO_2) produced by the plant roots and microbes.

Materials and Methods

Heritage golf course

The geographical location of Heritage Golf Course in Westminster, Colorado is 39º 53' 59.34" N and 105º 07' 00.04"E located north of metro Denver near the foothills. The principal soil series found from the previous study included Renohill, Ulm and Platner (Qian and Mecham, 2005). Two perennial ryegrass fairways were selected, named as fairway 1 and fairway 10. Within these two fairways individual sensors were installed along transects of uniform turf quality with little undulation. Individual transects were 27.4 meters in length, with a total of six plots spaced at 4.5 meter intervals apart. At each plot two 5TE sensors manufactured by Decagon Devices were installed into an undisturbed soil profile at depths of 15 and 30 cm below the soil surface. The 5TE was the latest in Decagon's ECH2O®-TE sensor series. The 5TE simultaneously monitored soil water content, soil salinity, and soil temperature. Volumetric soil water contents were measured using dielectric permittivity of the media adjacent to the prongs. Bulk soil electrical conductivity was measured by a resistance reading via an alternating current applied to a two probe array. The soil temperature was measured by a thermistor housed in the sensor body.

Wire leads from each sensor were contained within subsurface conduit and connected to a data logger (Campbell Scientific CR1000 unit) located at the edge of the fairway. Data logging units ran a program that record soil salinity, soil water content, and soil temperature three times daily (6 AM, 2 PM and 10 PM). Data loggers were accompanied by a multiplexing unit (Campbell Scientific AM16/32B) and a 12 volt 7.5 amp hour DC battery that was regularly rotated with a freshly charged unit. Installation of sensors was completed in June of 2008. Data logging equipment was removed from the site just before the most extreme months of winter in an attempt to prolong usable investigation lifetime. Data collection on fairways started in August 2008 and concluded in December 2009.

Laboratory calibration 5TE

Strong linear correlation was observed between 5TE sensor-measured soil salinity versus saturated paste extracted soil salinity (Fig. 1), suggesting that these sensors could be accurate in monitoring the real-time soil salinity. 5TE sensor-measured soil electrical conductivity (EC) was compared to conventional saturated paste extracted soil EC to assess data accuracy. Conventional measurement of soil salinity utilizes the electrical conductivity of an extract from a saturated soil paste made using distilled water (U.S. Salinity Laboratory Staff, 1954). Soils with various salinity levels were used for the test ranging from less than 1 dS/m in conductivity up to soils with as high 20 dS m^{-1} of conductivity. Soil samples with known salinities were utilized and blended by hand to create the range of salinity values. A total of 15 sensors were placed in the experiment for in-situ measurement of soil salinity. The sensor measured salinity was taken by placing sensors into a soil sample of approximately 2464 cm³ in volume equal to about 3.70 kg of soil having moisture content in the range of 30-40% by volume and compacted manually to a range of 95-105 psi. A total of 22 sensor readings were then taken by running the CR1000 5TE monitoring program used in the field and the soil directly surrounding the sensors prongs (72cm³) was then removed for saturated paste extraction.

Soil texture

Measurements of soil compaction and texture were taken from the sensor equipped plots on both fairways. Compaction was measured using a digital penetrometer (Field Scout SC-900) periodically during the 2009 growing season. Compaction readings were recorded from surface depths down to 30 cm for the profiles directly adjacent to the sensor installation points for each plot. Texture analysis consisted of a rudimentary jar test for quantifiable percent compositions (Sammis, 1996) and field ribbon-feel tests.

An irrigation audit was performed on each fairway's study location in early April 2009. Irrigation distribution uniformity was measured by auditing with 126 cups on 1.5 meter grid with 10 minute run times. Distribution Uniformity (DU) was calculated as: DU = (average water output of the low quarter / average water output) x 100%.

Turf quality

Turf quality was visually rated on a 1 to 9 scale, with 1 being dead, 9 being dark green, dense, and actively growing turf, and 6 being acceptable turfgrass quality. Quality was rated 11 times with approximately two weeks between readings from mid-June until September.

Common ground golf course

The Common Ground Golf Course situated at 39º 42' 53.88" N and 104º 52' 09.11" E in Aurora, Colorado was renovated in 2008. Prior to renovation Common Ground Golf Course was using municipal potable water to irrigate turf. Included in the renovation was a transition to municipal effluent water for irrigation. The course reopened at the start of the 2009 golfing season.

Toro Turf Guard Dual Level (TG2) sensors use principles of soil permittivity and frequency response to measure soil water content and salinity of soils. The theory and principles of using permittivity and frequency response to measure soil salinity have been well researched and proven effective with early work being done in the 1970's by Rhoades and Ingvalson (1971). TG2 sensors use this established method of measurement to simultaneously measure soil water content and soil salinity. The sensors collect data every five minutes. The resolution of the sensors is within 0.1% for all three readings of temperature, EC (dS/m) and SWC. Using two sets of three prongs (6.4 cm x 0.48 cm) positioned 11 cm apart along a body, the sensor can conduct measurements at 2 depths simultaneously cm). The sensor body contains a battery (3-year expected lifetime), the components to produce and monitor a generated frequency along with communication components for radio frequency data acquisition. Data on soil water content, salinity, and soil temperature is relayed by a radio frequency mesh network. The RF mesh network requires signal repeaters and a base-station with broadband internet connectivity. The number of repeaters required is dependent on terrain or obstacles to signal transmission. The station uploads the data to the Golf Vision Interface.

In July 2009 a total of six Toro Turf Guard Dual Level (TG2) sensors were installed into two Kentucky bluegrass, Annual bluegrass and Perennial ryegrass fairways at the newly renovated Common Ground Golf Course. Three sensors were placed approximately 31 meters apart along the length of fairway 1. Common Ground fairway 1 is situated within an area not previously used as a playable area. Another three sensors were installed into Common Ground fairway 19 within the short course. These sensors were positioned 3 meters apart. Fairway 19 is located in a corner of the property known to be salt prone prior to renovation. All installed sensors monitor soil EC, soil water content and soil temperature at 7.6 and 19.1 cm below the soil surface. Soil texture was analyzed by a rudimentary jar test for quantifiable percent compositions (Sammis, 1996).

Laboratory calibration of 5TE and TG2

In order to calibrate TG2, a total of 13 soil samples with known salinities were utilized and blended by hand to create the range of salinity values. TG2 sensors were placed into samples of soil with moisture content around 30-40% by volume and manually compacted to a range of 95-105 psi. Sensor readings were then taken using a single base station with no repeaters. After the sensor measurement was taken, the portion of soil immediately surrounding the prongs (82 cm^3) was prepared into a saturated paste and put under a vacuum to collect an extract sample.

A regression analysis was run between the soil salinity data obtained by sensors and the conventionally measured salinity to assess the accuracy of sensor measurement. Laboratory testing indicated that Turf Guard sensors-measured soil salinity showed very strong exponential relationship with the conventional saturated paste extracted EC (Fig. 6).

Statistical analysis

Pearson Correlations namely correlation coefficient (r), coefficient of variation (CV) and Coefficient of determination (R^2) were performed using SAS version 9.2 statistical software to determine the relationship among various parameters such as electrical conductivity, soil water content, compaction, sand percentage, silt percentage, clay percentage and descriptive statistics. Proc Means procedure of SAS was used to determine descriptive statistics including mean, standard deviation, and coefficient of variation.

Conclusions

Salinity accumulations within a single fairway are highly variable and fluctuate seasonally. In this study, the variations observed were partially attributed to soil texture, soil water content, and drainage effectiveness. The relationship between soil salinity and compaction were not significant. The highest soil salinities for the transitional course were observed within fairway 19, which was also high in SWC. There is a significant relationship between SWC and soil salinity under effluent water irrigation. The high SWC throughout the season are associated with high average soil salinity.

Drainage appears to be vital in maintaining low soil salinity levels under effluent irrigation in clay soils. Proper planning, adaptations and cultural practices can help to mitigate some of the negative issues associated with effluent water irrigation. Drainage could be aided by the installation of multiple drain tiles at both the edges and center of fairways. It can be concluded that provision of adequate drainage network in predominantly clay soils, irrigated with effluent water, could better manage salinity accumulation. The salinity variations on golf courses may be managed by modern precision technology.

Acknowledgments

Authors acknowledge The United States Golf Association and the Colorado Agricultural Experimental Station (Projects 658) for their support.

References

Affleck SB (1980) Moisture flow optimization in porous media for land leaching and for seedbed design. Ph.D. thesis. Iowa State Univ. Ames.

Asano T (1987) Wastewater Reclamation and Reuse. Geo J. 15(3):273-282

Bishop D (1990) Some basic considerations in using effluent water. Golf Course Manage. 58(5):28-34

Brown JW, BernsteinL (1953) Salt tolerance of grasses. Effects of variation in concentration of sodium, calcium, sulfate and chloride. Report to Collaborators. U.S. Salinity Lab., Riverside, CA.

Carrow R (2006) Can we maintain turf to customers' satisfaction with less water? Agric Water Manage. 80: 117–131.

Carrow RN, HuckM, Duncan RR (2000) Leaching for salinity management on turfgrass sites. USGA Green Section Record 38 (6):15-24. (TGIF Record 70760)

Carrow RN, Krum JM, Flitcroft I, Cline V (2009) Precision turfgrass management: Challenges and field applications for mapping turfgrass soils and stress. Precis Agric. DOI 10.1007/s11119-009-9136y

Coppola A, Santini A, Botti P, Vacca S, Comegna V, Severino G (2004) Methodological approach for evaluating the response of soil hydrological behavior to irrigation with treated municipal wastewater. J Hydrology. 292:114–134.

Devitt DA, Lockett M, Morris R, Bird B (2007) Spatial and temporal distribution of salts on fairways and greens irrigated with reuse water. Agron J. 99:692–700.

Devitt DA, Morris R, Kopec D, Henry M (2004) Golf course superintendents attitudes and perceptions toward using reuse water for irrigation in the southwestern United States. Hort Technology. 14(4):1–7.

Ghassemi F, Jakeman AJ, Nix HA (1995) Salinisation of Land and Water Resources. CAB International, Wallingford, UK. 526 pp.

Kotuby-Amacher J, Koenig R, Kitchen B (2000) Salinity and plant tolerance. Utah State University Cooperative Extension Publication AG-SO-03.

Lazarova V, Asano T (2004) Challenges of sustainable irrigation with recycled water. In: Lazarova, V., Bahri, A. (Eds.), Water Reuse for Irrigation: Agriculture, Landshapes, and Turf Grass. CRC Press, Boca Raton, FL, pp.1-30.

Lockett AM, Devitt DA, Morris RL (2008) Impact of Reuse Water on Golf Course Soil and Turfgrass Parameters Monitored Over a 4.5-Year Period. Hort Sci 43(7):2210–2218.

Mancino CF, Pepper IL (1992) Irrigation of turfgrass with secondary sewage effluent-soil quality. Agron J. 84: 650–654.

Marcum KB (2006) Use of saline and non-potable water in the turfgrass industry: Constraints and developments. Agric Water Manage. 80:132–146.

Miyamoto S, Chacon A(2006) Soil salinity of urban turf areas irrigated with saline water: II. Soil factors. Landscape and Urban Planning 77: 28–38.

NOAA (2010) NCAR Boulder Foothills Lab. Boulder, Colorado Climate and Weather Data, Monthly Precipitation from 1893 to Feb 2010 <http://www.esrl.noaa.gov/psd/

boulder/Boulder.mm.precip.html> [verified 26 April 2010]

Pereira LS, Oweis T, Zairi A (2002) Irrigation management under water scarcity. Agric Water Manag. 57:175–206.

Pessarakli M, Szabolics I (1999) Soil salinity and sodicity as particular plant/crop stress factors. In: Pessarakli, M. (Ed.), Handbook of Plant and Crop Stress. second ed. Marcel Dekker, New York, NY, pp. 1–16.

Qian YL, Wilhelm SJ, Marcum KB (2001) Comparative responses of two Kentucky bluegrass cultivars to salinity stress. Crop Sci. 41; 1890–1895.

Qian YL, Mecham B (2005) Long-term effects of recycled wastewater irrigation on soil chemical properties on golf course fairways. Agron J. 97: 717-721.

Rhoads JD, Ingvalson RD(1971) Determining salinity in field soils with soil resistance measurements. Soil Sci Soc Am Proc. 35:54-60.

Sammis T (1996) Soil Texture Analysis. New Mexico State University. <http://weather.nmsu.edu/teaching_Material/soil456/soiltexture/soiltext.htm>

Thomas JC, White RH, Vorheis JT, Harris HG, Diehl K (2006) Environmental impact of irrigating turf with type I recycled water. Agron J. 98:951–961.

Toze S (2006) Reuse of effluent water-benefits and risks. Agric Water Manage. 80:147–159.

U.S. Golf Association (1994) Wastewater reuse for golf course irrigation. Lewis Publishers, New York, NY.

U.S. Salinity Laboratory Staff (1954) Diagnosis and improvement of saline and alkali soils. USDA Handbook. 60. U.S. Gov.