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Irrigation Requirements for Salinity Management on Perennial Ryegrass (Lolium perenne L.) Turf

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Irrigation Requirements for Salinity Management on Perennial Ryegrass (*Lolium perenne* L.) Turf

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of the requirements for the degree of

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in

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by

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March 2014

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ABSTRACT OF THE THESIS

Irrigation Requirements for Salinity Management on Perennial Ryegrass (*Lolium perenne* L.) Turf

by

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Master of Science, Graduate Program in Plant Biology
University of California, Riverside, March 2014
Dr. James H. Baird, Chairperson

Irrigation scheduling based on reference evapotranspiration (ET_o) multiplied by a crop coefficient (K_c) is an accepted approach for managing and conserving water applied to turfgrass. However, increasing use of recycled water that is often high in salinity warrants further examination of irrigation practices for turfgrass health and salinity management. A 2-yr study was conducted 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 gradient experiment was designed to alternate 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. 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***), cover (R^2 = 0.26***), and clipping yield (R^2 = 0.08***) 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. Soil salinity (EC_e), and sodium absorption ratio (SAR) were highly correlated with irrigation water quality, but not irrigation amount. Stepwise linear regression revealed that soil EC_e at 20-30 cm (*P* < 0.05), and SAR at 10-20 cm (*P* < 0.001) and 20-30 cm (*P* < 0.01) accounted for 43% of the variability in quality and cover in August 2012. In September 2012, soil EC_e at 10-20 cm (r = -0.62) and 0-30 cm (r = -0.60) had the highest correlation with turfgrass quality and cover. Regression results revealed that soil EC_e at 10-20 cm (*P* < 0.001) and SAR at 10-20 cm (*P* < 0.05) accounted for 41% of the variability in quality and cover in September 2012. Our results suggest that perennial ryegrass requires irrigation scheduling above 120% ET_o, irrigation water quality below EC_w ~ 1.7 dS m^{-1}, and soil salinity (EC_e) below 3.8 dS m^{-1} to maintain acceptable quality and cover for over one year in Riverside, CA.

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Extended drought periods 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 the Coachella Valley, CA 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).

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, where excess water above plant evapotranspiration (ET) 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 irrigated agriculture including turf may be overestimated assuming that plant response to salinity is represented by average root zone salinity and that the water demands of the crop are fixed independently (Ayers 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). In the Coachella Valley, perennial ryegrass is commonly used for overseeding bermudagrass during winter dormancy to provide green color, aesthetic quality, and optimal playing conditions. However, 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 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 response to salinity under field conditions has been evaluated using a line-source irrigation system (LSIS), which generates a continuous distribution of irrigation water with distance from the sprinkler, creating a gradient of irrigation water quantity (Hanks, 1976). Variations of this system have been used to determine growth response to drought and salinity in barley (*Hordeum vulgare* L.) (Royo and Aragüés, 1999), corn (*Zea mays* L.) (Frenkel et al., 1990), wheat

(*Triticum* spp.) (Singh et al., 2009), and pasture grasses (Smeal et al., 2005). Ervin and Koski (1998) used a LSIS to study drought avoidance mechanisms in tall fescue and Kentucky bluegrass in Colorado. They determined crop coefficients of 0.70 for Kentucky bluegrass and 0.60 for tall fescue. Dean et al. (1996) used two line-source gradients supplying saline aquifer water and municipal water to determine species-specific salinity thresholds (irrigation volume relative to potential evapotranspiration) of 0.65 and 0.80 for bermudagrass and tall fescue, respectively.

Plant responses to both 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, growth, and cover to predict more accurately leaching requirements for turfgrass salinity management.

Materials and Methods

A study was conducted from 2011-2012 at the University of California, Riverside (UCR) Turfgrass Research Facility in Riverside, CA. Soil was a Hanford fine sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerothents). A modified line-source experiment was constructed on a 972-m^2 area illustrated in 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 4.6 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). Toro 300 series pop-up stream sprinklers (Toro Company, Bloomington, MN) were spaced 9 m apart along the irrigation lines and operated at a pressure of 345 kPa with a wetted radius of 9 m.

The area was seeded with perennial ryegrass 'SR 4550' (Seed Research of Oregon, Corvallis, Oregon) on 18 April 2011 at a rate of 4.5 kg ha^{-1} and irrigated with potable water only during establishment. Turf was maintained at 6 cm twice weekly using a rotary mower and fertilized monthly during active shoot growth at 49 kg N ha^{-1} (16N-2.6P-6.6K; Simplot, Boise, ID) throughout the experiment.

The study area was divided into four separate irrigation zones perpendicular to the irrigation lines, each controlled by a separate valve interfaced to a central irrigation controller. Each zone was irrigated independently by the four alternating irrigation line sources, further dividing the study area into twelve 81-m^2 plots (three plots per irrigation zone). Irrigation amounts or crop coefficients (Kc) of 80, 100, 120, and 140% reference evapotranspiration (ET_o) were randomly assigned to the areas. 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 at 12 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 12 plot areas was further subdivided into nine 9-m^2 subplots to assess turfgrass and soil responses to varying irrigation salinity. Distribution uniformity was evaluated periodically using catch cans (54 cm^2) throughout the experiment. Irrigation water volume was collected from locations within every other 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. Actual irrigation volumes varied greatly at each irrigation zone, where some areas that were supposed to receive excessive amounts of water (120% and 140% ET_o) were actually receiving lower amounts (80% and 100% ET_o), and vice versa. To account for variability in sprinkler distribution uniformity, irrigation volumes from catch-cans were averaged within every other subplot, and ranked from lowest to highest per irrigation zone. The total range in irrigation volume was divided equally into 4 groups, where the first group (driest subplots) were assigned to 80% ET_o. The next group of subplots were re-assigned to 100% ET_o, then 120% ET_o, and the last group (wettest subplots) was re-assigned to 140% ET_o. These data were used for comparison with EC_w and turf response throughout the experiment.

Saline water and irrigation treatments were initiated on 21 July 2011. Visual assessments of turfgrass quality and cover were evaluated at the start of the experiment and bi-weekly thereafter. Quality was evaluated by texture, color, uniformity, and density on a 1 to 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 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. Shoots were dried in a forced-air oven at 55°C for at least 24h, and dry weight was determined. Clippings were not collected during winter months (December 2011 to February 2012) due to limited growth.

Composite soil samples were collected before irrigation treatments were initiated, in October 2011 prior to the rainfall season and cooler temperatures in Riverside, CA, and in October 2012. Five soil cores were taken across every other subplot at a depth of 0 to 10 cm using a 2.5-cm-diameter soil auger, and composited into one sample per subplot. As saline and summer stress conditions worsened in 2012, additional soil samples were collected in August and September 2012 within the same subplots at three locations, and at three depths of 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm using a 2.5-cm-diam hammer drive corer. Visual ratings of turfgrass quality and cover were taken within a 61-cm-diam. area from which each soil sample was taken. 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 saturated paste extract (EC_e), sodium absorption ratio (SAR), sodium concentration [Na], and other chemical constituents.

Proc corr was used to correlate turf response variables (quality, cover and dry weight) with irrigation quantity (% ET_o), water quality (EC_w) and soil salinity. 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).

Results

The experiment was conducted for 442 d from 21 July 2011 to 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 2001-2010 were 207 mm, 1440 mm, and 17.6 °C, respectively (CIMIS, 2013). During the study period in 2011, nearly 61 mm of rainfall was recorded, most all of which occurred from October to December (Table 2). Reference evapotranspiration 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. Turf quality ranged from 4 to 9 in 2011 and was lowest from September to November in higher EC_w (1.7, 3.0, 3.5, and 4.2 dS m^{-1}) sub-plots irrigated 80 and 100% ET_o; furthermore, there was no loss in turf cover during 2011 (data not shown). Clipping yields in 2011 were highest in August at 120 and 140% ET_o and moderate EC_w (3.0 dS m^{-1}). Few turf responses to % ET_o and EC_w in 2011 suggest that soil salinity was not at a level to cause adverse effects on turf quality, cover and dry weight.

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 August. In 2012, turf quality and cover ranged from 1 to 8 and 0 to 100%, respectively (data not shown). Turf quality and cover were lowest from August to October in higher EC_w (3.0, 3.5, and 4.2 dS m^{-1}) subplots irrigated at 80 and 100% ET_o. In 2012, clipping yields were variable but generally highest in March, regardless of % ET_o and EC_w (data not shown).

Results from stepwise linear regression revealed that changes in turf quality and cover during the 2-yr study were best described by irrigation amount, water quality, and time (Appendix A). Results revealed a significant ($P < 0.001$)

relationship among irrigation amount, water quality, time, and turfgrass quality, yielding a model coefficient of determination (R^2) of 0.48. 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 at 100, 120, and 140% ET_o, with model R^2 values of 0.42, 0.33, and 0.34, respectively (P < 0.001). Similar results were observed for turf cover during the experiment, with irrigation amount, water quality and time accounting for 35% of the variability in turf cover. When cover data were separated by irrigation amount, model R^2 values were highest at 80% ET_o (R^2 = 0.46), followed by 0.36, 0.21, and 0.23 at 100, 120, and 140% ET_o, respectively. Dry weight was significantly (P < 0.001) affected by water quality and time across both years, although R^2 was low (0.10). When analyzed separately by irrigation amount, R^2 values remained low, ranging from 0.11 (P < 0.001) at 100% ET_o, to 0.18 (P < 0.05) at 140% ET_o.

Regression equations were subsequently used to calculate the number of days for perennial ryegrass quality to fall below a minimally acceptable quality rating of 6 (1 to 9 scale, 9 = best) and turf cover to drop to 90% for each EC_w treatment during the experiment (Table 3). At 80% ET_o, the equation predicted that turf quality (Quality = 8.31 - 0.39EC_w - 0.01Days; R^2 = 0.54***) and cover (Cover = 123.2 - 3.6EC_w - 0.15Days; R^2 = 0.46***) could not be maintained above minimally acceptable levels for one year regardless of water quality. Similarly, at 100% ET_o, turf quality and cover 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***) and cover (Cover = 122.2 - 5.2 EC_w - 0.09Days, R^2 = 0.36***) thresholds at 318 d and 323 d, respectively (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***) and cover (Cover = 107 - $0.96EC_w$ - 0.05Days; R^2 = 0.21*) could not be maintained above minimally acceptable levels for one year, reaching thresholds of 332 d and 328 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***) and cover (Cover = 110.5 - $2.08EC_w$ - 0.04Days; R^2 = 0.23***) above minimally acceptable standards for 441 d and 481d, respectively when irrigated with potable water (0.6 dS m^{-1}). Given the soil and environmental conditions in Riverside, CA, these data indicated that perennial ryegrass 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 and cover in 2012 (Appendix B). Temperature was represented as the sum of average daily soil temperatures from 1 January 2012 to 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. These variables also described 53% of the variability in cover (P <

0.001). Temperature alone explained 35% of the variability in quality and 40% of the variability in cover. Dry weight was significantly (P < 0.001) affected by temperature and water quality, but the relationship was not strong (R^2 = 0.22).

To assess the change in soil salinity during the experiment, soil samples were collected in July 2011 prior to saline and deficit irrigation, in October 2011 prior to the winter rainfall season, and October 2012 near the conclusion of the experiment. Soil samples were analyzed for electrical conductivity of the saturated paste extract (EC_e), sodium concentration [Na], and SAR at 0 to 10 cm soil depth (Appendix C). These data were used to model turfgrass response (quality, cover, dry weight) to soil salinity. 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. In October 2011, soil EC_e ranged from 1.7 to 5.1 dS m^{-1}, SAR ranged from 3.9 to 7.6, and [Na] ranged from 189 to 606 mg L^{-1}. By the end of the study period (October 2012), soil EC_e ranged from 1.5 to 16.6 dS m^{-1}, SAR ranged from 1.8 to 16.7, and [Na] ranged from 91.4 to 2,474 mg L^{-1}. There was a strong negative correlation among the soil parameters and turf quality, cover and dry weight (Table 4). Despite no significant correlation among irrigation amount and soil parameters, stepwise linear regression revealed a significant (P < 0.001) interaction among soil EC_e, [Na], SAR and turfgrass cover at 80% ET_o (R^2 = 0.56). Soil EC_e alone accounted for 41% of the variability in quality at 80% ET_o. Turfgrass quality at 80% ET_o was explained by soil EC_e (P < 0.001) and [Na] (P < 0.001; R^2 = 0.58). At 100 and 120% ET_o, soil EC_e and [Na] were significant (P <

0.001) predictors of quality, yielding R^2 = 0.70 (100% ET_o) and 0.61 (120% ET_o). Similarly, at 100 and 120% ET_o, soil EC_e and [Na] were significant (P < 0.001) predictors of turf cover at 100% ET_o (R^2 = 0.69) and 120% ET_o (R^2 = 0.55). At 140% ET_o, soil EC_e predicted 61% (P < 0.001) of the variability in quality and 53% (P < 0.001) of the variability in cover. When data were pooled by irrigation amount, dry weight was significantly (P < 0.001) affected by soil EC_e, [Na], and SAR (R^2 = 0.46). At all irrigation levels, SAR contributed the most to model R^2 values (P < 0.001), ranging from 0.24 (80% ET_o), to 0.53 (140% ET_o). Soil [Na] also significantly (P < 0.001) contributed to model R^2 values at 80, 100, and 120% ET_o (Appendix D).

As saline and summer stress conditions worsened in 2012, additional soil samples were collected in August and September at three locations within every other sub-plot, and at three depths of 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm. When data were pooled across EC_w for each irrigation amount, soil EC_e and SAR at all depths were highest at 80% ET_o compared to 100, 120 and 140% ET_o at both sampling times (Appendix E). Overall, soil EC_e and SAR dropped slightly at each depth across all irrigation amounts from August to September 2012 collection dates. Figure 3 shows EC_e and Figure 4 shows SAR at 0-10, 10-20, 20-30, and 0-30 cm depths in September 2012 for each water quality (EC_w) treatment. Soil salinity (EC_e) and SAR were highest at 0-10 cm, and lowest at 20-30 cm for all water quality treatments. At 0-10 cm, soil EC_e ranged from 2.1 dS m^{-1} at low EC_w (0.6 dS m^{-1}) and 7.4 dS m^{-1} at high EC_w

(4.2 dS m^{-1}), while SAR ranged from 3.3 at low EC_w (0.6 dS m^{-1}) and 10.2 at high EC_w (4.2 dS m^{-1}).

Soil EC_e and SAR data from August and September 2012 were compared to water quality, irrigation amount, and visual ratings taken on the same day using general correlation analyses and stepwise linear regression. For both dates, EC_w was negatively correlated ($P < 0.001$) with soil EC_e and SAR at each depth, and when samples were averaged over all depths (0-30 cm) (Tables 5 and 6). Turf quality and cover were most highly correlated with soil EC_e at 20-30 cm (r = -0.61) and SAR at 10-20 cm (r = -0.61) in August 2012 (Table 5). Stepwise linear regression revealed that soil EC_e at 20-30 cm ($P < 0.05$), SAR at 10-20 cm ($P < 0.001$) and 20-30 cm ($P < 0.01$) accounted for 43% of the variability in quality and cover in August 2012 (Appendix F). In September 2012, soil EC_e at 10-20 cm (r = -0.62) and 0-30 cm (r = -0.60) had the highest correlation with turfgrass quality and cover (Table 6). Regression results revealed that soil EC_e at 10-20 cm ($P < 0.001$) and SAR at 10-20 cm ($P < 0.05$) accounted for 41% of the variability in quality and cover in September 2012. Relationships among EC_w, soil EC_e, and SAR were positively correlated ($P < 0.001$) on both dates, while irrigation amount did not correlate with soil EC_e, SAR, turf quality and cover on both dates.

Soil EC_e and SAR in August and September 2012 were compared to turf response under non-limiting irrigation conditions (140% ET_o), to determine soil salinity thresholds of perennial ryegrass ‘SR 4550’. At 395 d (August 2012), turf quality dropped to a minimally acceptable rating of 6 at 140% ET_o and EC_w of 1.7 dS m^{-1}. Average soil EC_e (0-30 cm) and SAR (0-30 cm) at that time (taken from August 2012 sampling date) were 3.8 dS m^{-1} and 6.1, respectively. At 442 d (September 2012), turf quality dropped to a minimally acceptable rating of 6 at 140% ET_o and at low EC_w (0.6 dS m^{-1}). Average soil EC_e (0-30 cm) and SAR (0-30 cm) at that time (taken from Sept. 2012 sampling date) were 1.5 dS m^{-1} and 2.7, respectively. Our results suggest that perennial ryegrass 'SR 4550' requires non-limiting irrigation conditions (above 120% ET_o), and water quality below EC_w ~ 1.7 dS m^{-1} to maintain acceptable quality and cover in Riverside, CA. Furthermore, soil salinity (EC_e) must be maintained below 3.8 dS m^{-1}.

Discussion

Perennial ryegrass response (quality, cover and weight) 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 and cover during the 442-d study period. The effects of soil salinity on turf response over time coincides with research from Devitt et al. (2007), where 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 matric and osmotic stresses caused by high saline and drought conditions.

The effects of irrigation amount, water quality, and soil temperature, as a function of heat stress, contributed to the variability in quality and cover of perennial ryegrass in 2012. 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 (*Festuca arundinacea* L.) and perennial ryegrass. Furthermore, results from Sevostianova et al. (2011) suggested that low visual quality ratings of perennial ryegrass and creeping red fescue may have been caused by high summer temperatures rather than salinity.

The significant correlations among dry weight, soil salinity, sodium content and SAR suggests that plant growth declines under saline conditions. These findings coincide with existing research demonstrating that plant growth declines in response to saline and drought conditions (Alshammary et al. 2004, Dean et al. 1996, Dean-Knox et al. 1998, Marcum and Pessarakli, 2010). However, turfgrass managers are more concerned about quality and cover rather than reductions in yield (Dean et al. 1996, Leskys et al. 1999).

Irrigation water salinity, rather than irrigation amount, was significantly correlated with soil salinity and SAR at all depths during the course of the study.

These results coincide with Devitt et al. (2007) who reported that irrigation water salinity accounted for the variability in soil salinity (0-15 cm). These results confirm that using irrigation water with high soluble salts can increase overall salinity of the soil profile over time.

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). 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. For these reasons, perennial ryegrass use is restricted mainly to overseeding warm-season turf during winter months when temperatures are cooler and water is less limited. In our study, turf quality and cover was maintained at an acceptable level during the late fall, winter, and late spring in Riverside, CA, with less water (100% ET_o) and with a higher irrigation water salinity ($EC_w \sim 3.0$ dS m^{-1}). These results suggest that growing and maintaining good quality perennial ryegrass during the overseeding period in the Coachella Valley can be done using much less water, and water of poorer quality if proper management practices are implemented. Overall, the performance of perennial ryegrass 'SR 4550' in this experiment suggests that a sufficient amount of irrigation water (120 – 140% ET_o) above reference evapotranspiration (ET_o)

must be applied to maintain acceptable quality and cover in Riverside, CA, especially when using recycled water for irrigation.

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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

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

				Average Daily Temperature			
Year	**Month**	**Precipitation**	**Average Monthly ET_o†**	**Air Minimum**	**Air Maximum**	**Air Average**	**Soil Average**
		mm	mm	°C	°C	°C	°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

† ET_o, reference evapotranspiration

Table 3. Time (d) for perennial ryegrass quality to fall below a minimally acceptable quality rating of 6 (1 to 9 scale, 9 = best) and turf cover to drop below 90% 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†**			
		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
Turf Cover (Rating=90%)	0.6	207	323	328	442
	1.7	180	258	307	423
	3.0	150	186	283	358
	3.5	138	158	274	333
	4.2	121	115	259	294

†% ET_o, irrigation treatment

Table 4. Correlation coefficients (r) between perennial ryegrass quality (1 to 9 scale, 9 = best), percent turf cover, irrigation treatment (% ET_o), water quality (EC_w), electrical conductivity of saturated paste extract (EC_e), Na, and sodium absorption ratio (SAR) at 0-10 cm soil depth in July 2011, October 2011, and October 2012 during the line-source gradient study in Riverside, CA.

	Turf Cover	**% ET_o**	**EC_w**	**EC_e**	**Na**	**SAR**
				0-10 cm		
Turf Quality	0.93***	0.26***	- 0.17*	- 0.68***	- 0.61***	- 0.59***
Turf Cover		0.23*	- 0.18*	- 0.69***	- 0.64***	- 0.59***
Dry Weight		NS	NS	-0.61***	-0.63***	-0.68***
% ET_o				NS	NS	NS
EC_w				0.39***	0.38***	0.40***

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
*** Significant at the 0.001 level of probability.
NS, not significant at the 0.05 probability level.

Table 5. Correlation coefficients (r) between perennial ryegrass quality (1 to 9 scale, 9 = best), percent turf cover, irrigation treatment (% ET_o), water quality (EC_w), electrical conductivity of saturated paste extract (EC_e), and sodium absorption ratio (SAR) at 0-10, 10-20, 20-30 and 0-30cm soil depths in August 2012 during the line-source gradient study in Riverside, CA.

	% ET_o	**EC_w**	**EC_e**				**SAR**			
			0-10	**10-20**	**20-30**	**0-30**	**0-10**	**10-20**	**20-30**	**0-30**
			cm							
Turf Quality	NS	-0.45***	-0.33***	-0.55***	-0.61***	-0.52***	-0.39***	-0.61***	-0.47***	-0.55***
Turf Cover	NS	-0.44***	-0.32***	-0.55***	-0.61***	-0.52***	-0.38***	-0.61***	-0.47***	-0.54***
% ET_o			NS	NS	NS	NS	NS	NS	NS	NS
EC_w			0.60***	0.67***	0.62***	0.70***	0.63***	0.71***	0.71***	0.78***

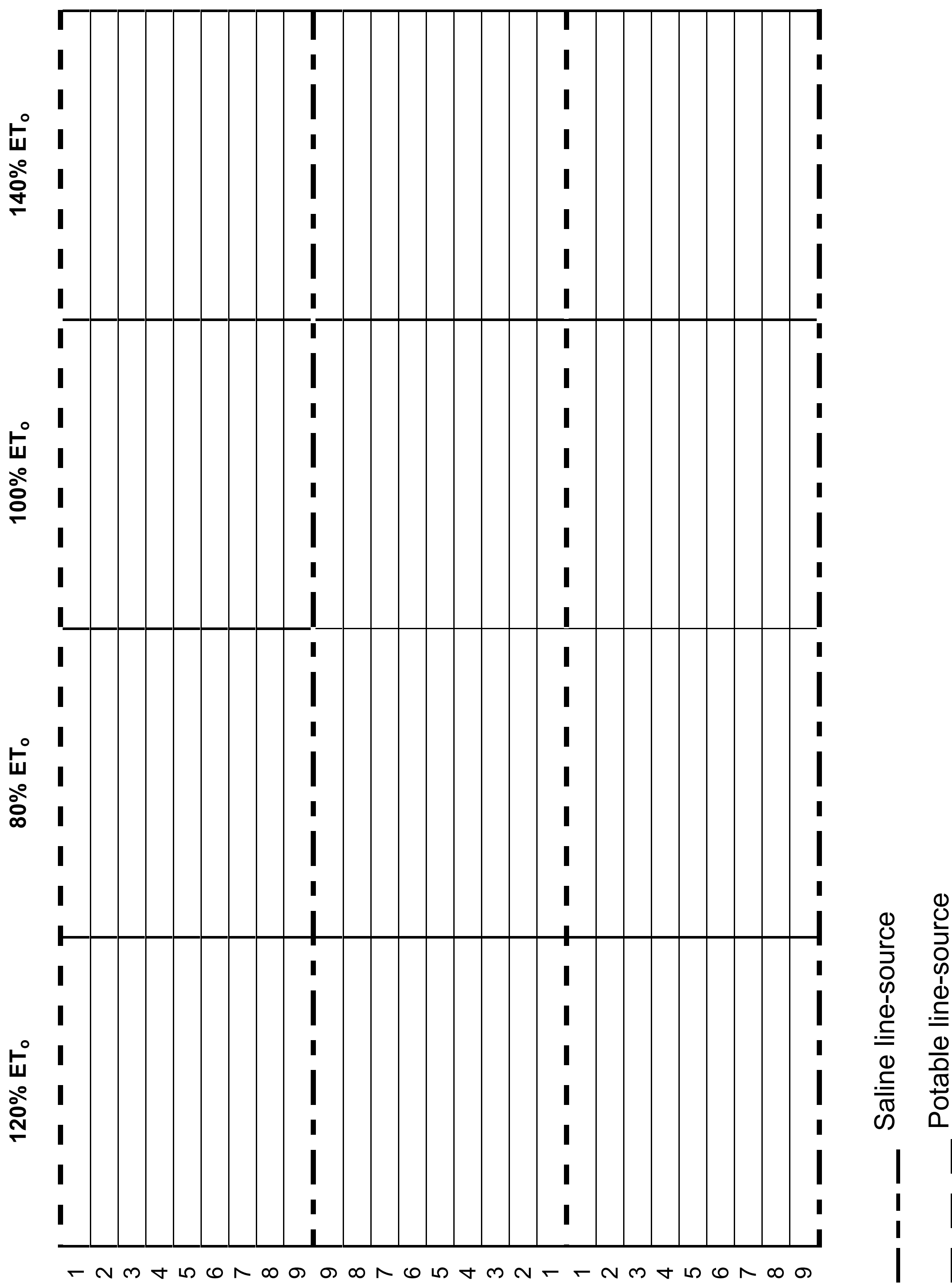
*** Significant at the 0.001 level of probability.
NS, not significant at the 0.05 probability level.

Table 6. Correlation coefficients (r) between perennial ryegrass quality (1 to 9 scale, 9 = best), percent turf cover, irrigation treatment (% ET_o), water quality (EC_w), electrical conductivity of saturated paste extract (EC_e), and sodium absorption ratio (SAR) at 0-10, 10-20, 20-30 and 0-30cm soil depths in September 2012 during the line-source gradient study in Riverside, CA.

	% ET_o	**EC_w**	**EC_e**				**SAR**			
			0-10	**10-20**	**20-30**	**0-30**	**0-10**	**10-20**	**20-30**	**0-30**
			cm							
Turf Quality	NS	-0.43***	-0.47***	-0.62***	-0.54***	-0.60***	-0.54***	-0.48***	-0.30***	-0.51***
Turf Cover	NS	-0.43***	-0.47***	-0.62***	-0.54***	-0.60***	-0.54***	-0.47***	-0.30***	-0.51***
% ET_o			NS	NS	NS	NS	NS	NS	NS	NS
EC_w			0.66***	0.65***	0.67***	0.74***	0.74***	0.80***	0.74***	0.85***

*** Significant at the 0.001 level of probability.
NS, not significant at the 0.05 probability level.

Fig. 1.



120% ET$_o$
80% ET$_o$
100% ET$_o$
140% ET$_o$
1 2 3 4 5 6 7 8 9 9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
Saline line-source
Potable line-source

Fig. 2.

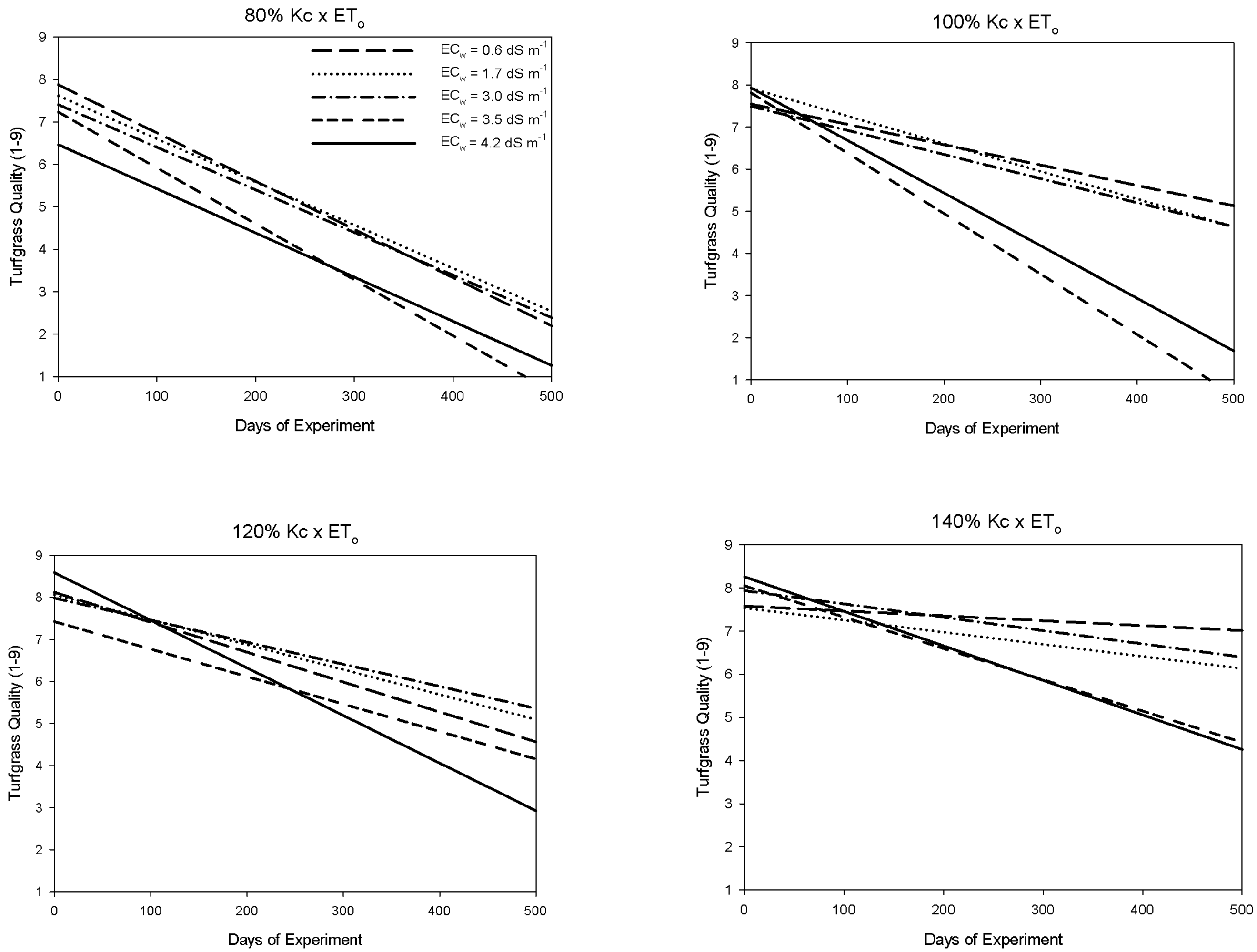

80% Kc x ET$_o$
100% Kc x ET$_o$
120% Kc x ET$_o$
140% Kc x ET$_o$
EC$_w$ = 0.6 dS m^{-1}
EC$_w$ = 1.7 dS m^{-1}
EC$_w$ = 3.0 dS m^{-1}
EC$_w$ = 3.5 dS m^{-1}
EC$_w$ = 4.2 dS m^{-1}
Turfgrass Quality (1-9)
Days of Experiment

Fig. 3.

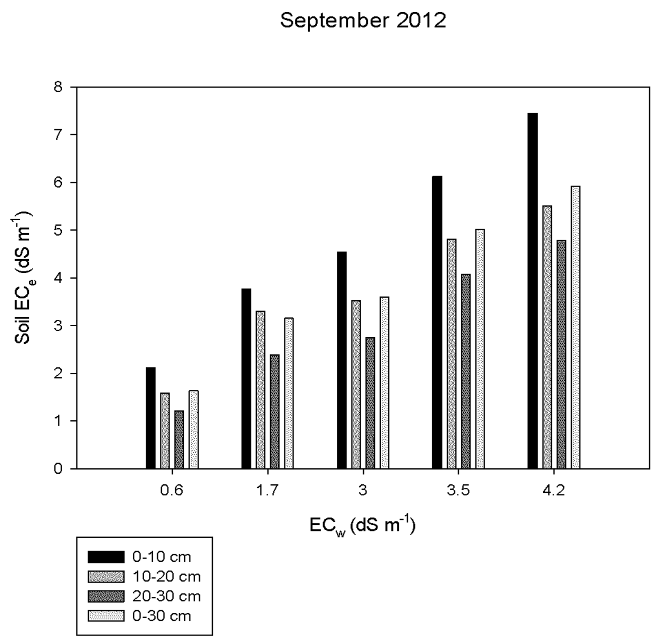
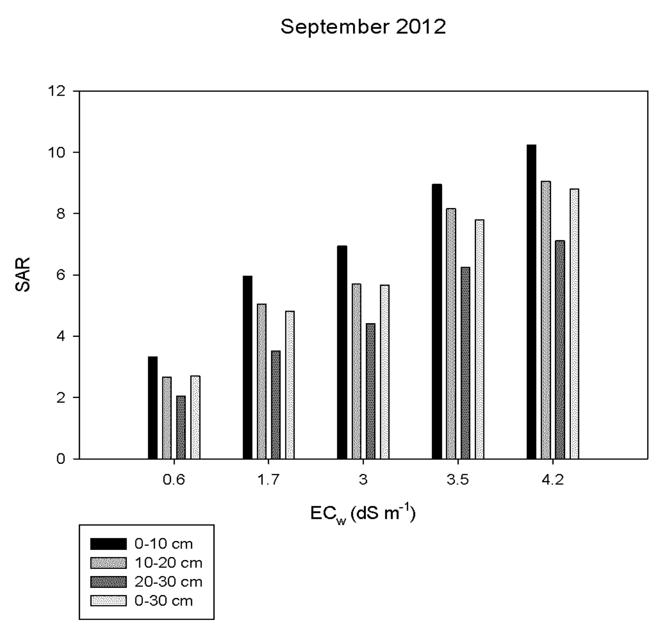

September 2012
Soil EC_e (dS m^{-1})
8
7
6
5
4
3
2
1
0
0.6
1.7
3
3.5
4.2
EC_w (dS m^{-1})
0-10 cm
10-20 cm
20-30 cm
0-30 cm

Fig. 4.


September 2012
SAR
12
10
8
6
4
2
0
0.6
1.7
3
3.5
4.2
EC_w (dS m^{-1})
0-10 cm
10-20 cm
20-30 cm
0-30 cm

Appendix A. Stepwise linear regression of perennial ryegrass quality (1 to 9 scale, 9 = best), percent turfgrass cover, dry weight (kg ha^{-1}), time (days), irrigation treatment (% ET_o), and water quality (EC_w) over the 442-d experiment.

Parameter	**Variables**		
	Days	**% ET_o**	**EC_w (dS m^{-1})**
		R^2	
Turf Quality	0.30***	0.43***	0.48***
Turf Cover	0.26***	0.32***	0.35***
Dry Weight	0.08***	NS	0.10***

Parameter		**Variables**	
		Days	**EC_w (dS m^{-1})**
	% ET_o	**R^2**	
Turf Quality	80	0.46***	0.54***
	100	0.35***	0.42***
	120	0.31***	0.33***
	140	0.30***	0.34***
Turf Cover	80	0.43***	0.46***
	100	0.29***	0.36***
	120	0.20***	0.21*
	140	0.20***	0.23***
Dry Weight	80	0.13***	0.07***
	100	0.06***	0.11***
	120	0.10***	0.13***
	140	0.17***	0.19*

* Significant at the 0.05 level of probability.
*** Significant at the 0.001 level of probability.
NS, not significant at the 0.05 probability level.

Appendix B. Stepwise linear regression of perennial ryegrass quality (1 to 9 scale, 9 = best), percent turfgrass cover, dry weight (kg ha^{-1}), temperature, irrigation treatment (% ET_o), and water quality (EC_w) in 2012.

Parameter		**Variables**	
	Temperature	**% ET_o**	**EC_w (dS m^{-1})**
		R^2	
Turf Quality	0.35***	0.51***	0.57***
Turf Cover	0.40***	0.48***	0.53***
Dry Weight	0.18***	NS	0.22***

*** Significant at the 0.001 level of probability.
NS, not significant at the 0.05 probability level.

Appendix C. Electrical conductivity of saturated paste extract (EC_e), sodium concentration [Na], and sodium absorption ratio (SAR) at 0-10 cm soil depth for each irrigation treatment (80, 100, 120, and 140% ET_o) and water quality (EC_w = 0.6, 1.7, 3.0, 3.5, and 4.2 dS m^{-1}) in July 2011, October 2011, and October 2012 during the line-source gradient study in Riverside, CA.

	ET_o	EC_w	EC_e	Na	SAR
	%	dS m^{-1}		mg L^{-1}	
July 2011	80	0.6	1.3	79.3	1.7
		1.7	1.2	69.8	1.6
		3.0	1.0	51.4	1.3
		3.5	1.1	58.6	1.4
		4.2	1.0	58.0	1.5
	100	0.6	1.5	127.3	2.3
		1.7	1.1	88.1	1.9
		3.0	1.1	86.6	1.9
		3.5	0.9	64.9	1.5
		4.2	1.0	73.6	1.7
	120	0.6	1.5	98.4	2.0
		1.7	1.2	72.5	1.7
		3.0	1.0	67.3	1.7
		3.5	1.1	70.3	1.7
		4.2	1.3	88.6	2.0
	140	0.6	1.6	119.5	2.1
		1.7	1.4	115.4	2.1
		3.0	1.3	115.3	2.3
		3.5	1.1	85.6	1.8
		4.2	1.4	126.2	2.4
October 2011	80	0.6	2.8	279.8	4.5
		1.7	3.1	329.4	5.1
		3.0	3.6	405.0	6.3
		3.5	4.7	551.0	7.2
		4.2	5.1	601.8	7.5
	100	0.6	2.0	204.2	3.9
		1.7	2.2	262.2	5.6
		3.0	3.2	383.6	6.1
		3.5	3.4	426.1	6.9
		4.2	5.0	605.7	7.4
	120	0.6	2.2	232.2	4.2
		1.7	2.2	265.1	5.3
		3.0	3.8	452.7	6.7
		3.5	3.9	483.0	7.6
		4.2	3.9	474.2	7.2
	140	0.6	1.7	188.8	3.9
		1.7	2.4	263.0	4.8
		3.0	2.6	314.9	5.6
		3.5	3.3	379.0	5.9
		4.2	4.1	477.3	6.6

	ET_o	EC_w	EC_e	Na	SAR
	%		dS m^{-1}	mg L^{-1}	
October 2012	80	0.6	1.5	91.4	1.8
		1.7	3.1	276.4	4.3
		3.0	6.8	785.5	8.4
		3.5	8.8	1100.6	10.6
		4.2	16.6	2473.9	16.7
	100	0.6	2.2	177.6	3.1
		1.7	4.1	406.2	5.8
		3.0	4.6	438.6	5.8
		3.5	6.4	670.1	7.4
		4.2	8.6	979.4	9.3
	120	0.6	2.2	154.0	2.5
		1.7	4.2	422.0	5.8
		3.0	5.3	534.5	6.4
		3.5	6.8	768.5	8.6
		4.2	15.2	2247.3	15.8
	140	0.6	2.4	206.7	3.5
		1.7	4.1	361.1	4.8
		3.0	4.5	406.3	5.3
		3.5	6.7	664.9	7.0
		4.2	12.2	1596.5	12.6

Appendix D. Stepwise linear regression of perennial ryegrass quality (1 to 9 scale, 9 = best), percent turf cover, dry weight (kg ha^{-1}), electrical conductivity of saturated paste extract (EC_e), Na, and sodium absorption ratio (SAR) at 0-10 cm soil depth in July 2011, October 2011, and October 2012.

Parameter	Variables		
	EC_e (dS m^{-1})	**Na**	**SAR**
		R^2	
Turf Quality	0.47***	0.58***	0.59*
Turf Cover	0.48***	0.53***	0.55**
Dry Weight	0.46***	0.42***	0.27***

Parameter		Variables		
	% ET_o	**EC_e (dS m^{-1})**	**Na**	**SAR**
			R^2	
Turf Quality	80	0.44***	0.58***	NS
	100	0.51***	0.70***	NS
	120	0.45***	0.61***	NS
	140	0.61***	NS	NS
Turf Cover	80	0.41***	0.50**	0.56*
	100	0.61***	0.69***	NS
	120	0.46***	0.55**	NS
	140	0.53***	NS	NS
Dry Weight	80	NS	0.40**	0.24***
	100	NS	0.56***	0.31***
	120	0.42*	0.33*	0.25***
	140	NS	NS	0.53***

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
*** Significant at the 0.001 level of probability.
NS, not significant at the 0.05 probability level.

Appendix E. Electrical conductivity of saturated paste extract (EC_e), and sodium absorption ratio (SAR) at 0-10, 10-20, 20-30 and 0-30 cm soil depths in August and September 2012 for each irrigation treatment (80, 100, 120, and 140% ET_o) during the line-source gradient study in Riverside, CA.

	ET_o	**EC_e (dS m^{-1})**				**SAR**			
		0-10	**10-20**	**20-30**	**0-30**	**0-10**	**10-20**	**20-30**	**0-30**
	%				**cm**				
August 2012	80	6.3	4.8	3.5	4.9	8.5	7.5	5.2	7.1
	100	4.8	3.9	3.0	3.9	6.6	6.4	4.9	6.0
	120	4.4	3.9	2.5	3.7	6.6	6.4	4.9	6.0
	140	4.8	4.1	2.9	3.9	7.0	6.4	4.8	6.3
September 2012	80	5.5	4.4	3.9	4.6	8.0	6.9	4.8	6.6
	100	4.8	3.3	2.4	3.5	6.8	5.7	4.6	5.7
	120	4.4	3.4	2.8	3.5	6.7	5.7	4.6	5.7
	140	4.5	3.9	3.0	3.8	7.0	6.1	4.5	5.8

Appendix F. Stepwise linear regression of perennial ryegrass quality (1 to 9 scale, 9 = best), percent turf cover, electrical conductivity of saturated paste extract (EC_e), and sodium absorption ratio (SAR) at 0-10, 10-20, 20-30 and 0-30 cm soil depths in August and September 2012.

	Parameter	EC_e (dS m^{-1})				SAR			
		0-10	**10-20**	**20-30**	**0-30**	**0-10**	**10-20**	**20-30**	**0-30**
		cm							
August 2012	**Turf Quality**	NS	NS	0.41**	NS	NS	0.38***	0.43*	NS
	Turf Cover	NS	NS	0.41**	NS	NS	0.37***	0.43*	NS
September 2012	**Turf Quality**	NS	0.39***	NS	NS	NS	0.42*	NS	NS
	Turf Cover	NS	0.39***	NS	NS	NS	0.42*	NS	NS

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
*** Significant at the 0.001 level of probability.
NS, not significant at the 0.05 probability level.