EVALUATION OF WATER CONSERVATION SURFACTANTS ON TWO WARM-SEASON GRASSES IN SOUTHERN CALIFORNIA

FINAL REPORT

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BACKGROUND

Fresh water is a precious resource in southern California where average annual rainfall is 25.4 cm. This is particularly true when maintaining warm-season turfgrasses in Riverside (or in much of the southwestern United States) which theoretically require 115.3 cm of irrigation water per year. The availability of irrigation water to meet these requirements has, in recent years, been constrained by both the increase in water demands due to growing urbanization and multiple years of drought conditions. This has generated a need for water conservation efforts, including determining recommendations for landscape water allocation. While there is justification for this, there is also a need to be more efficient with irrigation practices, either through scheduling irrigation according to reference evapotranspiration (ET_o) (including "deficit irrigation", or irrigating below ET_{crop}) or by ensuring that irrigation water is more readily available for plant use.

One method of increasing irrigation efficiency is to schedule irrigation according to reference evapotranspiration (ET_o). ET_o is an estimate of the amount of water used by a healthy, 10- to 15- cm tall stand of cool-season turfgrass, such as tall fescue. It can be calculated in real-time from specific weather parameters, as well as historical average values which are available in tabular form. Actual turfgrass water use (ET_{crop}) is calculated as a percentage of ET_o by multiplying the latter by crop coefficients (K_c) which are specific for the crop of interest. For example, cool-season turfgrasses have an annual average K_c of 0.8 and warm-season turfgrasses have an annual average K_c of 0.6. Annual average water use for a warm-season turfgrass is therefore 60% of ET_o (ET_o x 0.6). ET_{crop} should then be divided by the distribution uniformity (DU) of the irrigation system. This increases the required water application because DU values are less than unity. In the previous example, if DU was 0.75 (a fair value for the industry) then actual irrigation requirements = (ET_{crop}/DU = 60% ET_o)/0.75 = 80% ET_o.

Irrigation efficiency can be further increased by ensuring that all applied water reaches the root zone where it is available for uptake and plant processes. Certain management practices can aid water infiltration. Core cultivation can reduce hydrophobic thatch layers and soil compaction, thus improving water infiltration. Irrigation can be applied with repeated cycles with sufficient time between cycles to allow water to infiltrate the soil. Irrigation systems with lower precipitation rates (such as drip) also can be employed to minimize runoff and water waste. Another strategy is to employ soil penetrants or wetting agents (surfactants) which mitigate hydrophobic conditions and improve water infiltration. The objective of this study was to evaluate the effectiveness of surfactant-product water conservation treatments on bermudagrass and zoysiagrass grown in Riverside, California and irrigated from 3 June through 3 November, 1998 with 100, 80 (or 70), and 60% ET_{crop}/DU (approximately 76, 61, and 45% ET_o, respectively).

MATERIALS AND METHODS

The performance of two warm-season turfgrasses treated with chemical surfactant (wetting agent) blends were evaluated when irrigated at three irrigation levels from 3 June through 3 November, 1998 (153 days). Irrigation levels were 100% ET_{crop}/DU, 80% ET_{crop}/DU (lowered to 70% ET_{crop}/DU on

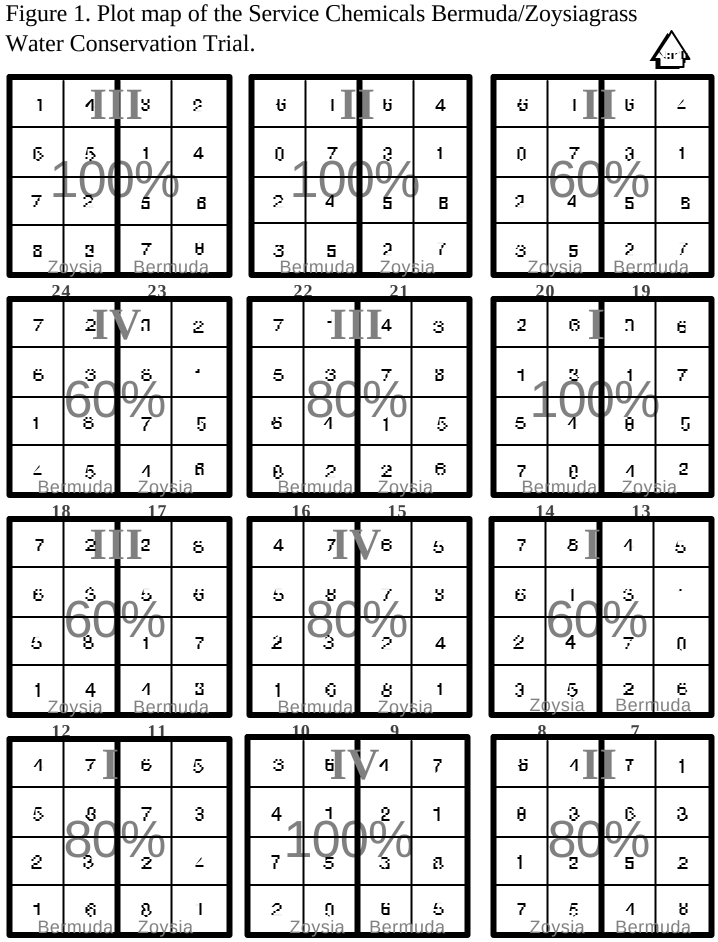
September 23), and 60% ET_{crop}/DU. These levels were equivalent (approximately) to 76, 61, and 45% ET_o, respectively. ET_{crop} was calculated as ET_o x K_c, where K_c is the crop coefficient for warm-season turfgrass. Though the annual average K_c for warm-season turfgrass is 0.6, monthly K_c values ranged from 0.54 to 0.79, as shown in Table 1. The 100% ET_{crop} treatment replenished approximately all of the water used by the bermudagrass and zoysiagrass each week. The 80 and 60% treatments applied a deficit amount of water, meaning that the water used by the turfgrass was not replenished fully each week, and therefore the soil slowly dried.

Table 1. Monthly warm-season turfgrass crop coefficients.

Month	January	February	March	April	May	June	July	August	September	October	November	December
K_c	0.55	0.54	0.76	0.72	0.79	0.68	0.71	0.71	0.62	0.54	0.58	0.55

Two warm-season turfgrasses, Arizona common bermudagrass (<u>Cynodon dactylon</u>) and El Toro zoysiagrass (<u>Zoysia japonica</u>), were sodded in winter of 1995 onto a special field plot designed to allow individual irrigation control of each of 12 irrigation main plots (Figure 1). Care was

Figure 1. Plot map of the Service Chemicals Bermuda/Zoysiagrass Water Conservation Trial.



100%, 80%, 60% = 100, 80, and 60% ETcrop/DU, or approx. 76, 61, and 45% ETo, respectively.
I,II,III,IV denote replication numbers. Blocks (replicates) were arranged by the DU of each irrigation main plot.
Bermuda and Zoysia refer to bermudagrass and zoysiagrass subplots, respectively, and are numbered 1 to 24.
1,2,3,4,5,6,7,8 denote sub-sub plot product treatments: 1=untreated, 2= GMB/A/02/LO, 3=GMB/A/02/IA, 4=GMB/A/02/I8, 5=GMB/A/02/I9, 6=GMB/A/02/L1, 7=GMB/A/02/L3, 8=GMB/A/02/L7.

taken to assure that the root-zone soil of the sod was the same as the field plot to prevent layering. Irrigation main plots measured 6.1 m x 6.1 m and were irrigated with Hunter PGM rotors located at the four corners of each plot. Irrigation main plots were separated by 23-cm borders. Care was taken to maximize the DU of the 12 irrigation main plot systems by ensuring that head alignment was vertical, and system operating pressures were within the manufacturer's recommended range. The average DU was 0.86 and ranged from 0.82 to 0.90.

Experimental design was a split-split-plot design with four complete blocks (replications) (Figure 1). Irrigation level treatments formed the main plots and turfgrass species formed subplots which measured 3.0 m x 6.1 m. Main plots and subplots were separated by 23-cm borders. Chemical treatments formed rectangular sub-sub plots which measured 1.4 m x 1.5 m.

The pre-study fertility regime included a $22N\text{-}3P_2O_5\text{-}9K_2O$ granular fertilizer, 48 kg N ha^{-1} (1.0 lb N 1000 ft^{-2}), applied in February, 1998, a $15N\text{-}15P_2O_5\text{-}15K_2O$ granular fertilizer, 48 kg N ha^{-1} (1.0 lb N 1000 ft^{-2}), applied once per month in February and March, 1998, and a $16N\text{-}6P_2O_5\text{-}8K_2O$ granular fertilizer, 48 kg N ha^{-1} (1.0 lb N 1000 ft^{-2}), applied 31 March and 14 April, 1998. The green-up fertilizer regime was changed to a typical maintenance regime on April 30: 24 kg N ha^{-1} (0.5 lb N 1000 ft^{-2}) $16N\text{-}6P_2O_5\text{-}8K_2O$ granular fertilizer was applied 30 April , 14 May, and 28 May. The $16N\text{-}6P_2O_5\text{-}8K_2O$ granular fertilizer was applied every two weeks during the study at a rate of 24 kg N ha^{-1} (0.5 lb N 1000 ft^{-2}) per month (12 kg N ha^{-1} or 0.25 lb N 1000ft^{-2} per application). This fertility regime was maintained from 10 June through 21 October, 1998.

Plots were mowed on Tuesday and Friday, beginning 14 April, with a 51-cm wide walk-behind 7-blade McClane reel mower. Height of cut was set at 19 mm (0.75 inch). Zoysiagrass plots were vertical mowed (verticut) with four passes in April 1998 to reduce thatch. Routine maintenance included checking irrigation systems every two weeks for proper operation, edging plots with Roundup (2% glyphosate) to prevent overgrowth and contamination between subplots, and hand weeding as necessary. Ronstar G (2% Oxadiazon) pre-emergent herbicide was applied February 26 at a rate of 16.8 kg product ha^{-1} to prevent crabgrass and broadleaf weed growth. Oxalis was controlled with Gordon's Trimec turf herbicide [Dimethylamine Salt of 2,4-Dichlorophenoxyacetic acid, 30.56%, Dimethylamine Salt of 2-(2-methyl-4-chlorophenoxy) propionic acid, 16.34%, Dimethylamine Salt of Dicamba (3,6-dichloro-o-anisic) acid, 2.77%].

All irrigation main plots were irrigated Monday and Thursday with one of three irrigation levels: 1) 100% ET_{crop}/DU (?76% ET_o), 2) 80% ET_{crop}/DU (?61% ET_o), or 3) 60% ET_{crop}/DU (?45% ET_o). Note that the 80% treatment level was lowered to 70% ET_{crop}/DU (?53% ET_o) on September 23 and remained at this level through 3 November. The level was lowered because there were no visual differences between the 100% ET_{crop}/DU and 80% ET_{crop}/DU irrigation levels. (Note that above percentages of ET_o were calculated assuming an average crop coefficient, or K_c value, for the evaluation period of 0.65 and an average DU of 0.86 for the 12 irrigation main plots. Calculation of weekly percentages is discussed below.)

The irrigation controller was programmed weekly using the appropriate monthly K_c and weekly ET_o

from a CIMIS (California Irrigation Management Information System) station located approximately 100 m from the research plot. Irrigation run times used to program the irrigation controller were calculated as follows. ET_{crop} (mm) was calculated by multiplying CIMIS ET_o (cumulative, from the previous 7 days, mm) by the monthly warm-season K_c. Monthly warm-season K_c values for June, July, August, September, and October are 0.68, 0.71, 0.71, 0.62, and 0.54, respectively, and reflect changes in warm-season turfgrass water requirements during different summer months. ET_{crop} was then multiplied by individual irrigation main plot system precipitation rates (mm hr^{-1}, determined from catch-can tests) and then by a treatment factor (1.0, 0.8, or 0.6 for the 100, 80, or 60% treatments, respectively) to determine run times (min) for each of the 12 stations. Run times were then divided by the respective DU of each main plot. Dividing run times by DUs less than unity resulted in increased water application to compensate for dry areas within each plot. Resulting run times were programmed into the controller every Wednesday. Irrigation events were cycled five times to preclude runoff and occurred in the early morning to avoid potentially windy conditions..

Catch-can tests were performed by placing straight-sided cans on the turfgrass surface in a grid pattern. Irrigation systems were run for a specified amount of time and the depth of collected water was measured. DU was calculated as the mean collected water depth of the low quarter (one-fourth of cans with lowest water depth) divided by the overall mean depth (all cans). Numbers for typical irrigation systems range from 0.6 to 0.9, with higher numbers representing higher irrigation system uniformity. Catch can tests were conducted on each irrigation main plot on May 21, 1998. Average DU for the 12 plots was 0.86 and ranged from 0.82 to 0.90.

Chemical surfactant treatments

Surfactant blend treatments were comprised of three granular materials, three liquids applied with a calibrated research sprayer, and one treatment mixed with water and applied with a watering can as a drench. An untreated control plot was also included for comparison purposes. The total number of surfactant treatment subplots was eight, randomly assigned within each bermudagrass and zoysiagrass subplots. All treatments were applied according to manufacturer’s directions. Specific application notes are included in Table 3. A description of the eight treatments are listed below:

1. Untreated control
2. GMB/A/02/LO: 50 L ha^{-1} in 20,000 L ha^{-1} water, single application with watering can, watered in after application.
3. GMB/A/02/IA: granular, 250 kg ha^{-1}, single application, watered in after application.
4. GMB/A/02/I8: granular, 250 kg ha^{-1}, single application, watered in after application.
5. GMB/A/02/I9: granular, 250 kg ha^{-1}, single application, watered in after application.
6. GMB/A/02/L1: 20 L ha^{-1} in 1000 L ha^{-1} water, monthly spray application, not watered in after application.
7. GMB/A/02/L3: 20 L ha^{-1} in 1000 L ha^{-1} water, monthly spray application, not watered in after application.
8. GMB/A/02/L7: 20 L ha^{-1} in 1000 L ha^{-1} water, monthly spray application, not watered in after application.

Note that all chemical treatments were initially applied 17 and 19 June, 1998. Spray treatments 6, 7, and 8 were re-applied monthly. Watering can treatment 2 was re-applied on 9 September, 1998 and granular treatments 3, 4, and 5 were re-applied on 21 September, 1998.

Visual turfgrass ratings

All turfgrass sub-subplots were visually rated to determine what effect the irrigation level, turfgrass species, and surfactant blend treatments had on turfgrass visual quality, color, and the expression of drought symptoms within the canopy. Visual turfgrass ratings began on 26 June and were taken every other Tuesday prior to mowing, through 29 October, 1998. Visual turfgrass quality was measured on a 1 to 9 scale with 1=poorest and 9=best bermudagrass or zoysiagrass quality. A rating of 5 was considered minimally acceptable turfgrass quality. Visual turfgrass color was measured on a 1 to 9 scale with 1=poorest and 9=best (darkest green) bermudagrass or zoysiagrass color. Ratings for percent brown tissue and percent rolled and wilted leaves within each sub-subplot turfgrass canopy were measured concurrently with visual quality and color ratings.

Soil water content and soil water tension

Soil water content levels were monitored in each bermudagrass and zoysiagrass subplot by two methods, which provided information on how the three irrigation treatments were wetting the soil profile, and how the two turfgrass species might be extracting soil water differently. The first of these methods was volumetric soil water content (m^3 H_2O m^{-3} soil) which was measured by neutron scattering (Boart Longyear CPN 503 DR Hydroprobe) in plot centers at 30-, 60-, 90-, 120-, 150-, and 180-cm depths (12-, 24-, 36-, 48-, 60-, and 72-inch depths) using one neutron probe access tube per species subplot. Pre-irrigation readings (measured when soil is the driest) were taken once every two weeks, beginning 14 May and ending 21 October, 1998. A calibration curve relating count ratio (measured counts divided by base count) to volumetric soil water content was derived from 39 soil samples extracted from the current project's plot and two nearby plots. The soil classification from each plot was the same and was considered to have equivalent ratios of sand, silt, clay, and organic matter. The equation was:

Volumetric soil water content (m^3 H_2O m^{-3} soil) =

$$(36.379 * \text{count ratio}) - 12.927. \quad R^2 = 0.90$$

The second method used to monitor soil water content was to measure soil water tension (MPa) with Watermark granular matrix sensors installed at 30- and 60-cm (12- and 24-inch) depths in close proximity to the neutron probe access tubes. Care was taken during installation to ensure good soil to sensor contact. Sensors were read Wednesday and Thursday (before and after all treatments irrigated) from remote terminals (Watermark Remote Readers, Irrometer Co., Riverside, CA) installed in the center of the study area. Readings began 26 May and ended 3 November, 1988 and provided information about seasonal soil water tension and how it may have been affected by irrigation treatments and turfgrass species.

Statistical analysis of data

Visual rating data were subjected to a split-split plot analysis of variance (ANOVA) and Fischer's protected LSD means separations with SAS's general linear model procedure (SAS Institute, 1985).

Irrigation level constituted main plots, turfgrass species (bermudagrass or zoysiagrass) formed subplots, and surfactant treatments formed sub-subplots. Visual rating data were further subjected to a repeated-measures (overall) ANOVA (split-split-split-plot design for split-split-plot ANOVA) to investigate seasonal effects of irrigation level, species, and surfactant treatments on turfgrass performance. A single-degree-of-freedom orthogonal contrast of surfactant treated treatments *vs*. untreated check treatments was also performed for visual ratings.

Soil water content and soil water tension data were subjected to a split-plot ANOVA and Fischer's protected LSD means separations with SAS's general linear model procedure (SAS Institute, 1985). Irrigation level constituted main plots and species (bermudagrass or zoysiagrass) formed subplots. Soil water content and tension data were also subjected to a repeated-measures (overall) ANOVA (split-split-plot design for split-plot ANOVA) to investigate seasonal effects of irrigation level and species on soil water content and tension.

Table 2. Materials and methods outline for the 1998 Service Chemical Water Conservation Trial.

Objective:	To evaluate the effectiveness of surfactant-product water conservation treatments on bermudagrass and zoysiagrass grown in Riverside, California and irrigated from 3 June through 3 November, 1998 with 100, 80 (or 70) and 60% ET_{crop}/DU (▾76, 61, and 45% ET_o, respectively).
Genotypes:	Arizona common bermudagrass and El Toro zoysiagrass.
Location and root zone:	Block 12 E, plot No. 14, UCR Turfgrass Field Research Facility. Plot was established with sod in December 1995. Root zone soil was a well-drained native alluvial soil classified as a Hanford fine sandy loam (coarse-loamy, mixed, Thermic Haplic Durixeralf) with a sand, silt, and clay content of approximately 42, 43, and 15% (mass/mass), respectively. Further soil characteristics were as follows: pH= 7.1; CEC=16.5 meq $100g^{-1}$ soil; OM=2.14%; SAR=2.
Experimental design:	Split-split plot design with four complete blocks (replications) (Figure 1). Irrigation treatments formed the main plots which measured 6.1 m x 6.1 m (20.0 ft x 20.0 ft). Species formed subplots which measured 3.0 m by 6.1 m (10.0 ft x 20.0 ft). Chemical treatments formed rectangular sub-sub plots which measured 1.4 m by 1.5 m (4.5 x 4.8 ft). Irrigation main plots and species subplots were separated with 23-cm (9-inch) borders.
Fertilization:	22N-3P_2O_5-9K_2O granular fertilizer, 48 kg N ha^{-1} (1.0 lb N 1000 ft^{-2}), was applied in February. 15N-15P_2O_5-15K_2O granular fertilizer, 48 kg N ha^{-1} (1.0 lb N 1000 ft^{-2}), was applied once per month in February and March. 16N-6P_2O_5-8K_2O granular fertilizer, 48 kg N ha^{-1} (1.0 lb N 1000 ft^{-2}), was applied March 31 and April 14. The green-up fertilizer program was changed to 16N-6P_2O_5-8K_2O granular fertilizer, 24 kg N ha^{-1} (0.5 lb N 1000 ft^{-2}), applied April 30, May 14, and 28 May, 1998. 16N-6P_2O_5-8K_2O granular fertilizer, 24 kg N ha^{-1} (0.5 lb N 1000 ft^{-2}) per month, was applied every two weeks during the study (12 kg N ha^{-1} or 0.25 lb N $1000ft^{-2}$ per application), beginning 10 June, 1998.
Mowing:	All plots were mowed Tuesday and Friday with a walk-behind, 51-cm (20-inch), seven-blade McClane reel mower with clippings collected. Height of cut was set at 1.9 cm (0.75 inch).
General plot maintenance:	- Vertical mowing in early spring, four directions, zoysiagrass plots only. - Monthly edging with Roundup (2% glyphosate). - Ronstar G (2% Oxadiazon) pre-emergent herbicide was applied in February, 1998 at a rate of 16.8 kg product ha^{-1} (3.5 lb product 1000 ft^{-2}) to control crabgrass and broadleaf weeds.

- Oxalis controlled with Gordon's Trimec turf herbicide [Dimethylamine Salt of 2,4-Dichlorophenoxyacetic acid, 30.56%, Dimethylamine Salt of 2-(2-methyl-4-chlorophenoxy) propionic acid, 16.34%, Dimethylamine Salt of Dicamba (3,6-dichloro-o-anisic) acid, 2.77%].

- Hand weeding performed as necessary.
- Aisles and plots topdressed with field soil as needed for a level, flat mowing surface.

Irrigation:

Two irrigation events per week, according to irrigation treatment protocol (see section below). Irrigation events were on Monday and Thursday mornings, before sunrise. Irrigation water was from the Riverside potable water supply with the following characteristics: pH=8.4, EC=0.60 mmhos cm^{-1}, Ca=3.9 meq L^{-1}, Mg=1.1 meq L^{-1}, Na=1.5 meq L^{-1}, SAR<1, Cl=8.6 meq L^{-1}, B=0.1 ppm, HCO_3=3.4 meq L^{-1}, CO_3 <0.1 meq L^{-1}, SO_4-S=24 ppm. Main plots were irrigated by four Hunter PGM rotors equipped with 1.0-gpm nozzles and located at the four corners of each plot.

Irrigation system checks:

Vertical of all heads was checked with a level and adjusted once every two weeks. Catch can tests were performed in May to determine system precipitation rates and DUs of each irrigation main plot. Maximum DUs were obtained by ensuring system operating pressures (measured at solenoid valve) were close to manufacturer's recommendation (40 psi) and by maintaining head alignment and arc adjustment. Precipitation rate and DU determinations of each irrigation main plot were used in calculating irrigation run times.

Proper clock (Rainbird ISC24+) operation was monitored by 24 VAC hour meters (IVO model B148) wired in parallel with solenoid valves.

Irrigation treatments (Initiated 3 June, 1998):

All main plots were irrigated Monday and Thursday with one of three irrigation levels: 1) 100% ET_{crop}/DU (? 76% ET_o), 2) 80% ET_{crop}/DU (? 61% ET_o), or 3) 60% ET_{crop}/DU (? 45% ET_o). Note that the 80% treatment level was lowered to 70% ET_{crop}/DU (? 53% ET_o) on 23 September, 1998 through the remainder of the study (3 November, 1998). Percentages of ET_o were calculated assuming an average K_c value for the evaluation period of 0.65 and an average DU of 0.86 for the 12 irrigation plots.

ET_{crop} was calculated by multiplying ET_o by the monthly warm-season K_c. Monthly warm-season K_c for June, July, August, September, and October were 0.68, 0.71, 0.71, 0.62, and 0.54, respectively, and reflected changes in warm-season turfgrass water requirements during different summer months.

ET_o values were obtained via phone modem from a CIMIS station located approximately 100 m from the research plot.

Distribution uniformity (DU) of each irrigation main plot indicated how uniformly sprinklers applied water over the irrigated surface. DU and system precipitation rates were calculated by performing a catch- can test where straight sided cans were placed on the turf surface in a grid pattern. Irrigation systems were run for a specified amount of time and the depth of collected water was measured. Catch can tests were conducted on each irrigation main plot on 21 May, 1998. These values were then used in the calculations for irrigation treatments. Average DU for the 12 plots was 0.86 and ranged from 0.82 to 0.90.

Irrigation treatments were programmed into the controller every Wednesday based on the previous week's accumulative 7-day ET_o. The following steps were used to calculate run times for each plot.

1. 7-day ET_o accumulation from CIMIS x monthly K_c = ET_{crop} (mm).

2. ET_{crop} (mm) x plot precipitation rate (min per mm) x irrigation treatment (1.0, 0.8, or 0.6) = irrigation run time (min).

3. Irrigation run time/plot distribution uniformity (DU) = adjusted irrigation run time per week.

4. Adjusted irrigation run time per week/2 = run time per day.

5. Run time per day/5 cycles = run time programmed into controller which was applied 5 times (cycles).

Irrigation events were cycled 5 times to preclude runoff and occured in early morning (2:00 a.m. to 6:00 a.m.) To avoid potentially windy conditions.

Chemical treatments:

Note that all chemical treatments were initially applied 17 June and 19, 1998. Spray treatments 6, 7, and 8 were re-applied monthly. Watering can treatment 2 was re-applied on September 9, 1998 and granular treatments 3, 4, and 5 were re-applied on September 21, 1998. Treatments were as follows:

1. Untreated control
2. GMB/A/02/LO: 50 L ha^{-1} in 20,000 L ha^{-1} water, single application with watering can, watered in after application.
3. GMB/A/02/IA: granular, 250 kg ha^{-1}, single application, watered in after application.
4. GMB/A/02/I8: granular, 250 kg ha^{-1}, single application, watered in after application.
5. GMB/A/02/I9: granular, 250 kg ha^{-1}, single application, watered in after application.

6. GMB/A/02/L1: 20 L ha^{-1} in 1000 L ha^{-1} water, monthly spray application, no watering in after application.

7. GMB/A/02/L3: 20 L ha^{-1} in 1000 L ha^{-1} water, monthly spray application, no watering in after application.

8. GMB/A/02/L7: 20 L ha^{-1} in 1000 L ha^{-1} water, monthly spray application, no watering in after application.

See Table 3 for further details.

Measurements:

Turfgrass visual ratings:

- Visual turfgrass quality measured on a 1 to 9 scale with 1 = poorest and 9 = best bermudagrass/zoysiagrass visual quality. A rating of 5 would constitute minimum acceptable quality. Visual turfgrass quality ratings were based upon density, texture, uniformity, color, growth-habit, and smoothness.
- Visual turfgrass color measured on a 1 to 9 scale with 1=brown and 9=best (darkest) green bermudagrass/zoysiagrass color (5=minimum acceptable turfgrass color).
- Percent brown/fired leaf tissue. Scale was 1 to 100% of total plot surface area.
- Percent rolled/wilted leaf tissue. Scale was 1 to 100% of total plot surface area affected.

All visual ratings were taken every other Tuesday prior to mowing.

Soil Water Content

- Soil tension at 30- and 60-cm (12- and 24-inch) depths in each turfgrass species subplot using Watermark granular matrix sensors connected to remote readers at the plot center. Sensors were located in each subplot (24 locations) and were read weekly before and after (Wednesday, Thursday) an irrigation event.

-Volumetric soil water content was measured with neutron scattering to a 1.8 m (6-ft) overall depth. Individual readings were taken at each of 23-, 30-, 61-, 91-, 122-, 152-, and 183-cm (9-, 12-, 24-, 36-, 48-, 60-, and 72-inch) depths in each bermudagrass and zoysiagrass subplot (24 locations). Readings were taken prior to irrigation (Wednesday) once every two weeks. The calibration curve relating count ratio to volumetric soil water content was derived from 39 soil samples extracted from the current study plot and two other plots nearby. The soil classification from each plot was the same and was considered to have equivalent ratios of sand, silt, clay, and organic matter.

The equation was:

Volumetric soil water content (m^3 H_2O m^{-3} soil) =
(36.379 * count ratio) - 12.927. R^2 =0.90

where count ratio was measured counts divided by a base count.

Statistical analyses of measurements:

Visual rating data were subjected to a split-split plot analysis of variance (ANOVA) and Fischer's protected LSD means separations with SAS's general linear model procedure (SAS Institute, 1985). Irrigation level constituted main plots, species (bermudagrass or zoysiagrass) formed subplots, and chemical treatments formed sub-subplots. Visual rating data was further subjected to a repeated-measures (overall) ANOVA (split-split-split-plot design for split-split-plot ANOVA) to investigate seasonal effects of irrigation level, species, and chemical treatments on turfgrass performance. A single-degree-of-freedom orthogonal contrast of surfactant treated treatments *vs*. untreated check treatments also was performed on visual rating data.

Soil water content and soil water tension data were subjected to a split-plot ANOVA and Fischer's protected LSD means separations with SAS's general linear model procedure (SAS Institute, 1985). Irrigation level constituted main plots and species (bermudagrass or zoysiagrass) formed subplots. Soil water content and tension data were also subjected to a repeated-measures (overall) ANOVA (split-split-plot design for split-plot ANOVA) to investigate seasonal effects of irrigation quantity and species on soil water content and tension.

Project duration:

15 April, 1998 through 31 March, 1999. (See Table 4 for more details)

Table 3. Chemical treatment application notes for the 1998 Service Chemical Water Conservation Trial.

Treatment number	Treatment designation	Application rates	Application per plot [z]	Application directions
1	Untreated	Untreated	None	None
2	GMB/A/02/LO	50 L ha^{-1} in 20,000 L ha^{-1} water	10.3 mL product in 4.12 L water per sub-subplot	Single application, product mixed in a watering can then applied in two directions with back and forth motion, water in after application
3	GMB/A/02/IA	granular, 250 kg ha^{-1}	51.4 g per sub-subplot mixed with 150 mL # 20 silica sand[y]	Single application. Product is mixed with sand in plastic bag, then transferred to a container with holes in lid. Mixture is applied with 'shaker' in three directions. An application box the size of an individual subplot is used to prevent contamination of adjacent subplots. Product watered in after application
4	GMB/A/02/I8	granular, 250 kg ha^{-1}	51.4 g per sub-subplot mixed with 150 mL # 20 silica sand	See application directions for treatment number 3.
5	GMB/A/02/I9	granular, 250 kg ha^{-1}	51.4 g per sub-subplot mixed with 150 mL # 20 silica sand	See application directions for treatment number 3.
6	GMB/A/02/L1	20 L ha^{-1} in 1000 L ha^{-1} water	4.12 mL product in 205.9 mL water per sub-subplot [x]	Monthly spray application with calibrated CO_2 pressurized research backpack sprayer, two directions. Application is made while being timed to ensure consistent application over all subplots Not watered in after application
7	GMB/A/02/L3	20 L ha^{-1} in 1000L ha^{-1} water	4.12 mL product in 205.9 mL water per sub-subplot	See application directions for treatment 6.
8	GMB/A/02/L7	20 L ha^{-1} in 1000L ha^{-1} water	4.12 mL product in 205.9 mL water per sub-subplot	See application directions for treatment 6.

[z]Individual sub-sub plots measure 1.40 m by 1.47 m (4.6 ft by 4.8 ft) and are 2.05 m^2 (22.15 ft^2) in area. There are 24 sub-subplots per chemical treatment for a total area of 49.4 m^2 (531.6 ft^2) per treatment.

[y]Granular treatments 3, 4, and 5 are mixed with 150 mL #20 silica sand (150 mL beaker filled to overflowing) and applied with a shaker (plastic container with holes in lid) in three directions. A box is placed on each sub-subplot for application to avoid contamination of adjacent subplots.

[x]Total spray volume for treatments 6, 7, and 8 is 98.9 mL product in 4942 mL final spray volume per surfactant treatment. Working mixture is 151.3 mL product in 7.6 L (2 U.S. gallons) mix. Product is applied using two blue (8003VS) Teejet nozzles and a 30 psi working pressure (nozzle output=0.059 m^3 hr^{-1}). Spray nozzle tips are held 74 cm from the ground. Spraying is done on Tuesday following mowing, or on Wednesday in the morning before wind arises. Spray application for each sub-subplot is timed by a second person (two 3.5-sec passes) to ensure consistent application volume over all sub-subplots.

Table 4. Calendar of major activities for the 1998 Service Chemical Water Conservation Trial.

Date	Activity
7 December, 1995	Bermudagrass and zoysiagrass sod planted on research plot.
14 April, 1998	Verticut zoysiagrass subplots.
	Biweekly (Tuesday, Friday) mowing initiated, 19 mm mowing height.
24 April	Broadleaf weed control spray (2,4-D, MSMA) applied.
14 May	First volumetric soil water content (neutron probe) readings.
18 May	Initiate Monday, Thursday irrigation schedule.
21-28 May	Catch-can tests to measure irrigation system uniformity and precipitation rates.
26 May	Initiate Watermark sensor readings (readings taken every Wednesday and Thursday hereafter).
28 May	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product.
3 June	Initiate irrigation treatments (100, 80, 60% ET_{crop}/DU applied twice per week).
5 June	Broadleaf weed control spray (Trimec) .
5-9 June	Measure, string, and mark chemical treatment sub-sub plots.
10 June	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product. First Watermark soil water tension measurement.
11 June	Neutron probe readings.
17 June	Initial application of liquid treatment 2 and granular treatments 3, 4, and 5.
18 June	Photos taken.
19 June	Research spray equipment calibrated and spray treatments 6, 7, and 8 applied.
24 June	Neutron probe readings taken, and every other week hereafter through 21 October, 1998.
26 June	First visual ratings for quality, color, rolling/wilting, and leaf firing.
29 June	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product.
7 July	Visual ratings for quality, color, rolling/wilting, and leaf firing.
15 July	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product.
21 July	Spray treatments 6, 7, and 8 applied.
22 July	Visual ratings for rolling/wilting and leaf firing.

29 July	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product.
7 August	Visual ratings for quality and color.
9 August	16 mm rain which alleviated drought symptoms for approximately 2 weeks. Rainfall was subtracted from 12 August irrigation program.
12 August	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product.
18 August	Spray treatments 6, 7, and 8 applied.
26 August	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product Ratings for rolling/wilting, and leaf firing.
26 August	Photos taken.
4 September	Visual ratings for quality and color.
9 September	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product Spray treatments 6, 7, and 8 applied, Re-applied liquid treatment 2.
18 September	Photos taken.
21 September	Granular treatments 3, 4, and 5 re-applied.
23 September	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product Initiated revised irrigation treatments (100, 70, and 60% ET_{crop}/DU).
30 September	Visual ratings for quality, color, rolling/wilting, and leaf firing.
7 October	Fertilize all plots, 24.4 kg N ha^{-1}, 16-6-8 soluble product.
9 October	Spray treatments 6, 7, and 8 applied.
21 October	Final neutron probe soil water content readings taken.
26 October - 2 November	Med test soil sampling of all sub-subplots.
29 October	Final rating for visual quality and color.
3 November	Final rating for rolling/wilting and leaf firing, photos taken. Final Watermark soil water tension readings taken. Terminate irrigation treatments.

III. RESULTS AND DISCUSSION

Irrigation application

Data was collected from 14 May through 3 November, 1998 (174 days) during which time each main plot received a depth of 100% ET_{crop}/DU (100%), 80% ET_{crop}/DU (80%), or 60%ET_{crop}/DU (60%). These three irrigation levels were roughly equivalent to 91%, 71%, or 51% ET_o, respectively. Note that the 80% treatment level was lowered to 70% ET_{crop}/DU (?53% ET_o) on 23 September and remained at this level through 3 November, 1998. The treatment level was lowered because there were no visual differences between the 100% and 80% irrigation levels. Lowering the irrigation level resulted in some differential visual drought symptoms.

Visual ratings

Visual turfgrass color ratings for both turfgrass species remained acceptable (▾ 5.0) for the duration of the study. Surfactant treatments had no significant effect on visual turfgrass color on any rating date while the effect of irrigation and species treatments was significant (Table 5). Visual turfgrass color ratings were significantly higher for zoysiagrass compared to bermudagrass on all dates except 29 October. Visual turfgrass color ratings also were significantly higher in plots irrigated with 100% and 80% compared to those irrigated with 60%. It should be noted that the latter treatment remained acceptable. The contrast of surfactant treated *vs.* untreated plots revealed a significant contrast on September 30, with treated sub-subplots having higher visual color ratings compared to untreated sub-subplots.

Visual turfgrass quality ratings were acceptable (▾ 5.0) between 26 June and 29 October, 1998 for all treatments (Table 6). Significant differences (P? 0.10) among surfactant treatments for visual turfgrass quality were observed on 4 September and 30 September. There was a significant contrast (P? 0.10) between surfactant treated vs. untreated plots on 30 September and overall. Visual turfgrass quality also was significantly influenced by irrigation treatments on all dates. Visual turfgrass quality was highest (ranging from 6.4 to 7.2) in plots irrigated with 100% and 80% compared to those irrigated with 60% (ratings ranging from 5.6 to 6.8). Visual turfgrass quality decreased between 26 June and 29 October, but this decrease was most evident in plots irrigated with 60%, indicating that this level of irrigation was insufficient to maintain a high level of visual quality for bermudagrass and zoysiagrass. Visual quality of zoysiagrass was significantly higher than bermudagrass throughout the season due to superior shoot density, color, and uniformity of the zoysiagrass canopy.

Surfactant treatments did not significantly influence ratings for percent leaves rolled and/or wilted on any date (Table 7). However, there was a significant (P? 0.10) contrast between treated and untreated sub-subplots on 22 July, 26 August, and 30 September, as well as overall. These data indicate that surfactant treated plots showed fewer wilt symptoms (less plot area affected) compared to the untreated control plots.

Significant differences in percent leaves rolled and/or wilted due to irrigation treatments were seen on all dates. Percent leaves rolled and/or wilted were significantly lower in plots irrigated with 100% and 80% compared to those irrigated with 60%. This is consistent with visual turfgrass quality and visual turfgrass color ratings which also were higher in plots irrigated with 100% and 80%. It should be noted that until 29 October, there were no significant differences in wilt ratings between the 100% and 80% irrigation treatments. The 80% treatment level was lowered to 70% ET_{crop}/DU on 23 September and remained at this level through 3 November in an effort to create visual differences between the high and middle irrigation treatments. The result was that means for percent leaves rolled/and or wilted were significantly different between all irrigation treatments on 29 October, with the 100% plots showing the fewest wilt symptoms, the 80% plots showing more wilt symptoms, and the 60% plots showing the most.

Wilt symptoms generally increased between 26 June and 29 October for the 80% and 60% treatments, indicating that irrigation at these levels was insufficient to prevent drought symptoms. Visual wilt symptoms were essentially nonexistent in plots irrigated with 100%. Percent rolled and/or wilted ratings were significantly different (*P*? 0.10) between species on most dates after 26 June. Wilt ratings for zoysiagrass were significantly higher (*P*? 0.10) than those for bermudagrass, indicating a greater susceptibility to drought symptoms in the former. Previous soil core/root analysis from 1997 data from the same research plot has shown that bermudagrass is more deeply rooted compared to zoysiagrass. This would suggest that bermudagrass has the ability to extract water from a larger soil volume compared to zoysiagrass, therefore better avoiding drought symptoms.

Ratings for percent brown/fired leaves increased between 26 June and 29 October, indicating the research plots became drier as the season progressed. Surfactant treatments significantly (*P*? 0.10) influenced ratings for percent brown (fired) leaves on three of six rating dates (7 July, 22 July, and 30 September) (Table 8). The contrast between treated and untreated plots also was significant on 22 July, 26 August, and 30 September, as well as overall, indicating that the surfactant treatments, as a whole, may be effective in reducing leaf firing in bermudagrass and zoysiagrass grown under the conditions of these research plots.

Ratings for percent brown/fired leaves were significantly influenced by the irrigation level treatments on all dates except 22 July (Table 8). There were significantly more brown leaves in plots irrigated with 60% compared to those irrigated with 80% or 100%, indicating that the low irrigation level was insufficient to prevent leaf firing in the two turfgrass species. Ratings for percent brown/fired leaves for zoysiagrass were significantly higher than those for bermudagrass on 29 October and overall, indicating, as above, a greater susceptibility to drought symptoms in zoysiagrass.

Soil water content and tension

Volumetric soil water content (m^3 H_2O m^{-3} soil) was measured in one location within each bermudagrass and zoysiagrass subplot by neutron scattering. Although we were unable to investigate surfactant treatment effects on soil water content, we were able to monitor the effects of irrigation and species treatments on soil water at depths between 23 cm and 173 cm. Volumetric soil water content data are presented in Tables 9 through 15. Soil water content generally decreased between 14 May and 21 October. This indicates that more water was being extracted from the soil than was being replenished through irrigation, especially the 60 % irrigation level treatment.

Irrigation treatments significantly influenced soil water content at the 23-, 30-, 60-, and 91-cm depths between 21 June and 21 October. Volumetric soil water content generally was highest in plots irrigated with 100% and 80% compared to those irrigated with 60% at these depths. There were no significant differences in soil volumetric water content due to irrigation treatments at the 122-, 152-, and 173-cm depths.

Soil water tension measured with Watermark granular matrix sensors at 30- and 60-cm depths were not significantly affected by irrigation level and species treatments (Tables 16 and 17). However, there appears to be a strong biological trend toward higher soil water tensions in plots irrigated with 60% compared to the other two irrigation treatments. Soil water tension did increase between 10 June and 3 November (rising from a 12-plot, two-depth average of 10 MPa to an average of 85 MPa), indicating that the soil became drier as the evaluation progressed. It should be noted that soil water tension values greater than 80 to 100 MPa (80 to 100 centibars) are normally considered dry for turfgrasses.

Summary

Mature bermudagrass and zoysiagrass turfgrasses irrigated with three irrigation levels showed varying degrees of drought stress. Plots irrigated at 100% ET_{crop}/DU showed good visual quality, color, and no drought symptoms. Those irrigated with 80% ET_{crop}/DU showed good visual quality, color, and began to show wilt and leaf firing symptoms only after this irrigation level was decreased to 70% ET_{crop}/DU on 23 September. Plots irrigated with 60% ET_{crop}/DU had significantly lower visual turfgrass quality and color and showed significantly more drought symptoms, measured as percent leaves rolled and/or wilted and percent brown/fired leaves. Thus we feel that the irrigation treatments were effective in producing a range of drought symptoms in the two species of warm-season turfgrass. Additionally, there were significant differences between the species with respect to visual turfgrass quality, color, leaves rolled and/or wilted, and percent brown leaves. Zoysiagrass visual quality and visual color was significantly higher than bermudagrass on all dates and overall. Ratings for percent leaves rolled and/or wilted were significantly higher for zoysiagrass than bermudagrass on all dates after 26 June, and overall. Percent brown (fired) leaves ratings were significantly higher for zoysiagrass on 29 October, and overall. Although zoysiagrass had superior visual quality and color, it showed more drought symptoms than bermudagrass under the conditions of this study.

Surfactant chemical treatments had little effect on visual turfgrass color ratings, with the exception of a significant (P? 0.05) contrast between treated and untreated plots on 30 September. Surfactant chemical treatments resulted in some significant (P? 0.10) differences in visual turfgrass quality, as well as a significant (P? 0.10) improvement in quality (30 September and overall only) when treated and untreated groups were contrasted. Individual chemical treatments did not significantly influence ratings for percent leaves rolled and/or wilted, however there were some differences (P? 0.10) in ratings for percent brown leaves between the surfactant treatments. Percent leaves rolled and/or wilted and percent brown leaves ratings from treated plots contrasted significantly (P? 0.10) with untreated plots on 22 July, 26 August, and 30 September. Significant contrasts suggest that surfactant treatments may reduce drought symptoms in bermudagrass and zoysiagrass, but it would be difficult to conclude from these data which surfactant blends are most effective.

The research plots were managed to minimize runoff (maximize infiltration) of irrigation water, i.e., zoysiagrass subplots were verticut annually to reduce thatch buildup, and irrigation events were cycled numerous times. Differential effects of the surfactant treatments may have been more visible had hydrophobicity and water runoff been more of a problem. Furthermore, the 6-month evaluation period may not have been sufficient for buildup of the material in the soil.

Table 5. The effect of surfactant, species, and irrigation-level treatments on the visual turfgrass color of two warm-season turfgrasses (1 to 9 scale, with 1=worst, 5=minimally acceptable, and 9=best bermudagrass/zoysiagrass color).

Treatment factor	Date						
	26 Jun	Jul 7	7 Aug	4 Sep	30 Sep	29 Oct	Overall
Surfactant Treatment							
GMB/A/02/I9[z]	7.0	6.8	6.2	6.8	6.4	6.2	6.6
GMB/A/02/L0	7.0	6.9	6.2	6.9	6.5	6.1	6.6
GMB/A/02/IA	7.0	6.8	6.3	6.9	6.6	6.2	6.6
Untreated	7.0	6.8	6.2	6.8	6.2	6.0	6.5
GMB/A/02/I8	6.9	6.7	6.2	6.8	6.4	6.2	6.5
GMB/A/02/L1	6.9	6.7	6.1	6.8	6.3	6.2	6.5
GMB/A/02/L7	6.9	6.7	6.3	6.9	6.5	6.1	6.6
GMB/A/02/L3	6.9	6.7	6.2	6.8	6.5	6.2	6.6
LSD, *P*? 0.05	NS	NS	NS	NS	NS	NS	NS
Contrast							
Treated *vs.* untreated	NS	NS	NS	NS	*	NS	NS
Species Treatments							
Bermudagrass[y]	6.6	6.1	5.8	6.6	6.0	6.0	6.2
Zoysiagrass	7.3	7.4	6.6	7.1	6.8	6.3	6.9
LSD, *P*? 0.05	0.2	0.2	0.1	0.3	0.3	0.4	0.2
Irrigation Treatments							
100% ET_{crop}/DU[x]	7.0	7.0	6.6	7.2	6.7	6.7	6.9
80% ET_{crop}/DU	7.0	7.0	6.5	7.0	6.7	6.3	6.8
60% ET_{crop}/DU	6.8	6.3	5.5	6.3	5.8	5.5	6.0
LSD, *P*? 0.05	0.2	0.4	0.2	0.5	0.3	0.5	0.3
Split-split plot statistical effects by date and overall ANOVA effects via a repeated-measures design							
Irrigation (I)	*	**	***	*	***	**	***
Species (S)	***	***	***	**	***	+	***
Surfactant (C)	NS	NS	NS	NS	NS	NS	NS
I*S	+	***	**	NS	NS	NS	NS
I*C	NS	NS	**	NS	NS	NS	+
S*C	NS	NS	NS	NS	+	NS	NS
I*S*C	NS	NS	NS	+	NS	NS	NS
Date (D)							***
D*I							***
D*S							***
D*C							NS
D*I*S							***
D*I*C							NS
D*S*C							NS
D*I*S*C							NS

NS,+,*,**,***: Nonsignificant or significant at *P*? 0.10, 0.05, 0.01, or 0.001, respectively.
[z]Means are the average of replications, and species and irrigation treatments.
[y]Means are the average of replications, and surfactant and irrigation treatments.
[x]Means are the average of replications, and surfactant and species treatments.

Table 6. The effect of surfactant, species, and irrigation-level treatments on the visual turfgrass quality of two warm-season turfgrasses (1 to 9 scale, with 1=worst, 5=minimally acceptable, and 9=best bermudagrass/zoysiagrass quality).

Treatment factor	Date						Overall
	26 Jun	7 Jul	7 Aug	4 Sep	30 Sep	29 Oct	
Surfactant treatments							
GMB/A/02/I9[z]	7.0	7.0	6.6	6.9	6.6	6.2	6.7
GMB/A/02/L0	7.0	6.9	6.6	6.9	6.5	6.2	6.7
GMB/A/02/IA	7.0	6.9	6.6	7.0	6.6	6.3	6.8
Untreated	6.9	6.9	6.5	6.8	6.3	6.1	6.6
GMB/A/02/I8	6.9	6.9	6.6	6.7	6.4	6.2	6.6
GMB/A/02/L1	7.0	6.8	6.6	6.8	6.3	6.2	6.6
GMB/A/02/L7	7.0	6.9	6.7	6.9	6.4	6.1	6.7
GMB/A/02/L3	6.8	6.9	6.5	6.8	6.5	6.3	6.6
LSD, *P*? 0.05	NS	NS	NS	0.2	0.3	NS	NS
Contrast							
Treated *vs*. untreated	NS	NS	NS	NS	+	NS	+
Species treatments							
Bermudagrass[y]	6.5	6.1	5.7	6.5	5.9	5.9	6.1
Zoysiagrass	7.4	7.7	7.5	7.2	6.9	6.5	7.2
LSD, *P*? 0.05	0.2	0.2	0.2	0.3	0.3	0.4	0.2
Irrigation treatments							
100% ET_{crop}/DU[x]	7.0	7.1	6.9	7.2	6.8	6.6	6.9
80% ET_{crop}/DU	7.1	7.0	6.8	7.0	6.7	6.4	6.8
60% ET_{crop}/DU	6.8	6.6	6.0	6.4	5.9	5.6	6.2
LSD, *P*? 0.05	NS	0.4	0.3	0.4	0.4	0.5	0.3
Split-split plot statistical effects by date and overall ANOVA effects via a repeated measures design							
Irrigation (I)	NS	*	***	**	**	**	**
Species (S)	***	***	***	***	***	**	***
Surfactant (C)	NS	NS	NS	+	+	NS	NS
I*S	NS	+	NS	NS	NS	NS	NS
I*C	NS	NS	NS	+	+	NS	+
S*C	NS	NS	NS	NS	NS	NS	NS
I*S*C	NS	NS	NS	NS	NS	NS	NS
Date (D)							***
D*I							***
D*S							***
D*C							NS
D*I*S							***
D*I*C							NS
D*S*C							NS
D*I*S*C							NS

[NS,+,*,**,***]: Nonsignificant or significant at *P*? 0.10, 0.05, 0.01, or 0.001, respectively.
[z]Means are the average of replications, and species and irrigation treatments.
[y]Means are the average of replications, and surfactant and irrigation treatments.
[x]Means are the average of replications, and surfactant and species treatments.

Table 7. The effect of surfactant, species, and irrigation-level treatments on percent leaves rolled and/or wilted (0 to 100 scale, with 0=no leaves rolled/wilted and 100=100 percent of leaves on plot area rolled/wilted).

Treatment factor	Date						Overall
	26 Jun	7 Jul	22 Jul	26 Aug	30 Sep	29 Oct	
Surfactant treatments							
GMB/A/02/I9[z]	1	10	18	24	14	29	16
GMB/A/02/L0	3	9	14	21	15	32	16
GMB/A/02/IA	1	11	18	22	14	21	15
Untreated	5	16	21	32	25	29	21
GMB/A/02/I8	4	12	16	26	18	29	18
GMB/A/02/L1	4	15	19	23	23	24	18
GMB/A/02/L7	1	9	17	23	20	31	17
GMB/A/02/L3	7	14	18	24	20	24	18
LSD, *P*? 0.05	NS	NS	NS	NS	NS	NS	NS
Contrast							
Treated *vs.* untreated	NS	NS	+	**	*	NS	*
Species treatments							
Bermudagrass[y]	2	7	10	16	15	14	11
Zoysiagrass	4	17	25	33	22	41	24
LSD, *P*? 0.05	NS	10	9	11	9	15	9
Irrigation treatments							
100% ET_{crop}/DU[x]	1	1	1	2	2	4	2
80% ET_{crop}/DU	1	5	9	11	10	22	10
60% ET_{crop}/DU	7	30	43	60	44	55	40
LSD, *P*? 0.05	5	11	23	14	16	13	10
Split-split plot statistical effects by date and overall ANOVA effects via a repeated measures design							
Irrigation (I)	*	**	**	***	**	***	***
Species (S)	NS	+	**	**	+	**	**
Surfactant (C)	NS	NS	NS	NS	NS	NS	NS
I*S	NS	+	**	*	NS	+	+
I*C	+	+	NS	+	**	NS	*
S*C	NS	NS	NS	NS	NS	NS	NS
I*S*C	NS	NS	NS	NS	NS	NS	NS
Date (D)							***
D*I							***
D*S							***
D*C							NS
D*I*S							***
D*I*C							NS
D*S*C							NS
D*I*S*C							NS

NS,+,*,**,***: Nonsignificant or significant at *P*? 0.10, 0.05, 0.01, or 0.001, respectively.
[z]Means are the average of replications, and species and irrigation treatments.
[y]Means are the average of replications, and surfactant and irrigation treatments.
[x]Means are the average of replications, and surfactant and species treatments.

Table 8. The effect of surfactant, species, and irrigation-level treatments on percent brown (fired) leaves (0 to 100 scale, with 0=no leaves brown/fired and 100=100 percent of leaves on plot area brown/fired).

Treatment factor	Date						
	26 Jun	7 Jul	22 Jul	26 Aug	30 Sep	29 Oct	Overall
Surfactant treatment							
GMB/A/02/I9[z]	0	0	3	3	5	15	4
GMB/A/02/L0	0	1	1	1	2	15	3
GMB/A/02/IA	0	1	1	3	4	9	3
Untreated	1	2	3	3	9	17	6
GMB/A/02/I8	1	2	2	3	5	16	5
GMB/A/02/L1	1	3	2	1	7	11	4
GMB/A/02/L7	0	1	1	1	6	15	4
GMB/A/02/L3	1	3	4	2	7	11	5
LSD, *P*? 0.05	NS	2	2	NS	4	NS	NS
Contrast							
Treated *vs.* untreated	NS	NS	+	**	*	NS	*
Species treatments							
Bermudagrass[y]	0	1	2	2	6	6	3
Zoysiagrass	1	2	2	2	5	22	6
LSD, *P*? 0.05	NS	NS	NS	NS	NS	10	3
Irrigation treatments							
100% ET_{crop}/DU[x]	0	0	0	0	0	2	0
80% ET_{crop}/DU	0	0	1	1	2	11	3
60% ET_{crop}/DU	1	4	5	6	15	28	10
LSD, *P*? 0.05	1	1	5	3	7	10	3
Split-split plot statistical effects by date and overall ANOVA effects via a repeated measures design							
Irrigation (I)	*	***	+	**	**	**	***
Species (S)	NS	NS	NS	NS	NS	**	+
Surfactant (C)	NS	+	+	NS	+	NS	NS
I*S	NS	NS	NS	NS	NS	+	NS
I*C	NS	*	*	NS	NS	NS	+
S*C	NS	NS	NS	NS	NS	NS	NS
I*S*C	NS	NS	NS	NS	NS	NS	NS
Date (D)							***
D*I							***
D*S							***
D*C							NS
D*I*S							***
D*I*C							NS
D*S*C							NS
D*I*S*C							NS

[NS,+,*,**,***]: Nonsignificant or significant at *P*? 0.10, 0.05, 0.01, or 0.001, respectively.

[z]Means are the average of replications, and species and irrigation treatments.

[y]Means are the average of replications, and surfactant and irrigation treatments.

[x]Means are the average of replications, and surfactant and species treatments.

Table 9. The effect of irrigation-level treatments and warm-season turfgrass species on volumetric soil water content (m^3 H_2O m^{-3} soil) at the 23-cm (9-inch) depth.

Irrigation level treatment	Date											Overall
	14 May	11Jun	24 Jun	8 Jul	22 Jul	5 Aug	19 Aug	4 Sep	16 Sep	30 Sep	21Oct	
100% ET_{crop}[z]	21.6	19.6	18.8	19.4	19.2	18.7	19.2	20.2	20.5	17.5	17.6	19.3
80% ET_{crop}	21.5	19.2	18.1	17.5	16.7	15.2	17.3	16.6	17.0	15.5	13.3	17.1
60% ET_{crop}	21.5	16.4	12.6	10.0	9.3	7.7	10.3	7.8	7.9	9.2	10.2	11.2
LSD, *P* ?0.05	NS	NS	3.7	4.0	3.6	3.3	2.6	3.2	4.2	NS	NS	3.2
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	**	**	***	***	***	***	***	NS	NS	**
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												***
DxS												NS
DxIxS												NS

NS, *, **, ***: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 10. The effect of irrigation-level treatments and warm-season turfgrass species on volumetric soil water content (m^3 H_2O m^{-3} soil) at the 30-cm (12-inch) depth.

Irrigation level treatment	Date											Overall
	14 May	11Jun	24 Jun	8 Jul	22 Jul	5 Aug	19 Aug	4 Sep	16 Sep	30 Sep	21Oct	
100% ET_c [z]	21.9	19.8	19.6	19.7	19.7	19.4	19.9	20.2	20.6	19.2	17.1	19.7
80% ET_c	21.7	19.7	18.8	17.4	17.1	15.6	17.8	17.1	17.2	15.7	14.1	17.5
60% ET_c	21.3	16.9	13.9	11.3	10.2	8.8	11.1	7.2	8.8	8.3	9.6	11.6
LSD, *P* ?0.05	NS	NS	3.1	4.0	3.5	3.6	2.6	5.0	4.1	4.1	5.6	3.0
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	**	**	**	***	***	**	***	**	*	**
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												***
DxS												NS
DxIxS												NS

NS, *, **, ***: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 11. The effect of irrigation-level treatments and warm-season turfgrass species on volumetric soil water content (m^3 H_2O m^{-3} soil) at the 60-cm (24-inch) depth.

Irrigation level treatment	Date											Overall
	14 May	11Jun	24 Jun	8 Jul	22 Jul	5 Aug	19 Aug	4 Sep	16 Sep	30 Sep	21Oct	
100% ET_c [z]	20.1	18.7	18.4	18.9	18.7	18.4	18.6	19.0	19.2	17.6	17.5	18.7
80% ET_c	19.9	18.4	17.9	17.5	16.9	16.4	17.9	17.1	17.0	15.7	14.7	17.2
60% ET_c	19.9	17.9	16.7	14.8	13.0	11.6	12.1	11.5	11.0	10.3	11.8	13.7
LSD,*P* ??.05	NS	NS	NS	1.5	3.2	2.3	1.7	2.4	2.5	2.4	NS	1.8
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	NS	**	**	***	***	***	***	***	NS	***
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												***
DxS												NS
DxIxS												NS

[NS, *, **, ***]: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 12. The effect of irrigation-level treatments and warm-season turfgrass species on volumetric soil water content (m^3 H_2O m^{-3} soil) at the 91-cm (36-inch) depth.

Irrigation level treatment	Date											Overall
	14 May	11Jun	24 Jun	8 Jul	22 Jul	5 Aug	19 Aug	4 Sep	16 Sep	30 Sep	21Oct	
100% ET_c [z]	15.8	14.3	14.3	15.0	14.9	14.9	15.0	15.4	15.3	13.5	16.5	15.0
80% ET_c	14.4	12.5	13.1	12.3	11.8	11.5	12.5	11.9	11.9	11.1	10.5	12.1
60% ET_c	14.8	13.8	13.3	12.8	11.5	10.3	10.1	10.8	9.1	8.8	9.3	11.3
LSD, *P* ??.05	NS	NS	NS	NS	2.3	2.2	2.1	3.2	2.7	2.9	NS	2.2
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	NS	NS	*	**	**	*	**	*	NS	*
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
I*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												***
DxS												NS
DxIxS												NS

[NS, *, **, ***]: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 13. The effect of irrigation-level treatments and warm-season turfgrass species on volumetric soil water content (m^3 H_2O m^{-3} soil) at the 122-cm (48-inch) depth.

Irrigation level treatment	Date											Overall
	14 May	11Jun	24 Jun	8 Jul	22 Jul	5 Aug	19 Aug	4 Sep	16 Sep	30 Sep	21Oct	
100% ET_c [z]	14.5	13.9	13.7	14.0	14.1	14.0	14.7	14.7	14.5	13.0	13.1	14.0
80% ET_c	13.7	13.0	12.7	12.8	12.6	12.5	12.7	12.8	12.5	11.9	12.0	12.6
60% ET_c	15.6	15.2	14.6	14.6	13.8	13.0	12.6	12.2	11.3	11.1	11.3	13.2
LSD, *P* ??.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
I*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												***
DxS												*
DxIxS												NS

NS, *, **, ***: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 14.The effect of irrigation-level treatments and warm-season turfgrass species on volumetric soil water content (m^3 H_2O m^{-3} soil) at the 152-cm (60-inch) depth.

Irrigation level treatment	Date											Overall
	14 May	11Jun	24 Jun	8 Jul	22 Jul	5 Aug	19 Aug	4 Sep	16 Sep	30 Sep	21Oct	
100% ET_c [z]	17.5	17.2	17.1	17.4	17.3	17.4	18.1	18.2	17.9	17.5	17.0	17.5
80% ET_c	17.1	17.0	16.8	17.1	16.7	16.2	16.3	16.7	16.3	14.8	14.7	16.3
60% ET_c	18.5	18.5	18.1	18.3	18.0	17.4	17.1	16.6	16.1	15.6	14.6	17.2
LSD, *P* ??.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												***
DxS												NS
DxIxS												*

[NS, *, **, ***]: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 15. The effect of irrigation-level treatments and warm-season turfgrass species on volumetric soil water content (m^3 H_2O m^{-3} soil) at the 173-cm (72-inch) depth.

Irrigation level treatment	Date											Overall
	14 May	11Jun	24 Jun	8 Jul	22 Jul	5 Aug	19 Aug	4 Sep	16 Sep	30 Sep	21Oct	
100% ET_c [z]	19.9	19.8	19.2	21.1	19.6	19.5	20.4	20.5	20.3	19.7	18.7	20.0
80% ET_c	18.7	18.8	18.4	18.6	18.0	17.4	17.5	17.5	17.8	17.0	17.1	17.9
60% ET_c	18.9	18.7	18.4	18.5	18.1	17.6	17.2	17.4	17.1	16.0	16.9	17.7
LSD, *P* ??.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												NS
DxS												NS
DxIxS												NS

NS, *, **, ***: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 16. The effect of irrigation-level treatments and warm-season turfgrass species on Watermark soil water tension (MPa) at the 30-cm (12-inch) depth.

Irrigation level treatment	Date											
	10 Jun	1 Jul	15 Jul	29 Jul	12 Aug	26 Aug	9 Sep	23 Sep	7 Oct	21 Oct	3 Nov	Overall
	MPa											
100%ET_{crop} [z]	13	38	73	76	26	40	71	77	80	82	78	60
80%ET_{crop}	7	15	16	20	2	14	18	20	39	65	70	26
60% ET_{crop}	12	35	80	124	41	77	135	145	144	150	125	97
LSD, *P*? 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IxS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date (D)												***
DxI												***
DxS												NS
DxIxS												NS

[NS, *, **, ***]: Nonsignificant, or significant at *P* ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.

Table 17. The effect of irrigation-level treatments and warm-season turfgrass species on Watermark soil water tension (MPa) at the 60-cm (2-foot) depth.

Irrigation level treatment	Date											
	10 Jun	1 Jul	15 Jul	29 Jul	12 Aug	26 Aug	9 Sep	23 Sep	7 Oct	21 Oct	3 Nov	Overall
	MPa											
100% ET_{crop} [z]	10	20	41	61	65	60	72	68	75	80	73	57
80% ET_{crop}	3	10	11	13	3	10	12	13	19	30	48	16
60% ET_{crop}	10	20	43	72	88	96	105	111	119	122	114	82
LSD, P? 0.05	5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Split-plot statistical effects and overall ANOVA effects via a repeated-measures design												
Irrigation (I)	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IxS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS	*
Date (D)												***
DxI												***
DxS												NS
DxIxS												NS

NS, *, **, ***: Nonsignificant, or significant at P ? 0.05, 0.01, 0.001, respectively.

[z] Means are the average of two turfgrass species.