Summer Cultivation Increases Field Infiltration Rates of Water and Reduces Soil Electrical Conductivity on Annual Bluegrass Golf Greens

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Abstract. Summer decline of annual bluegrass (Poa annua L.) putting greens is a major concern of golf course superintendents. Low soil water infiltration rates and high concentrations of salts in the root zone are contributing factors. This study was conducted to determine the effects of various cultivation treatments on field infiltration rates of water, soil salinity, oxygen diffusion rates (ODR), bulk density, total and air-filled porosity, and root weight density. This research was conducted during two summer seasons (1996 and 1997) on a putting green located at Industry Hills Golf Courses, City of Industry, Calif. The green was constructed to U.S. Golf Association (USGA) specifications in 1978. Cultivation treatments consisted of: 1–3) water injection cultivation (WIC) applied with a Toro HydroJect every 21 d (raised position), and every 14 or 21 d (lowered position); 4) solid tine cultivation (STC) applied every 14 d; and 5) no cultivation (check). Results showed WIC and STC significantly increased field infiltration rates of water and lowered overall soil electrical conductivity of the extract (EC) at depths of 2.5 to 7.5 cm and 7.5 to 15.0 cm in the root zone. The effects of WIC, raised position, did not differ significantly from those of STC, but infiltration rates of water were greater on all rating dates. Cultivation treatments had no significant effects on overall soil ODR, bulk density, and porosity or on overall root weight density.

Summer decline of annual bluegrass putting greens is a major concern of golf course superintendents in southern California and in other regions of the United States. The decline is associated with the stresses due to heat, surface soil compaction, excess or lack of soil water, lack of soil aeration, excess of soil salinity, traffic, pests, and other factors. Though the successful management of annual bluegrass putting greens involves numerous aspects of the annual cultural program (Carroll and Duncan, 1998), summer cultivation helps to mitigate the effects of several factors associated with summer decline. Summer cultivation of putting greens is effective for reducing surface soil compaction and hardness due to increased summer traffic, maintaining soil water infiltration and percolation, and maintaining soil porosity (Murphy and Rieke, 1994). When a soil is irrigated with highly saline water [i.e., electrical conductivity (EC) ≥1.5 dS·m⁻¹], turfgrasses sensitive to salt are more susceptible to high temperature stress (Carroll and Duncan, 1998). Compacted soils with limited soil water infiltration and percolation, limited gas exchange, and high concentrations of salts probably exacerbate the detrimental effects of prolonged high temperatures. Maintenance of good soil physical characteristics is one key for successfully maintaining quality annual bluegrass putting greens during the summer. Carroll and Petrovic (1992), Carroll and Wiecko (1989), and Rieke and Murphy (1989) have reviewed soil compaction, wear stresses, and turfgrass cultivation methods. Mainten-
estimate at the beginning of the study indicated that the putting green was composed of ≈80% annual bluegrass and 20% creeping bentgrass.

Cultivation treatments were applied from 18 July to 18 Nov. 1996 and from 19 May to 22 Sept. 1997. The treatments were arranged in a randomized complete-block design with four replications. Plot size was 1.83 × 6.10 m. The treatments consisted of: 1–3) WIC applied every 21 d with a Toro HydroJect in the raised position, and applied either every 14 or 21 d with the same equipment in the lowered position; 4) STC applied every 14 d; and 5) no cultivation (check). The STC treatment was performed with a Toro greens aerifier (model 09100) equipped with 6-mm-diameter solid tines producing a hole spacing 0.9100 mm, spaced 76 mm apart. Holes created by the WIC treatment in the raised and lowered position, the HydroJect produced a hole spacing of 76 × 76 mm and 44 × 76 mm, respectively. Holes created by the WIC treatment in the raised and lowered position were ≈3 mm diameter × 108 mm deep and ≈1.5 mm diameter × 83 mm deep, respectively. Unlike the other cultivation treatments, the WIC treatment in the raised position created a surface entry (≈9 mm in diameter) that was wider than the hole.

The putting green was managed to satisfy the requirements of an in-use practice putting green located on a public golf course that annually receives ≈70,000 rounds of play. The green was maintained at a 4- to 5-mm cutting height, with the higher cutting heights utilized during the summer to reduce high-temperature stress. The green was irrigated to prevent visual drought symptoms and to provide the most satisfactory putting surface. The irrigation water source was effluent with an EC = 0.98 dS·m⁻¹. Leaching of excess salts was performed by applying ≈36 mm of irrigation on the last Sunday of each month during the period when cultivation treatments were applied. To maintain adequate turfgrass growth and color, N was applied at an annual rate of 488 kg·ha⁻¹ using a combination of ammonium, urea, and nitrate N sources. Annual applications of (NH₄)₂HPO₄, K₂SO₄, and FeSO₄ were made to supply 117, 610, and 36 kg·ha⁻¹ of P, K, and Fe, respectively. Fungicides were applied to prevent or control various summer diseases.

Field infiltration rates of water were measured during 2 consecutive days, twice in 1996 and three times in 1997 (see Table 1 for dates). On each of the 2 d, two complete blocks were measured. Measurements were taken after a date in which all cultivation treatments were applied (8 to 11 d and 8 to 9 d after cultivation, in 1996 and 1997, respectively). Also, measurements were normally taken 1 d after irrigation. On each date, two measurements were taken from the north 1.83 × 2.44 m end of each plot with a double-ring infiltrometer with a 20-cm inner ring, 30-cm outer ring, and a 5.0-cm ponding depth. Steady-state infiltration rate was obtained when readings in the inner ring approached a constant rate (Wu et al., 1997). The two measurements from each plot were averaged. Infiltration rate data were not normally distributed based on the Shapiro-Wilk test (Shapiro and Wilk, 1965). Therefore, these data were transformed using the common log, and subjected to analysis of variance (ANOVA), including a contrast and a mean separation procedure, and treatment means were back-transformed to the antilog (10^x, where x = mean in the common log scale).

The ODR was measured on the same dates as field infiltration rates of water plus an additional date on 16 Oct. 1996 (90 d after initial cultivation treatments and 9 d after a date in which all cultivation treatments were applied). The measurements followed the procedures of Phene (1986). Eight platinum microelectrodes were used to measure ODR for each plot at a depth of 2.5 cm (=1.0 cm below the soil-thatch line) with a soil ODR meter (Jensen Instruments, Tacoma, Wash.).

Measurements of the soil electrical conductivity of the extract (ECe) were taken as a sample set, each consisting of measurements before and after a leaching event (see Table 2 for leaching event dates). Measurements were normally 2 d before or after a leaching event. On each measurement date, five 2-cm-diameter cores were taken from the south 1.83 × 3.66 m end of each plot. A grid was used when taking cores for soil ECe, soil bulk density and porosity, and root weight density so that a 10 × 10-cm area was sampled only once over the course of the two-season study. The cores were separated into sections 0 to 2.5, 2.5 to 7.5, and 7.5 to 15.0 cm below the soil-thatch line (=1.5 cm below the surface), and sections for each plot were pooled by depth. A 10.0-g soil subsample was placed into a plastic cup and distilled water was added until a saturated soil paste was obtained. A solution from the paste was vacuum extracted and measured for EC, using a GLA M33.1 Instant EC Salinity Tester (GLA Agricultural Electronics, 1995).

Soil bulk density and porosity were measured 26 Nov. 1996 and 1 Oct. 1997 (134 and 135 d after initial cultivation treatments, respectively). Measurements were taken after a cultivation date on which all cultivation treatments were applied. They were taken 8 and 9 d after cultivation in 1996 and 1997, respectively. One undisturbed soil core, 5.0 cm diameter × 5.0 cm deep (with the 0 cm depth at the soil-thatch line), was taken from the south 1.83 × 3.66-m end of each plot. Soil water content at saturation, –10 and –100 kPa (Klute, 1986), and bulk density were determined from the undisturbed cores. Total and air-filled soil porosity were calculated from these measurements. The volumetric water content at –10 kPa was assumed to be field capacity for the modified root-zone soil (Cassel and Nielsen, 1986).

Root weight density was measured 26 Sept. and 26 Nov. 1996 (70 and 131 d after initial treatments, respectively) and on 30 Sept. 1997 (134 d after initial cultivation treatments). Four 3.0-cm-diameter cores were taken from the south 1.83 × 3.66-m end of each plot. The cores were separated into two sections 0 to 7.5 and 7.5 to 15.0 cm below the soil-thatch line (=1.5 cm below the surface). Cores from each

Table 1. The influence of water injection cultivation (WIC) and solid tine cultivation (STC) treatments on the field infiltration rate of water in an annual bluegrass putting green during 1996 and 1997.

| Date | WIC | Behaviour | Lowered position | STC | Behaviour | Check | ANOVA effect | Contrast, WIC and STC vs. check |
|------|-----|-----------|-----------------|-----|-----------|-------|--------------|-------------------------------|
| 5–6 Sept. (49–50) | 21 | 19.7 | 5.6 | 21.0 | 27.2 | 20.9 | 16.8 | 0.073 | 0.026 |
| 6–7 Sept. (51–52) | 14 | 5.1 | 1.6 | 5.1 | 8.2 | 8.3 | 4.9 | 0.052 | 0.066 |
| 26–27 Nov. (131–132) | 21 | 8.4 | 2.4 | 5.8 | 15.0 | 12.6 | 7.4 | 3.9 | 10.3 |
| 10–11 July (52–53) | 14 | 16.5 | 2.3 | 14.8 | 16.9 | 7.8 | 9.4 | 3.9 | 10.3 |
| 20–21 Aug. (93–94) | 14 | 16.5 | 2.3 | 14.8 | 16.9 | 7.8 | 9.4 | 3.9 | 10.3 |
| 30 Sept.–1 Oct. (134–135) | 14 | 16.5 | 2.3 | 14.8 | 16.9 | 7.8 | 9.4 | 3.9 | 10.3 |

2Total number of seasonal applications were ten and seven for treatments applied every 14 and 21 d, respectively.

3No. days after initial cultivation treatments.

4Mean separation within columns by Fisher’s protected LSD test, P = 0.05. Statistical analysis based on log transformed data.
Table 2. Main effects of water injection cultivation (WIC) and solid tine cultivation (STC) treatments, sample set, leaching, and their interactions on overall soil ECe at three root-zone depths in an annual bluegrass putting green during 1996 and 1997.

| Cultivation treatment (T) | Application interval (cm) | Root-zone depth (cm) below soil-thatch line |
|--------------------------|---------------------------|------------------------------------------|
|                          | 0–2.5                     | 2.5–7.5                                  | 7.5–15.0                                |
| WIC                      |                           |                                         |
| Raised position          | 21                        | 1.89 a                                  | 1.13 b                                  |
| Lowered position         | 14                        | 2.00 a                                  | 1.33 ab                                 |
| Lowered position         | 21                        | 1.84 a                                  | 1.15 b                                  |
| STC                      | 14                        | 1.86 a                                  | 1.08 b                                  |
| Check                    |                           |                                          |
|                          | 31 Aug. 1997 (104)        | 2.67 a                                  | 1.56 a                                  |
|                          | 28 July 1997 (70)         | 1.87 b                                  | 1.27 bc                                 |
|                          | 29 June 1997 (41)         | 2.47 a                                  | 1.34 b                                  |
|                          | 27 Nov. 1996 (Table 1)    | 0.29                                    | 0.09                                    |
| ANOVA effect (P)         |                           |                                         |
| Sample set (S)           |                           | 0.001                                   | 0.001                                   |
| Date of leaching event (d after initial cultivation treatments) |                           |                                         |
| 29 Sept. 1996 (73)       | 1.32 c                    | 1.18 c                                  | 0.92 b                                  |
| 28 Oct. 1996 (102)       | 1.31 c                    | 0.99 d                                  | 0.82 b                                  |
| 29 June 1997 (41)        | 2.67 a                    | 1.56 a                                  | 1.29 a                                  |
| 28 July 1997 (70)        | 1.87 b                    | 1.27 bc                                 | 0.95 b                                  |
| 31 Aug. 1997 (104)       | 2.47 a                    | 1.34 b                                  | 0.96 b                                  |
| ANOVA effect (P)         |                           | 0.29                                    | 0.09                                    |
| Leaching                 |                           |                                          |
| Before leaching event    | 1.90 a                    | 1.34 a                                  | 1.01 a                                  |
| After leaching event     | 1.95 a                    | 1.19 b                                  | 0.96 a                                  |
| ANOVA effect (P)         |                           | 0.582                                   | 0.001                                   |
| ANOVA interaction effects and contrast |                           |                                         |
| T × S                    | 0.918                     | 0.384                                   | 0.786                                   |
| T × leaching             | 0.161                     | 0.422                                   | 0.046                                   |
| Contrast, WIC and STC vs. check × leaching | 0.698                     | 0.200                                   | 0.235                                   |
| S × leaching             | 0.018                     | 0.001                                   | 0.090                                   |
| T × S × leaching         | 0.891                     | 0.969                                   | 0.509                                   |

*The experimental design of this study was randomized complete blocks with four replications of each cultivation treatment. Measurements of soil ECe were taken as a sample set (S), each consisting of measurements before and after a leaching event (leaching). The overall ANOVA (by each root-zone depth) was a repeated measures design with S and leaching as the repeated measures factors. Total number seasonal applications were 10 and seven for treatments applied every 14 and 21 d, respectively.

*Mean separation within factors and columns by a Fisher’s protected LSD test, P = 0.05.

Field infiltration rates of water were significantly increased by WIC and STC treatments on each measurement date, with the exception of 26-27 Nov. 1996 (Table 1, see contrast, WIC and STC vs. check). Murphy and Rieke (1994) reported that WIC significantly increased saturated hydraulic conductivity during the second year of a 2-year study. The effect of WIC in the raised position did not differ significantly from that of STC, although it was greater on all measurement dates. This treatment created the fewest holes per unit area, but provided the widest-diameter surface entry into the holes. The latter characteristic may have increased field infiltration rates of water by causing holes to remain open for a longer period of time.

The ECe of the soil was measured as five sample sets (S) each consisting of measurements before and after a leaching event (leaching). An overall analysis of soil ECe for each root-zone depth consisted of a repeated measures design with S and leaching as the factors (Table 2). This method of analysis was used because emphasis was placed on cultivation treatments (T), leaching, and T × leaching, and because the interactions and contrast of T × S, T × leaching, T × S × leaching, and WIC and STC vs. check × leaching were generally nonsignificant.

The WIC and STC treatments significantly decreased overall soil ECe at depths of 2.5 to 7.5 cm and 7.5 to 15.0 cm (P = 0.004 in each case) but not to 2.5 cm (Table 2, see contrast, WIC and STC vs. check). The lack of salt leaching at shallow depth was probably due to the higher organic matter content and cation exchange capacity. Thus, less leaching occurred in the top layer than in the coarser-textured subsurface sand. No differences in soil ECe levels among WIC and STC treatments were significant, regardless of root-zone depth.

Sample set (S) and S × leaching were generally significant, which may suggest the dynamic nature of soil salinity during the two seasons. The overall leaching effect was only significant at the 2.5- to 7.5-cm depth. Leaching had a minimal effect, probably because of the relatively low salinity in the irrigation water and in the 0- to 15-cm root zone below the soil thatch line (=1.5 cm below the surface).

Measurements of ODR were normally taken 1 d after an irrigation. Overall ODR values (Table 3) were higher than the critical value of 0.2 to 0.3 µO·cm·min⁻¹, and therefore sufficient (Stolzy and Letey, 1964). There were no significant differences in overall ODR among cultivation treatments.

The WIC and STC treatments did not significantly affect overall soil bulk density or total and air-filled porosity (Table 3). Murphy and Rieke (1994) reported that WIC and HTC (13-mm-diameter hollow tines) significantly lowered soil bulk density and increased air-filled porosity and total porosity in the 0 to 76 mm depth of a creeping bentgrass putting green. One explanation as to why the results of our study differ from those of Murphy and Rieke is that their study site had a higher soil bulk density and a lower soil porosity, which made their improvement more likely. In our
study, WIC and STC did not change the bulk soil volume by creating narrow channels. Channels were significant for infiltration and salt leaching, but long-term changes in the bulk soil volume would probably require modifications in soil texture.

The WIC and STC treatments did not significantly affect overall root weight density in the 0- to 7.5-cm and 7.5- to 15.0-cm depths. Murphy and Rieke (1994) reported that WIC did not affect total root weight or root weight density in the 0- to 200-mm depth. However, HTSC significantly reduced total root weight and root weight density, especially in the 0- to 50-mm depth.

**Conclusions**

To compensate for stresses associated with summer decline of annual bluegrass putting greens, good soil physical and hydraulic properties must be maintained to allow sufficient water infiltration, salt leaching, and good aeration.

Summer treatment with WIC and STC significantly increased field infiltration rates of water and reduced soil salinity for an in-use practice putting green. Such treatments can help reduce multiple summer stresses in managing annual bluegrass putting greens in southern California. The WIC in the raised position did not differ significantly from STC, although it had greater field infiltration rates of water on all dates. The treatments did not significantly affect bulk density or total and air-filled porosity. Air-filled porosity and ODR measurements indicated that soil aeration at this site was sufficient for plant growth.

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