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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 ($EC_w \sim 0.6–4.2\,dS\,m^{-1}$) 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 $EC_w \sim 1.7\,dS\,m^{-1}$, 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