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Varying evapotranspiration and salinity level of irrigation water influence soil quality and performance of perennial ryegrass (*Lolium perenne* L.)☆

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ABSTRACT

Increasing use of recycled water that is often high in salinity warrants further examination of irrigation practices for turfgrass health and salinity management. A study was conducted during 2011–2012 in Riverside, CA to evaluate the response of perennial ryegrass (*Lolium perenne* L.) 'SR 4550' turf to varying quality and quantity of irrigation water. A modified line-source sprinkler irrigation system provided a salinity gradient (EC_w ~0.6–4.2 dS m^{-1}) in between lines. Irrigation was scheduled in four separate irrigation zones perpendicular to the irrigation lines according to 80, 100, 120, and 140% ET_o. Changes in turf quality ($R^2 = 0.30^{***}$), were primarily driven by the number of days that the area had been irrigated with saline water. When data were separated by irrigation amount, both time and water quality accounted for 54% and 46% of the variability ($P < 0.001$) in quality and cover, respectively at 80% ET_o. A model was created to quantify decline in turf quality in relationship to %ET_o replacement and salinity accumulation in the rootzone ($R^2 = 0.57$). Our results suggest that perennial ryegrass requires irrigation scheduling at 140% ET_o, irrigation water quality below EC_w ~1.7 dS m^{-1}, and EC_e below 3.8 dS m^{-1} to maintain acceptable quality for 442 d in Riverside, CA.

Extended drought and increasing urban development in California and other arid and semi-arid regions of the southwestern USA continue to put pressure on already diminishing potable water resources, especially for landscape and turfgrass irrigation. Since January 2010, all municipalities in California have been required to adopt a water efficient landscape ordinance in an effort to conserve water (California Model Water Official Landscape Ordinance, 2009). Using alternative sources of water for irrigation is one solution to limit the strain on fresh water resources. Recycled water, also known as effluent, reuse, reclaimed, or wastewater has become an increasingly common and necessary resource for irrigating larger turf areas. It was estimated that more than one-third of golf courses in the southwestern United States use recycled water for irrigation (Throssell et al., 2009). Moreover, rapidly depleting potable water resources from groundwater in the desert region are forcing the 124 golf courses in California's Coachella Valley to explore and expand recycled water for turf irrigation in addition to other sources such as the Colorado River (James, 2013). Previous research has demonstrated that agricultural crops and turfgrass can be irrigated with recycled water if proper management practices are implemented (Rhoades et al., 1989; Dean et al., 1996; Dean-Knox et al., 1998; Leskys et al., 1999; Schiavon et al., 2014a, b).

Increased levels of soluble salts, especially sodium (Na), are commonly found in recycled water and can be toxic to plants at high concentrations and detrimental to soil structure. The most common management practice for high salinity is to apply a leaching fraction, whereby water exceeding plant evapotranspiration is applied to move salts below the root zone, maintaining soil salinity at a level that does not adversely impact turf quality. Current leaching requirements for turf assumes that plant response to salinity is represented only by average root zone salinity without taking in consideration irrigation requirements for different species (Ayers

Abbreviations: EC, electrical conductivity; EC_e, electrical conductivity of the soil saturation extract; EC_w, electrical conductivity of water; ET_o, reference evapotranspiration; LSIS, line-source irrigation system; SAR, sodium absorption ratio; Na, sodium content; Kc, crop coefficient; r, correlation coefficient; R^2, coefficient of determination.

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and Westcot, 1985; Carrow and Duncan, 1998). However, soil and water dynamics in plant systems change through time, reflecting seasonal changes in rainfall and irrigation.

Conservation of water, even recycled water from a budgetary standpoint is not only important for resource management but also for maintaining quality turf, aesthetic value, and playing conditions. One limiting factor for the application of reduced water, especially under salt-affected conditions, is the omnipresence of cool-season turfgrasses on golf courses, athletic fields, public green space, and residential lawns in California. In general, cool-season species require more water and are less tolerant to salinity to sustain growth and quality relative to warm-season species (Biran et al., 1981; Carrow and Duncan, 1998; Gibeault et al., 1985). For example, perennial ryegrass is considered only moderately tolerant to soil salinity (EC_e), ranging from 4 to 8 dS m^{-1} (Harivandi et al., 1992).

Salinity tolerance among cool-season species can vary greatly (Carrow and Duncan, 1998). Alshammary et al. (2004) ranked the warm-season species saltgrass (*Distichlis spicata* L.) as being the most tolerant to salinity at 34.9 dS m^{-1}, compared to cool-season species: alkaligrass (*Puccinellia distans* L.) at 20 dS m^{-1}; tall fescue (*Festuca arundinacea* Schreb.) at 10.0 dS m^{-1}; and Kentucky bluegrass (*Poa pratensis* L.) at 4.9 dS m^{-1}. Salinity tolerance among cultivars can also vary. In a greenhouse study, 32 perennial ryegrass cultivars and three intermediate hybrids of perennial ryegrass and annual ryegrass (*Lolium multiflorum* Lam.) were evaluated for salinity tolerance in terms of shoot growth reduction, root weight, and visual quality under a 6 dS m^{-1} salt solution for a 6-wk period (Marcum and Pessarakli, 2010). The authors found that the perennial ryegrass cultivar Paragon exhibited the highest salt tolerance, sustaining 67% green leaf area after 6 wk in comparison to remaining cultivars. Intermediate hybrid cultivars ranked lowest in salt tolerance, dying after 3 wk in the salt solution. These experiments evaluated plant response to salinity and drought under controlled greenhouse conditions, making it difficult to predict plant response in the field.

Plant responses to heat, drought and salinity are complex and thus research is limited, especially for turfgrass and perennial ryegrass in particular. The objectives of this study were to evaluate the interactions of irrigation water quality, quantity, and soil salinity on perennial ryegrass turf quality to predict more accurately leaching requirements for salinity management.

1. Materials and methods

A study was conducted for 442 d from 21 July 2011–5 October 2012. Inland Mediterranean climates like Riverside, CA are characterized by warm, dry summers with most of the annual precipitation occurring during the winter months. Mean annual rainfall, ET_o, and air temperature from 2001 to 2010 were 207 mm, 1440 mm, and 17.6 °C, respectively (CIMIS, 2013). Soil was a Hanford fine sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerothents). In July 2011 prior to the start of the experiment, average soil EC_e, SAR, and [Na] were 1.2 dS m^{-1}, 1.8, and 86 mg L^{-1}, respectively.

A modified line-source experiment (Frenkel et al., 1990 Royo and Aragües, 1999; Singh et al., 2009; Smeal et al., 2005) was constructed on a 27 by 36-m area (Fig. 1). Four irrigation lines spaced 9 m apart alternated between distribution of potable and saline water to establish an irrigation salinity gradient (EC ~ 0.6 to 4.2 dS m^{-1}) in between lines. Potable water originated from the San Bernardino and Riverside Basins, while saline water was made by mixing salts in potable water within two 19000-L storage tanks (Snyder Industries, Inc., Lincoln, NE) containing submersible pumps for mixing and agitation (Table 1). Saline water ion composition was based on Colorado River water (personal communication, D.L. Suarez) and contained elevated concentrations of salts including Na^+, Cl^-, and SO_4^{2-} but not HCO_3^- and CO_3^{2-}. Total salinity of the water was chosen to simulate an extreme, but realistic irrigation salinity for turf in California (M. Huck, personal communication).

Table 1
Properties of saline and potable irrigation water used in the line-source gradient study in Riverside, CA.

Properties	Potable	Saline
pH	7.8	7.6
EC, dS m^{-1}	0.6	4.4
TSS, mg L^{-1}	390	2835
SAR, meq L^{-1}	3.2	18.3
Na^+, mg L^{-1}	53	524
K^+, mg L^{-1}	4	130
Ca^{2+}, mg L^{-1}	66	126
Mg^{2+}, mg L^{-1}	12	152
Cl^-, mg L^{-1}	31	996
NO_3^--N, mg L^{-1}	5.2	5.1
HCO_3^-, mg L^{-1}	215	210
CO_3^{2-}, mg L^{-1}	0.01	0.01
SO_4^{2-}, mg L^{-1}	78	708
B, mg L^{-1}	0.08	0.11

The study area was divided into four separate irrigation zones for different ET_o levels, each controlled by a separate valve interfaced to a central irrigation controller (Fig. 1). Each zone was irrigated independently by the four alternating irrigation line sources, further dividing the study area into twelve 9 by 9-m plots (main plots with three replicates per irrigation zone). Irrigation amounts or Kc values of 80, 100, 120, and 140% reference evapotranspiration (ET_o) were achieved by varying run times and randomly assigned to the 9 by 27-m zones. Toro 300 series pop-up stream sprinklers (Toro Company, Bloomington, MN) were installed on 9-m spacing and with a wetted radius of 9 m and operated at a pressure of 345 kPa. With the exception of the sprinklers placed in the corners of the 27 by 36-m study area, all other sprinklers irrigated at a radius of 180° to achieve desired replacement of ET_o and salinity gradient in each plot. Irrigation was applied based on the previous 7-d cumulative ET_o based on a modified Penman equation with a wind function (Doorenbos and Pruitt, 1984). Climate data to calculate ET_o was obtained from an on-site California Irrigation Management Information System (CIMIS) weather station in close proximity to the research area. The CIMIS reference crop was well-watered tall fescue turf mowed at 6 cm. The weekly irrigation amount was equally divided into seven irrigation events per week. Daily irrigation scheduling was necessary to minimize runoff and maximize infiltration. The 80 and 100% ET_o zones simulated deficit to near adequate irrigation conditions for perennial ryegrass in Riverside, CA, whereas the 120 and 140% ET_o zones simulated continuous leaching to move salts below the root zone. Each of the main plot areas was further subdivided into five 1.8 by 9-m subplots in between irrigation lines to assess turfgrass and soil responses across irrigation salinity gradient. Distribution uniformity was evaluated periodically using catch cans (54 cm^2) throughout the experiment. Irrigation water volume was collected from locations within each subplot and analyzed for salinity to establish water quality levels (EC_W) of 0.6, 1.7, 3.0, 3.5, and 4.2 dS m^{-1}. Irrigation system uniformity coefficients ranged from 0.65 to 0.80.

The area was seeded with perennial ryegrass 'SR 4550' (Seed Research of Oregon, Corvallis, Oregon) on 18 April 2011 at a rate of 22 g m^{-2} and irrigated with potable water only during establishment to ensure complete groundcover. Perennial ryegrass was used because of its sensitivity to salinity and widespread use. In California, the species is commonly used for overseeding from approximately Oct. to May (ca. 200 d) on warm-season turf or as

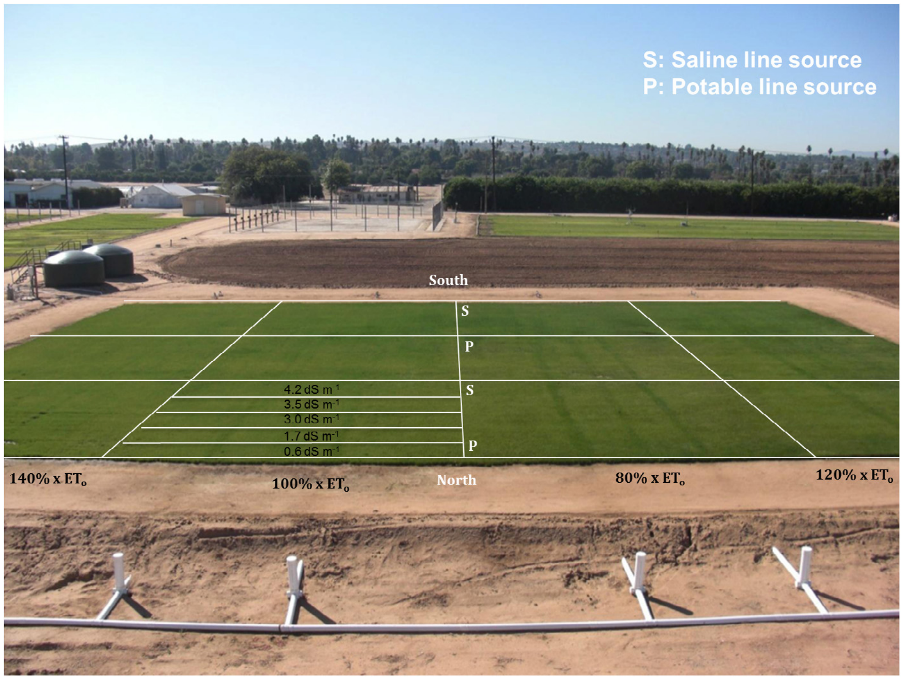

Fig. 1. Line source irrigation system used in the study area. Five salinity water quality levels (EC_w) of 0.6, 1.7, 3.0, 3.5, and 4.2 dS m^{-1}, each of 1.8 by 9-m, were detected using catch cans within each of the twelve 9 by 9-m plots [4 reference evapotranspiration (ET_o) and 3 replicates].

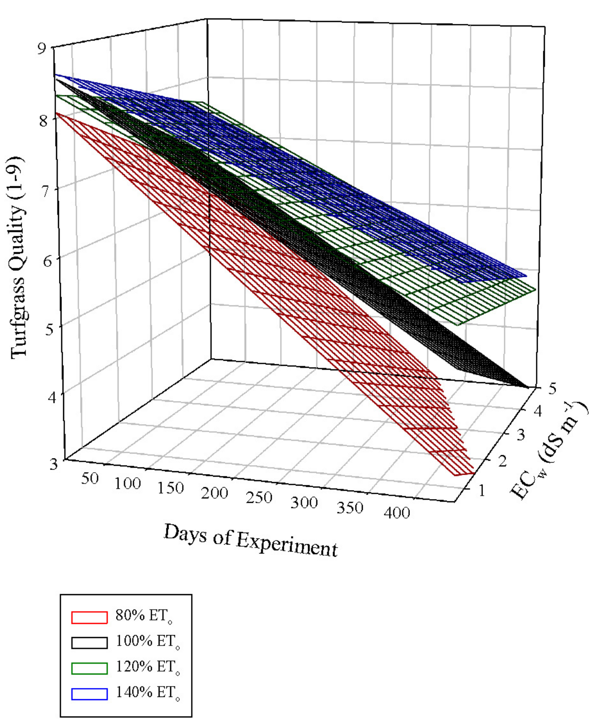

Fig. 2. Perennial ryegrass visual quality (1–9 scale, 9 = best) over time (d) for each water salinity level (EC_W) at 80, 100, 120, and 140% ET_o during the line-source gradient study in Riverside, CA.

the primary species year round on golf courses and athletic fields in cooler regions. Cultivar 'SR 4550′ was selected for its improved salinity tolerance relative to other cultivars. Turf was maintained at a height of 6 cm twice weekly using a rotary mower with clippings returned and fertilized monthly from Apr. to Oct. at 29 kg N ha^{-1} (16N-2.6P-6.6 K; Simplot, Boise, ID) throughout the experiment. Plots were mowed at 6 cm to avoid further stresses in addition to deficit irrigation and salts accumulation.

Visual assessments of turfgrass quality were evaluated at the start of the experiment and bi-weekly thereafter. Quality was evaluated by texture, color, uniformity, and density on a 1–9 rating scale (1 = dead turf, 6 = minimally acceptable, light green, thin and 9 = dark green, dense, uniform turf) (Krans and Morris, 2007). Turfgrass cover was visually estimated on a percentage scale (0% = no turf cover, and 100% = complete turf cover). Clippings were collected bi-weekly for each subplot using a walk-behind rotary mower. Clippings were dried in a forced-air oven at 85 °C for at least 24 h, and dry weight was determined. Clippings were not collected during winter months (December 2011 to February 2012) due to limited growth. Complete turf loss in the 80% and 100% ET replacement plots lead to the decision of terminating the study before the second winter. No data could have been collected on those plots. Moreover, reestablishment would have been hindered by effects of salinity on soil chemistry and structure detected at the end of the study. Composite soil samples were collected before irrigation treatments were initiated (June 2011), in October 2011 prior to the rainfall season, and in October 2012. Five soil cores were taken across each subplot at a depth of 0–10 cm using a 2.5-cm-diameter soil auger, and composited into one sample per subplot. Visual ratings of turfgrass quality were taken within a 61-cm-diam. area from which each soil sample was taken in order to minimize bias due to spatial variability. Chemical analysis of all soil samples was conducted at a commercial soil testing laboratory (AgSource Cooperative Services, Lincoln, NE). Soil solutions were extracted using distilled water to determine electrical conductivity from the soil saturation extract (EC_e), sodium absorption ratio (SAR), sodium concentration [Na], and other chemical constituents.

Stepwise and multiple linear regression were used to determine the relationship between irrigation quantity and water quality on soil salinity and turf response (SAS, Ver. 9.3, 2010, Cary, NC). Proc Corr was used to correlate turf quality with irrigation quantity (% ET_o), water quality (EC_W) and soil salinity. When data were tested for normality, only turf visual quality data satisfied normality conditions, therefore percent turf cover and clippings dry weight were omitted from the analysis. Diagnose of collinearity

Table 2
Climatic data collected during the line-source gradient study in Riverside, CA.

Year	Month	Precipitation	Monthly ET_o[a]	Average Daily Temperature			
				Air Minimum	Air Maximum	Air Average	Soil Average (5 cm depth)
		mm				°C	
2011	July	7.4	197.1	17.0	31.9	23.7	24.2
	August	0.0	194.3	16.9	33.7	24.4	23.9
	September	0.0	138.9	16.0	31.3	22.6	22.5
	October	10.9	102.4	12.5	27.6	19.2	19.2
	November	39.4	62.2	7.9	20.4	13.6	13.4
	December	9.9	71.6	5.0	18.6	11.5	9.1
2012	January	9.7	76.7	7.4	21.7	14	10.7
	February	16.3	86.6	6.7	19.8	12.9	11.8
	March	24.4	114.6	7.2	20.4	13.3	13.7
	April	22.1	148.6	9.9	24.4	16.6	17.3
	May	1.0	177.8	12.7	27.1	19.1	20.3
	June	0.0	193.5	13.9	29.3	20.7	22.2
	July	1.8	201.4	16.4	32.1	23.6	23.6
	August	4.6	198.9	20.0	35.1	26.8	25.2
	September	0.3	163.9	18.3	34.2	25.7	24.1
	October	4.3	111.3	13.7	27.8	20.1	19.2

[a] ET_o, reference evapotranspiration.

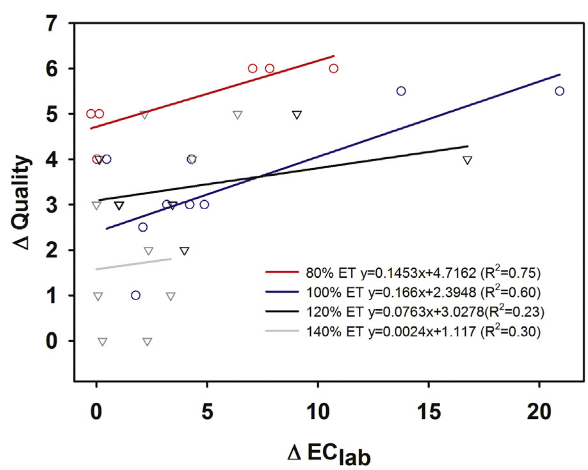

Fig. 3. Linear regression models to determine reduction in perennial ryegrass 'SR 4550′ quality (ΔQuality) from increase in soil electrical conductivity (ΔEC_e). Linear regressions are presented separately for ET_o replacements (80%, 100%, 120%, and 140%), but grouped over water salinity levels (EC_w).

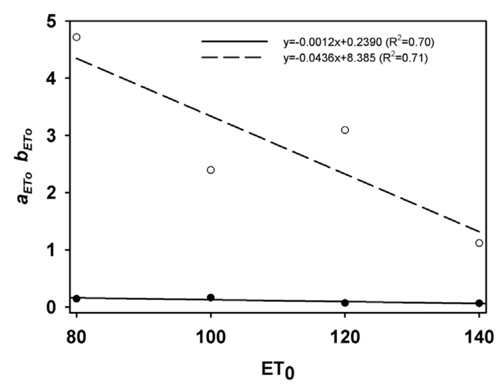

Fig. 4. Linear regressions between slopes (a_{ETo}) and intercepts (b_{ETO}) of the four models to determine reduction in perennial ryegrass 'SR4550′ quality at increasing levels of soil electrical conductivity, and ET_o replacements. Models were used to create a single model that includes effects of ET_o and EC_e on turfgrass quality.

was achieved through calculation of variance inflation factors. Preliminary analysis indicated stronger correlation between soil EC_e and turf quality than soil SAR and Na content. Therefore, in order to predict quality, a model that include $\%ET_o$ and EC_e was created following the formulation of Scudiero et al. (2012). Loss in turf quality in each ET_o replacement plot ($\Delta Quality_{ETo}$) was calculated subtracting initial recorded quality to quality assessed at the end of the study; similarly increase in EC_e (ΔEC_e) was calculated for each ET_0 replacement and EC_W plot. This relationship between ΔQuality and ΔEC_e was described with 4 linear regressions (i.e., one per each ET_o treatment), as follows (Fig. 3):

$$\Delta Quality_{ETo} = a_{ETo} * \Delta EC_e + b_{\ ETo}$$

Parameters *a* and *b* were found to be significantly correlated with the different ET_o treatments (i.e, amount of water applied) (Fig. 4). Therefore, following the methodology of Scudiero et al. (2012) , the four regression models were reformulated as single model, as follows:

$$\Delta Quality = (a' + a'' * \%ET_o replacement) * \Delta EC_e + (b' + b'' * \%ET_o\ replacement)$$

where a', a", b', and b" are empirical parameters. The model was subsequently used to calculate expected drops in quality that were correlated to the observed.

2. Results

During the study period in 2011, nearly 61 mm of rainfall was recorded, most all of which occurred from Oct. to Dec. (Table 2), and total reference evapotranspiration from July to December 2011 was 766 mm. In general, ET_o and temperature (air and soil) were highest at the start of the experiment and gradually decreased over time during 2011. In 2012, an additional 84 mm of rainfall was recorded mainly during winter and early spring, totaling 145 mm for the entire study period (Table 2). Reference evapotranspiration was 1473 mm from January to October 2012 and peaked in July. Air and soil temperatures reached a maximum in Aug.

Results from stepwise linear regression revealed that changes in turf quality during the 2-yr study were best described by irrigation amount, water quality, and time (Table 3). Results revealed a significant ($P < 0.001$) relationship among irrigation amount, water quality, time, and turfgrass quality, with a model coefficient of determination (R^2) of 0.55. When data were separated by irrigation amount, both time and water quality accounted for 54% of the variability ($P < 0.001$) in quality at 80% ET_o (Fig. 2). Water quality and time were also significant ($P < 0.001$) for predicting turf quality

Table 3
Stepwise linear regression and Variance Inflation Factors (VIF) of perennial ryegrass quality (1–9 scale, 9 = best), time (days), irrigation amount (% ET_o), and water salinity (EC_w) over the 442-d experiment.

Parameter	Variables		
	% ET_o	Days	EC_w (dS m^{-1})
	R^2		
Turf Quality	0.49***	0.35***	0.56***
VIF	1.03	1.00	1.03

Parameter		Variables	
	% ET_o	Days	EC_w (dS m^{-1})
		R^2	
Turf Quality	80	0.46***	0.54***
	100	0.35***	0.42***
	120	0.31***	0.33***
	140	0.30***	0.34***

*** Significant at the 0.001 level of probability.

Table 4
Time (d) for perennial ryegrass quality to fall below a minimally acceptable quality rating of 6 (1–9 scale, 9 = best) during the 442-d line-source gradient study in Riverside, CA. Values were generated by regression equations and are presented for each water quality (EC_w) treatment.

	EC_w	% ET_o[a]			
		80	100	120	140
	dS m^{-1}	%			
Turf Quality (Rating = 6)	0.6	207	318	332	441
	1.7	164	259	305	395
	3.0	115	191	275	343
	3.5	96	165	263	323
	4.2	67	126	245	292

[a] % ET_o, irrigation amount.

at 100, 120, and 140% ET_o, with model R^2 values of 0.42, 0.33, and 0.34, respectively ($P < 0.001$).

Regression equations were subsequently used to calculate the number of days for 'SR 4550′ quality to fall below a minimally acceptable quality rating of 6 (Table 4). At 80% ET_o, the equation predicted that turf quality (Quality = 8.31–0.39EC_w–0.01Days; R^2 = 0.54***) could not be maintained above minimally acceptable levels for one year regardless of water quality. Similarly, at 100% ET_o, turf quality could not be maintained above minimally acceptable levels for one year, reaching quality (Quality = 8.81–0.43EC_w–0.008Days; R^2 = 0.42***) thresholds at 318 d (June 2012) at low EC_w (0.6 dS m^{-1}). Even under non-limiting irrigation conditions (120% ET_o), the equation predicted that turf quality (Quality = 8.43–0.17EC_w– 0.007Days; R^2 = 0.33***) could not be maintained above minimally acceptable levels for one year, reaching thresholds of 332 d (June 2012) at low EC_w (0.6 dS m^{-1}). Only the highest irrigation amount (140% ET_o) was predicted to sustain turf quality (Quality = 8.8–0.25EC_w–0.006Days, R^2 = 0.34***) above minimally acceptable standards for 442 d when irrigated with potable water (0.6 dS m^{-1}). Given the soil and environmental conditions in Riverside, CA, these data indicated that 'SR 4550' quality and cover could be sustained with irrigation water quality (EC_w) up to ~1.7 dS m^{-1} applied at 140% ET_o.

When data were analyzed separately by year, irrigation amount, water quality and temperature played significant roles in predicting turfgrass quality (Table 5). Temperature was represented as the sum of average daily soil temperatures from 1 January 2012–5 October 2012. Stepwise linear regression revealed a significant ($P < 0.001$) relationship among irrigation amount, water quality, temperature, and turfgrass quality with a model R^2 = 0.57. Temperature alone explained 35% of the variability in quality.

Table 5
Stepwise linear regression and Variance Inflation Factors (VIF) of perennial ryegrass quality (1–9 scale, 9 = best), soil temperature, irrigation amount (% ET_o), and water quality (EC_w) in 2012.

Parameter	Variables		
	Soil Temperature	% ET_o	EC_w (dS m^{-1})
	R^2		
Turf Quality	0.35***	0.51***	0.57***
VIF	2.06	1.57	1.11

*** Significant at the 0.001 level of probability.

Soil chemical analysis data were used to model turfgrass response to soil salinity. By the end of the study period (October 2012), soil EC_e ranged from 1.4 to 16.6 dS m^{-1} (Table 6). Linear regressions between ΔQuality and ΔEC_e were always significant, although the model was a better predictor of drop in quality at 80% ET_o replacement (R^2 = 0.75) than at 120% (R^2 = 0.23) (Fig. 3). Subsequently, when slopes and intercepts where plotted against ET_o, both regressions where significant with regression coefficients of 0.70 and 0.71 respectively (Fig. 4). The two obtained regressions were finally used to create the following model:

$$\Delta Quality = (0.3239 - 0.0012 * \%ET_o replacement) * \Delta EC_e + (8.385 - 0.046\ \%ET_o replacement)$$

This model was characterized by R^2 of 0.57. According to this model, a drop of 4 quality points (and therefore the impossibility of maintaining turf above an acceptable turf quality level of six) is inevitable when %ETo replacements are below 120% ET_0, regardless of the EC_w used to irrigate grass. A loss of 4 visual quality points was also calculated for 120% ET_o replacement when high salinity water was used. Conversely, in our study, the 140% ET_o replacement treatment increased EC_e only 2.1 dS m^{-1} when 4.2 EC_w was used to irrigate 'SR 4550', determining a loss in quality of only 1.5 turf quality point.

3. Discussion

Perennial ryegrass 'SR 4550′ response over the 2-yr study was dependent upon irrigation amount, water quality, and time that the turf was irrigated under saline and deficit conditions. Soil salinity (EC_e) was also a significant predictor of turfgrass quality during the 442-d study period. The effects of soil salinity on turf response over time supports findings from Devitt et al. (2007), in which yearly changes in depth-weighted soil salinity on golf courses switching to recycled water was best described by the number of days a course was irrigated with recycled water, the leaching fraction, and uniformity of sprinkler distribution. Decline in turf quality and cover during their study resulted from the combination of soil structure deflocculation and osmotic stresses caused by high saline and drought conditions.

While leaching fraction (LF) for salt affected areas has been historically calculated (Rhoades, 1974) as:

$$LF = \frac{EC_w}{5EC_e - EC_w},$$

our results show that this formula may underestimate the requirements for leaching in a Mediterranean climate. In fact, assuming EC_e threshold of 6 for perennial ryegrass, leaching fraction calculated when EC_w of 4.2 dS m^{-1} would be 16%. Nevertheless, our results showed that irrigating at 120% ET_o in Riversde CA, not only lead to loss of turf quality, but also increased EC_e to a non-sustainable point for 'SR 4550′. Only the 140% ET_o replacement treatment was able to maintain acceptable turf quality and contemporarily leach salts from the rootzone.

Table 6
Electrical conductivity and Sodium Absorption Ratio (SAR) of soil saturation extract (EC_e; dS m^{-1}), in October 2012 for each irrigation treatment (80, 100, 120, and 140% ET_o) and salinity level (0.6, 1.7, 3.0, 3.5, 4.2 dS m^{-1}) at the end of line-source gradient study in Riverside, CA.

ET_o	0.6 dS m^{-1} (EC_w)	1.7 dS m^{-1} (EC_w)	3.0 dS m^{-1} (EC_w)	3.5 dS m^{-1} (EC_w)	4.2 dS m^{-1} (EC_w)
%	EC_e (dS m^{-1})				
80	1.5 e[1]	3.1 de	6.8 bcde	8.8 bc	16.6 a
100	1.7 e	3.6 de	5.8 bcde	8.8 bc	15.1 a
120	1.4 e	2.6 e	4.7 bcde	8.2 bcd	12.1 ab
140	1.7 e	2.9 de	4.2 cde	5.7 bcde	6.4 bcde

[1] values followed the same letter are not statistically different from one another (α = 0.05).

Since only 57% of the variability could be explained by the model, the effects of soil temperature, as a function of heat stress, probably contributed with irrigation amount, and water quality, to the variability in quality and cover of 'SR 4550'. Increasing air and soil temperatures, in combination with deficit irrigation, may have further exacerbated plant drought conditions during the second year. As a result, drought conditions may have caused reductions in plant transpiration, decreasing transpirational cooling and increasing internal heat stress. These findings are in agreement with results of Jiang and Huang (2001), who found that the combination of heat and drought stress, more so than heat stress alone, caused reductions in photosynthetic rate and root growth of tall fescue and perennial ryegrass. Furthermore, results from Sevostianova et al. (2011) suggested that low quality of perennial ryegrass and creeping red fescue may have been caused by high summer temperatures more than salinity. More research under controlled environment conditions is needed to determine the role played by heat and high ET_o rates when those stressors are combined with drought and salinity.

Irrigation at 80 and 100% ET_o could not sustain turf quality and cover at an acceptable level for one year regardless of water quality. These results differ from Gibeault et al. (1985) who reported that perennial ryegrass quality was optimal at 100% ET_o with low saline water under sprinkler irrigation in Irvine, CA (cooler climate with lower temperature and ET_o, and loamy sand soil). Cool-season grasses in general, and particularly perennial ryegrass, are not well adapted to high temperatures, drought, and heat stress that are characteristic to inland Mediterranean climates and desert conditions (Schiavon et al., 2013, 2014a,b,c).

4. Conclusions

Despite their abilities to maintain green color all year long, cool-season turf species are subjected to several abiotic stresses in semi-arid climates such as southern California. Nevertheless, their use is predominant to that of warm-season species. Overall, the performance of 'SR 4550' in this experiment suggests that a considerable amount of irrigation water (140% ET_o) above reference evapotranspiration must be applied to maintain acceptable quality and cover in Riverside, CA. Our results also suggest that even moderate levels of salinity may be too detrimental for perennial ryegrass in semi-arid climates, and leaching requirements are always underestimated if turf is subjected to multiple stressors.

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References

Alshammary, S.F., Qian, Y.L., Wallner, S.J., 2004. Growth response of four turfgrass species to salinity. Agric. Water Manage. 66, 97–111.

Ayers, R.S., Westcot, D.W., 1985. Water quality for agriculture. In: FAO Irrigation and Drainage Paper 29 (Rev. 1). Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy, URL http://www.fao.org/DOCReP/003/T0234e/T0234E00.htm (Accessed 31. June.16).

Biran, I., Bravdo, B., Bushkin-Harav, I., Rawitz, E., 1981. Water consumption and growth rate of 11 turfgrasses as affected by mowing height irrigation frequency, and soil moisture. Agron. J. 73, 85–90.

California Department of Water Resources, 2009. Model Water Efficient Landscape Ordinance (Accessed 31.May. 16) http://www.water.ca.gov/wateruseefficiency/docs/MWELO09-10-09.pdf.

Carrow, R.N., Duncan, R.R., 1998. Salt-affected Turfgrass Sites: Assessment and Management. Ann Arbor Press, Chelsea.

Dean, D.E., Devitt, D.A., Verhick, L.S., Morris, R.L., 1996. Turfgrass quality, growth, and water use influenced by salinity and water stress. Agron. J. 88, 844–849.

Dean-Knox, D.E., Devitt, D.A., Verchick, L.S., Morris, R.L., 1998. Physiological response of two turfgrass species to varying ratios of soil matric and osmotic potentials. Crop Sci. 38, 175–181.

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

Doorenbos, J., Pruitt, W.O., 1984. Guidelines for predicting crop water requirements. Environ. Assessment Office. Irrigation and Drainage Pap, 24. United Nations, Rome.

Frenkel, H., Mantell, A., Vinten, A., Meiri, A., 1990. Double line-source sprinkler system for determining the separate and interactive effects of water and salinity on forage corn. Irrig. Sci. 11, 227–231.

Gibeault, V.A., Meyer, J.L., Youngner, V.B., Cockerham, S.T., 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: performance of commonly used turfgrasses. Int. Turfgrass Soc. Res. J. 7, 347–356.

Harivandi, M.A., Butler, J.D., Wu, L., 1992. Salinity and turfgrass culture. In: Waddington, D.V., et al. (Eds.), Turfgrass Agron. Monogr, vol 32. ASA, CSSA, and SSSA, Madison.

James, I., 2013. Valley's Golf Courses Looking to Reduce Water Use: Effort by Golf Industry Will Involve Coachella Valley Water District. Gannett Company Inc (accessed 5.31.16) http://www.mydesert.com/article/20131119/NEWS07/311190036/.

Jiang, Y., Huang, B., 2001. Physiological responses to heat and stress alone or in combination with drought: a comparison between tall fescue and perennial ryegrass. HortSci 36, 682–686.

Krans, J.V., Morris, K., 2007. Determining a profile of protocols and standards used in the visual field assessment of turfgrasses: A survey of National Turfgrass Evaluation Program-sponsored university scientists. Appl. Turfgrass Sci., http://dx.doi.org/10.1094/ATS-2007-1130-01-TT.

Leskys, A.M., Devitt, D.A., Morris, R.L., Verchick, L.S., 1999. Response of tall fescue to saline water as influenced by leaching fractions and irrigation uniformity distributions. Agron. J. 91, 409–416.

Marcum, K.B., Pessarakli, M., 2010. Salinity tolerance of ryegrass turf cultivars. HortScience 45, 1882–1884.

Rhoades, J.D., Bingham, F.T., Letey, J., Hoffman, G.J., Dedrick, A.R., Pinter, P.J., Replogle, J.A., 1989. Use of saline drainage water for irrigation: imperial Valley study. Agric. Water Manage. 16, 25–36.

Rhoades, J.D., 1974. Drainage for salinity control. In: van Schilfgaarde, J. (Ed.), Drainage for Agriculture. Agronomy Monograph No.17. Amer. Soc. Of Agron, Madison.

Royo, A., Aragües, R., 1999. Salinity-yield response functions of barley genotypes assessed with a triple line source sprinkler system. Plant Soil 209, 9–20.

Schiavon, M., Barnes, B.D., Shaw, D.A., Henry, J.M., Baird, J.H., 2013. Strategies for converting tall fescue to warm-season turf in a Mediterranean climate. HortTechnology 23, 442–448.

Schiavon, M., Leinauer, B., Serena, M., Maier, B., Sallenave, R., 2014a. Plant growth regulator and soil surfactants' effects on saline and deficit irrigated warm-season grasses:I. Turf Quality, Color Retention, and Soil Moisture Distribution. Crop Sci. 54, 2815–2826.

Schiavon, M., Green, R.L., Baird, J.H., 2014b. Drought tolerance of cool-season turfgrasses in a Mediterranean climate. Eur. J. Hortic. Sci. 79, 175–182.

Schiavon, M., Leinauer, B., Serena, M., Maier, B., Sallenave, R., 2014c. Plant growth regulator and soil surfactants' effects on saline and deficit irrigated warm-season grasses: II. Pigment content and superoxide dismutase activity. Crop Sci. 54, 2827–2836.
Scudiero, E., Berti, A., Teatini, P., Morari, F., 2012. Simultaneous monitoring of soil water content and salinity with a low-cost capacitance-resistance probe. Sensors 12, 17588–17607.
Sevostianova, E., Leinauer, B., Sallenave, R., Karcher, D., Maier, B., 2011. Soil salinity and quality of sprinkler and drip irrigated cool-season turfgrasses. Agron. J. 103, 1503–1513.
Singh, R.B., Chauhan, C.P.S., Minhas, P.S., 2009. Water production functions of wheat (Triticum aestivum L.) irrigated with saline and alkali waters using double-line source sprinkler system. Agric. Water Manage. 96, 736–744.
Smeal, D., O'Neill, M.K., Arnold, R.N., 2005. Forage production of cool season pasture grasses as related to irrigation. Agric. Water Manage. 76, 224–236.
Throssell, C.S., Lyman, G.T., Johnson, M.E., Stacey, G.A., Brown, C.D., 2009. Golf course environmental profile measures water use, source, cost, quality, and management and conservation strategies. Appl. Turfgrass Sci., http://dx.doi.org/10.1094/ats-2009-0129-01-rs.