# CHAPTER 4

# Surface Root-zone Water Content and Bentgrass Water Stress During Drydown for Selected Putting Green Construction Systems

## ABSTRACT

Creeping bentgrass, a cool-season grass used extensively in golf courses and in recreational turf, often declines during hot summer periods. The relationships between the shoot water potential of bentgrass and the root zone water content of sand-based media with amendments during drought periods are not well understood. The objective of this study was to determine the water relations of ‘Penncross’ creeping bentgrass (*Agrostis palustris* Huds.) greens and the root zone water content during drought periods as affected by root zone construction systems with selected amendments. Four treatments were developed: California (100% sand), USGA (90% sand and 10% peat, v/v), California-P (82% sand and 15% Profile, v/v with 3% humate), and California-Z (85% sand and 15% zeolite, v/v). Once mature, the plots were allowed to drydown over 30 days from 24 June to 24 July

2000 and 2001. The four treatments were arranged in a randomized complete block with four replicates. The California treatment maintained a higher root zone volumetric water content during the 2000 and 2001 drought periods compared with the other treatments. This treatment had root zone water content that was equal to or higher than the California-P and California-Z treatments during 2001. The USGA treatment had the lowest root zone water content during 2001. In 2001, the California-Z treatment had a higher bentgrass shoot water potential (least stress). The USGA treatment had the lowest bentgrass shoot water potential (most stress) during the drydown period in 2001. The California-P and California-Z treatments had higher bentgrass quality and color ratings when compared with the USGA treatment and equal to or better than the California treatment after the drought stress period in 2001. The California construction system seems to be better than the USGA construction system during drought since the California uses native silt loam soil below the constructed root zone and therefore has a higher plant available water capacity. Thus, the California construction system may improve creeping bentgrass growth during drought periods by allowing better root zone water uptake and less drought stress.

## SIGNIFICANCE TO THE NURSERY INDUSTRY

Sand-based putting green root zones constructed with a California system (without a gravel sub-layer in the root zone) improved ‘Penncross’ creeping bentgrass (*Agrostis palustris* Huds.) performance compared to a USGA construction system during drought periods in 2000 and 2001. Sand-based root zones with Profile or zeolite and the California construction system is not well understood regarding its impact on putting green root zone plant water relations and grass quality. The effects of root zone construction systems on bentgrass water stress and quality were evaluated in this study. The addition of Profile and zeolite to the sand for the California construction system was shown to offer some benefits during the drought period. These treatments were found to have a higher root zone volumetric water content, bentgrass shoot water potential (less stress), and nutrient content. The California construction system with Profile or zeolite amendment was found to be a superior replacement to the USGA construction system with a peat amendment.

# INTRODUCTION

Summer decline of cool-season grasses is a major problem in turfgrass management in the transitional and warm climatic region. Creeping bentgrass grows vigorously when canopy and soil temperatures, and soil moisture are within its preferred range. During hot summer periods, when temperatures increase to 90$^{o}$F or higher, root zone soil moisture may decline due to increased evapotranspiration rates and the turf canopy may thin and turn brown. Although sand is an ideal medium for bentgrass greens as far as physical characteristics are concerned (e.g., particle size, compaction resistance, infiltration rate, and aeration porosity), it is lacking in water holding capacity and nutrient retention (Beard, 1982; Miller, 2000).

Addition of an organic amendment such as peat increases water and nutrient retention; however, peat decomposes over time (Habeck and Christians, 2000; McCoy, 1992). The use of inorganic amendments for putting green root zone mixtures such as Profile™ (calcined clays) and ZeoPro™ (clinoptilolite zeolite) offers a number of benefits for improving sand-based root zones. They are less prone to compaction than organic materials, have higher cation exchange capacities, adequate water holding capacities without reducing aeration porosity, and they are essentially permanent additions to the root zone persisting over a longer period (Bigelow et al., 2000; Habeck and Christians, 2000; Huang and Petrovic, 1996; McCoy, 1992).

Creeping bentgrass often requires daily irrigation and syringing (dry spot irrigation by hand) to persist in turf areas with warmer environments and high evapotranspiration rates. Recently, Miller (2000) found that bermudagrass grown in inorganic material as an amendment for a sand-based root zone had the best quality during drought stress when compare to the 100% sand treatment. Thus, sand-based root zones amended with inorganic materials have the potential to influence root zone soil water content, and also affect the evapotranspiration response during drought periods. Bigelow (2001) reported that the presence (USGA green system) or absence (California green system) of a pea gravel sub-layer affected the root zone water retention. The presence of a pea gravel sub-layer significantly reduced root zone water retention.

A study was planned to investigate the effects of two inorganic soil amendments: Profile and zeolite, incorporated into a sand-based root zone with the California construction system on bentgrass quality, root zone volumetric water content, and shoot water potential during periods without irrigation. These treatments were compared with a 100% sand California construction system and a traditional USGA construction system that contained a peat amendment. The hypothesis of this study was that the California construction system with inorganic materials may have a higher root zone volumetric water content due to the absence of a pea gravel sub-layer which would result in higher bentgrass shoot water potential during periods of drought.

# MATERIALS AND METHODS

Four treatments were compared: a California profile, a USGA profile, and two modified California profiles. The California profile (referred to as the California treatment) consisted of 0.3 m of 100% sand over a 0.13 m layer of silt loam soil with a drain system (PVC pipe), which was placed below the root zone mixture layer. The USGA profile (referred to as the USGA treatment) consisted of 90% sand and 10% Dakota reed sedge peat by volume, with a 0.3 m root zone mixture over a 0.13 m pea gravel layer (2-7 mm diameter) with a drain at the bottom of the this gravel layer. The sand/peat mixture was blended at the supplier, Capitol Sand, Jefferson City, MO. There were also two modified California profile green treatments, each consisting of a 0.25 m root zone mixture over a 0.18 m layer of silt loam with a drain which was placed below the root zone mixture layer. The first modified profile referred to as the California-P treatment consisted of 82% sand, 15% Profile, and 3% humate in root zone mixture; the second modified profile referred to as the California-Z treatment consisted of 85% sand and 15% zeolite by volume. These two mixtures were blended at the Turf Research Center with a small cement mixer. Two washed river sands were used for the different root zone mixtures in this study: coarse to medium sand (C-M-S) was blended with Dakota reed sedge peat for the USGA treatment and medium to fine sand (M-F-S) was used in the three California-style treatments. The particle size analyses of two sands, the amendments, and sand-based root zone mixtures are presented in Table 3.1.

Treatments were established in 1.2 m by 1.2 m wooden boxes. The four treatments were arranged in a randomized complete block with four replicates. The amended and unamended root zones were installed in August and ‘Penncross’ creeping bentgrass was seeded on September 27, 1998 at 49 kg $ha^{-1}$. From seeding through May 1999, each plot was supplied with 292.9 kg N $ha^{-1}$, 97.6 kg P $ha^{-1}$, and 732.3 kg K $ha^{-1}$, either from granular fertilizer or, in the case of the ZeoPro amended plots, as nutrients estimated to be available from the nutrient-charged ZeoPro (0.1-0.05-0.6). From June 1999 through July 2001 all plots received 375.2 kg N $ha^{-1}$, 76.1 kg P $ha^{-1}$, and 425.9 kg K $ha^{-1}$. The green was initially mowed to a height of 13 mm (October 98), reduced to 9 mm (November 98), and then lowered to 6 mm (March 99). It was mowed to a consistent height of 4 mm beginning May 1999. Mowing occurred four times weekly and clippings were collected. Irrigation was applied every two days based on atmometer-estimated evapotranspiration (an evaporation measurement adjusted for evapotranspiration from grass; Ervin and Koski, 1997), except during the drought stress periods for the experimental study during both 2000 and 2001.

All experimental data were collected using the following procedures. Irrigation was not applied from June 24 to July 24, 2000 to compare changes in the root zone volumetric water content. Temperatures of the root zone at 0.15 m were measured biweekly (three times per day; 8:00 am, 12:00 pm, and 4:00 pm) during the drought period in the field with an AquaTerr Instruments Meter (TEMP 200) (Spectrum Technologies, 1990) which is portable. This is a simple multi-function meter to use for measuring soil water content and soil temperature. The meter probe requires good contact with soil to function accurately. The probe is pushed into the ground until the temperature sensor is covered (0 to 199$^{o}$ F; -18 to 92$^{o}$ C). Root zone volumetric water content was measured immediately after measurement of the root zone temperature. Measurements were taken biweekly three times per day in the 0 to 0.1 m depth (8:00 am, 12:00 pm, and 4:00 pm) during the drought period in the field with a ThetaMeter (soil water content sensor) (Delta-T Devices Ltd, 1997). The ThetaMeter is portable and has a self-contained power supply with a readout unit which, when used with a ThetaProbe Type ML1, provides a compact and fully portable volumetric moisture measurement system. The ThetaMeter converts the output signal from the ThetaProbe into a volumetric water fraction reading with units of $m^3m^{-3}$. The working range is 0 to 0.54 $m^3m^{-3}$. The ThetaMeter probe was field calibrated with gravimetric water content measurements adjusted with measured bulk density. The regression between the ThetaMeter and gravimetric water content measurements is shown in Figure 4.1.

Visual ratings for creeping bentgrass shoot color and quality were made two times for each plot at the beginning of the drought period (June 25) and the end of the drydown period (July 25). Creeping bentgrass color ratings were measured on a scale in which 1 = brown and 9 = dark green grass. Quality ratings were also measured on a scale in which 1 = no live grass and 9 = a dense, uniform stand of turf (Skogley and Sawyer, 1992). After the 2000 drydown period, irrigation water was applied normally to recharge the root zones. Bentgrass in each plot recovered to acceptable quality levels after the 2000 drydown period.

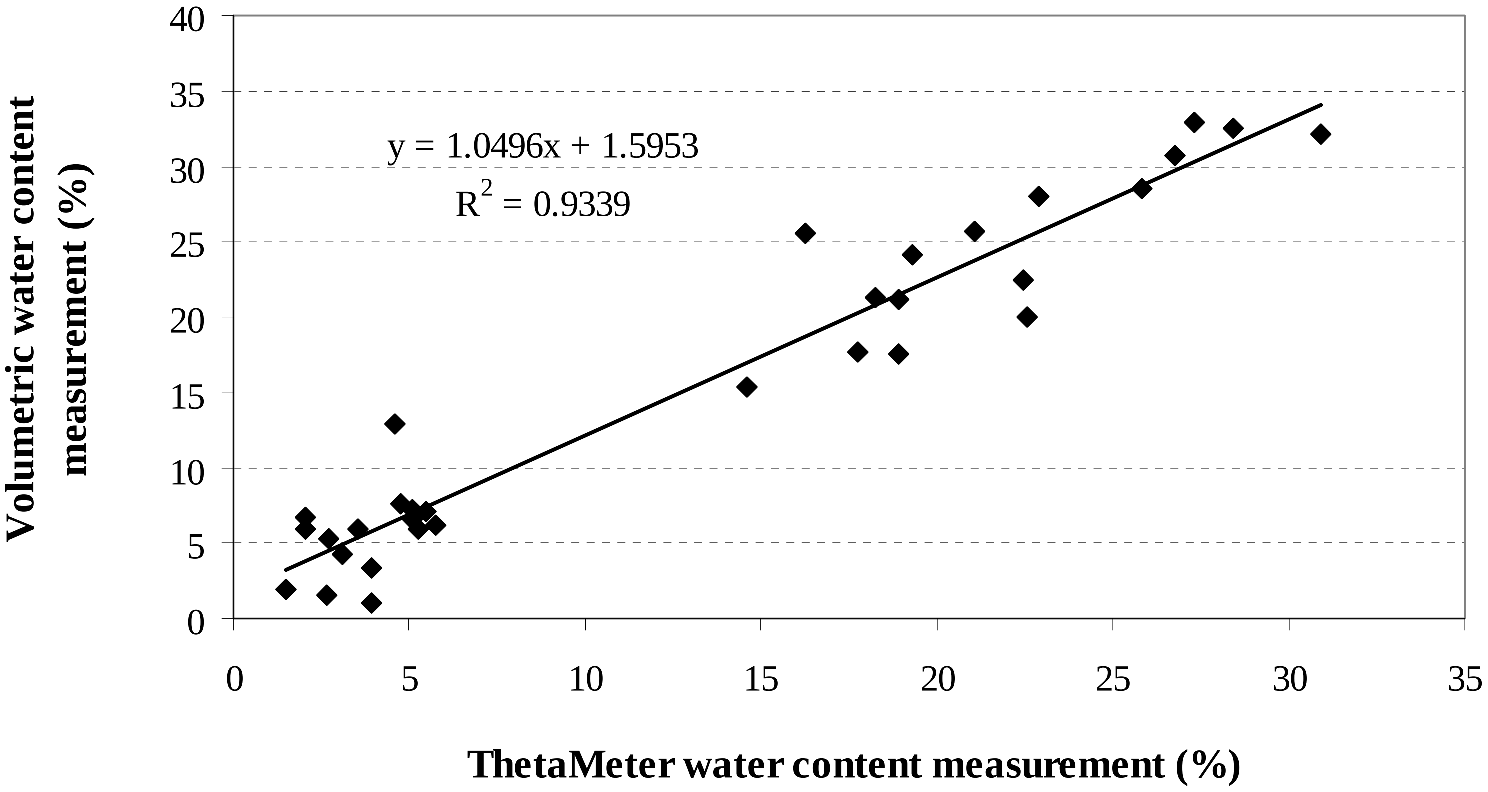

Figure 4.1. Calibration between volumetric water content(%) and ThetaMeter predicted water content(%).

Irrigation was also not applied from June 24 to July 24, 2001 to measure the effects on root zone volumetric water content and shoot water potential. The volumetric water content (%) was measured with the ThetaMeter and shoot water potential (MPa) of the creeping bentgrass tillers were measured with a pressure chamber (Lassoie and Hinckley, 1991) at the beginning of the drought period (June 24) and at the end (July 24). The pressure chamber can be one of the most reliable instruments available for plant water relations research. Simple construction and durability has made it the preferred method for measuring $\psi_w$ (plant water potential) in the field. The pressure chamber was used following the procedures described by Turner (Lassoie and Hinckley, 1991). Each bentgrass shoot per plot was excised and enclosed in plastic bags with moistened cheesecloth immediately after excision at noon. Shoot water potential was measured under rapid processing of samples to minimize water loss of excised samples. Root zone volumetric water content was determined before measuring shoot water potential using the ThetaMeter. The first measurements were made under irrigation based on the every other day evapotranspiration rate (ET) during the growing season (June 24). The second measurements were made after no irrigation for 30 days on July 24 (end of dry down). Visual ratings for shoot color and quality were made two times for each plot (June 25 and July 25). Rainfall was measured using a tipping bucket rain gauge. Potential evapotranspiration (PET) was estimated using the modified Penman equation (Rosenberg, 1974). Measurements were made of temperature, wind speed, relative humidity and solar radiation and used in the modified Penman ET equation. The estimated potential evapotranspiration was adjusted by a factor of 0.8 to approximate the potential evapotranspiration of grass (Carrow, 1995).

Statistical analysis of the data was computed using analysis of variance in the Michigan State Statistical software program (MSTAT, 1988) and the GLM model in the SAS software program (SAS, 1990). Means were separated with Fisher’s protected least significant difference (LSD) test at a 95% probability level.

## RESULTS AND DISCUSSION

Rainfall and estimated potential evapotranspiration adjusted for a grass surface (PETgrass) were estimated for each day from June 24 to July 24, 2000 and 2001 (Figures 4.2 and 4.3). Figures 4.4 to 4.6 show the root zone temperatures from 8:00 am, 12:00 pm, and 4:00 pm for the 2000 drought period. Figures 4.7 and 4.8 show the cumulative rainfall, estimated potential ET of grass, and the difference (rainfall – PETgrass) for time periods after no irrigation was applied for both 2000 and 2001 drought periods. During these periods, irrigation was not applied from June 24 to July 24 in each year. Plots apparently underwent stress in 2000 approximately 11 days after irrigation ceased (Figure 4.7). Figure 4.8 indicates that the experimental plots underwent stress near the beginning of the drydown in 2001. The potential evapotranpiration rate of the grass (PETgrass) was slightly higher in 2001 during this month period compared to 2000. The cumulative difference between rainfall and potential ET for the grass was about the same (-49 mm) for both years during this month drydown period.

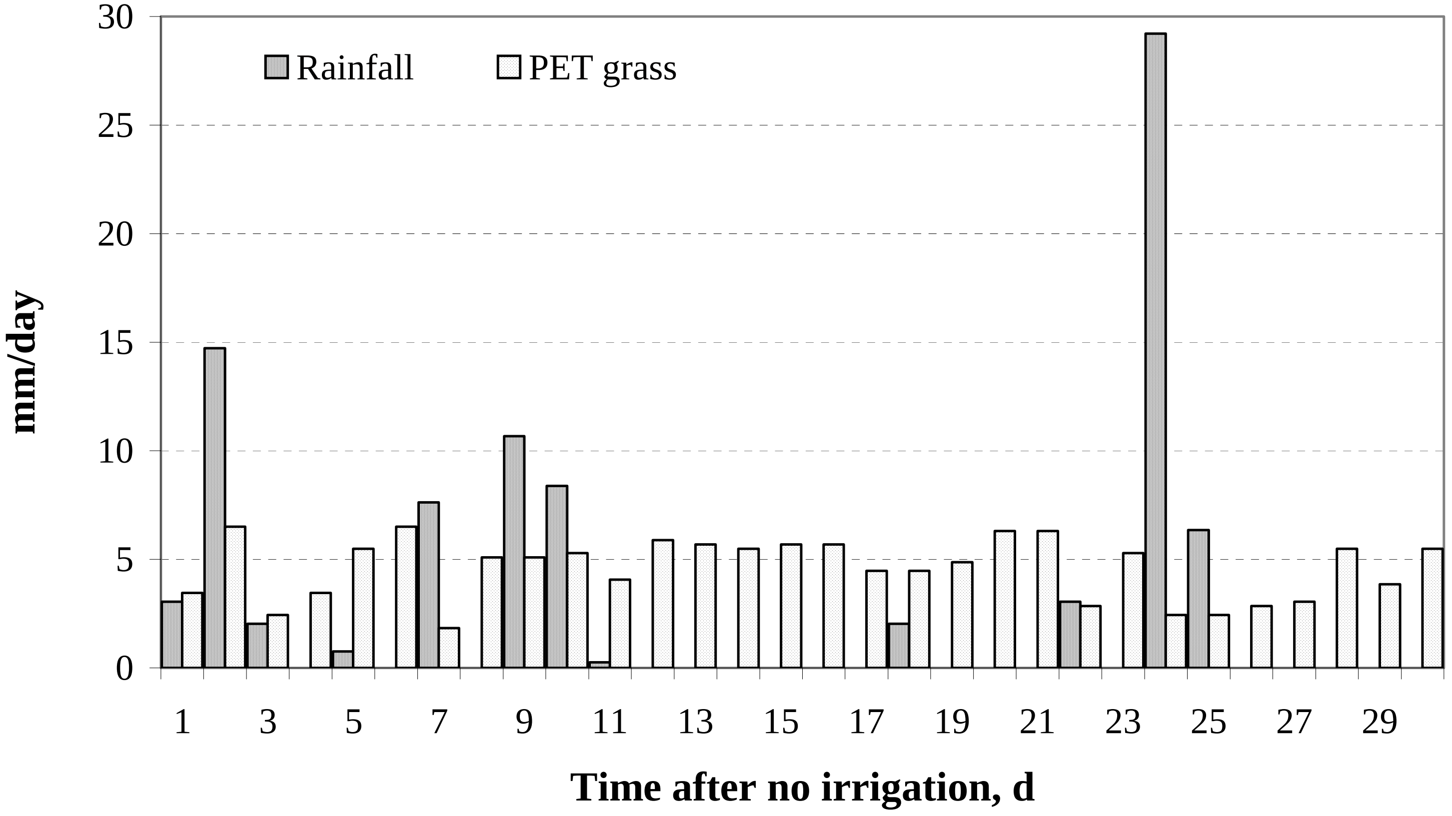

Figure 4.2. Rainfall and estimated PET adjusted for a grass surface during the 30 days of no irrigation from June 24 to July 24, 2000.

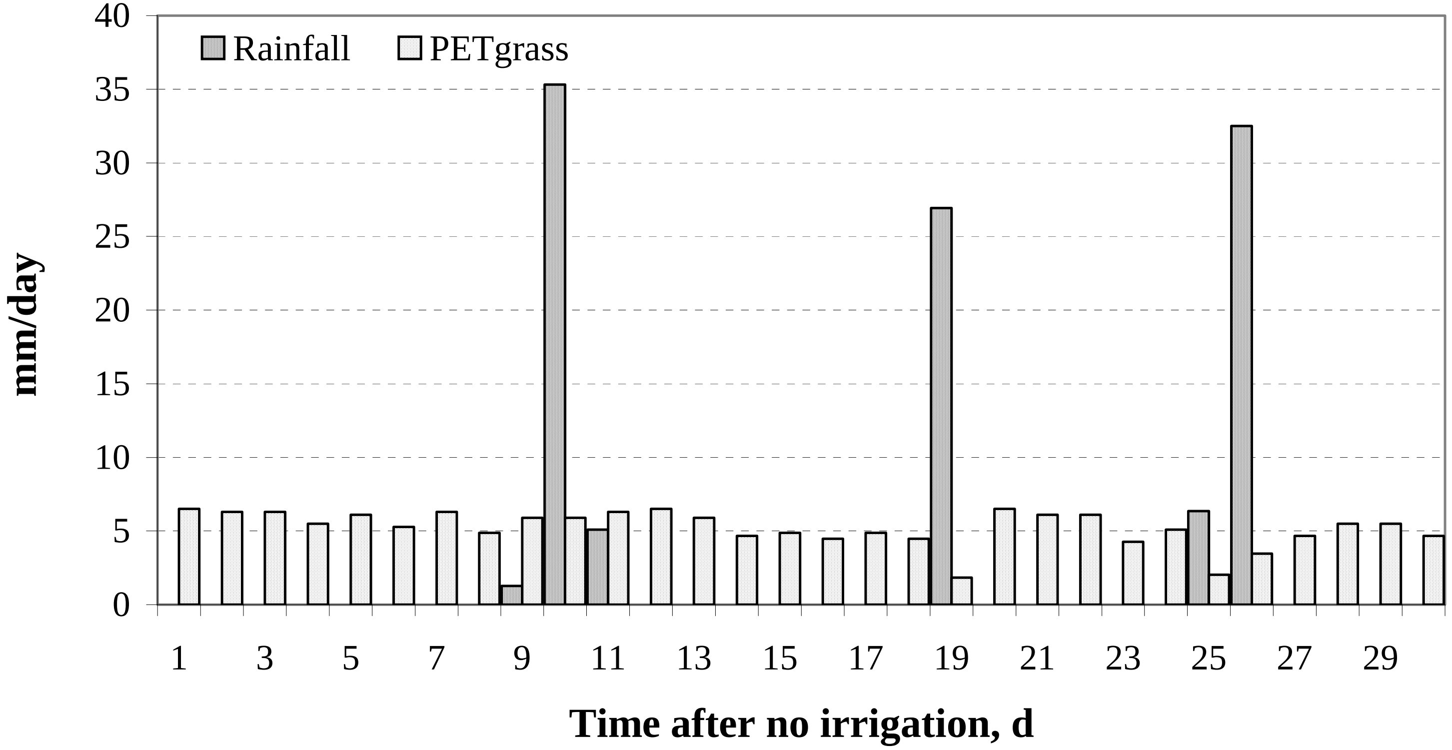

Figure 4.3. Rainfall and estimated PET adjusted for a grass surface during the 30 days of no irrigation from June 24 to July 24, 2001.

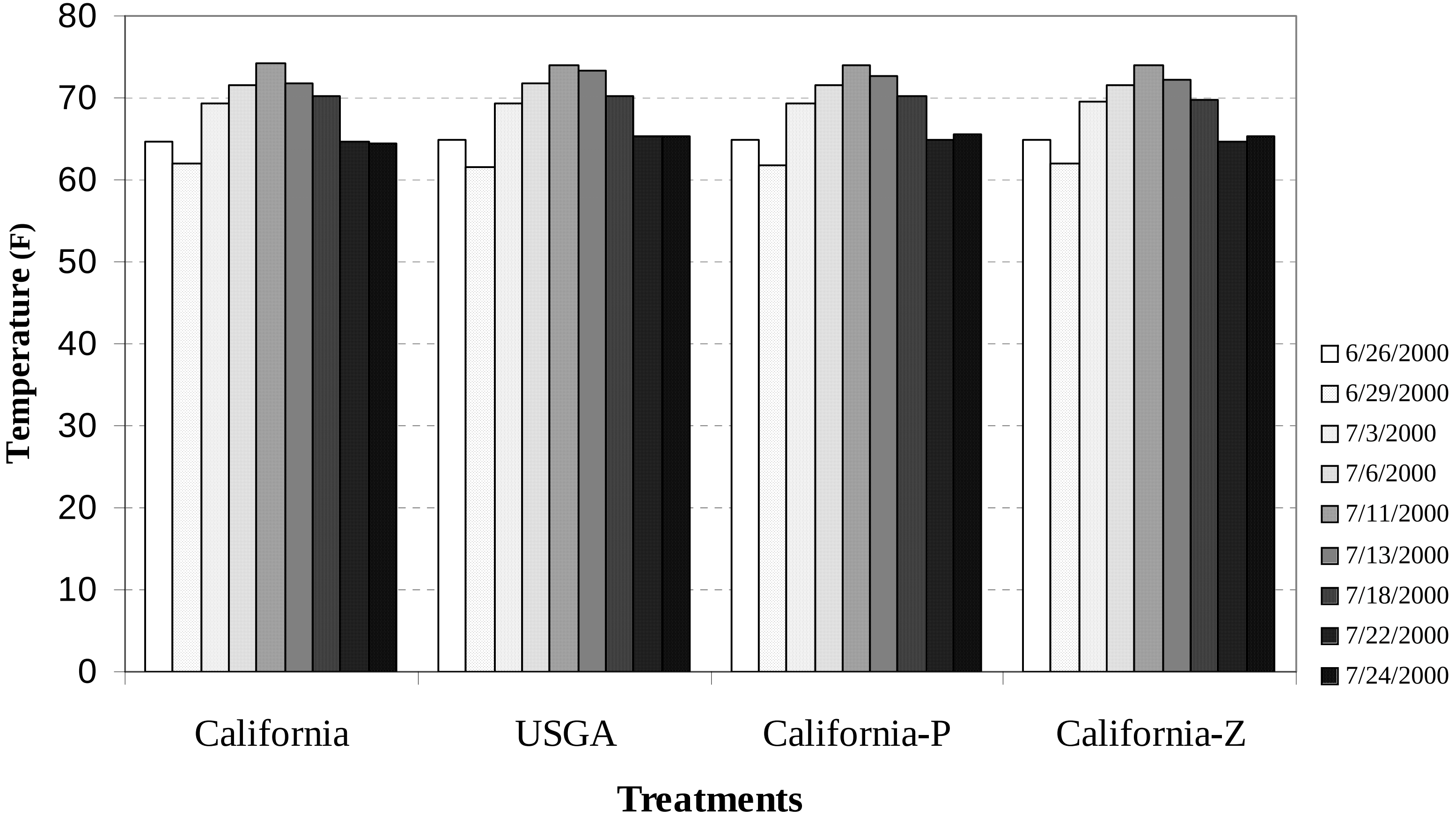

Figure 4.4. Temperatures in the sand-based root zone of 15 cm depth for the four treatments with AquaTerr at 8:00 am during drought periods (from June 24 to July 24, 2000).

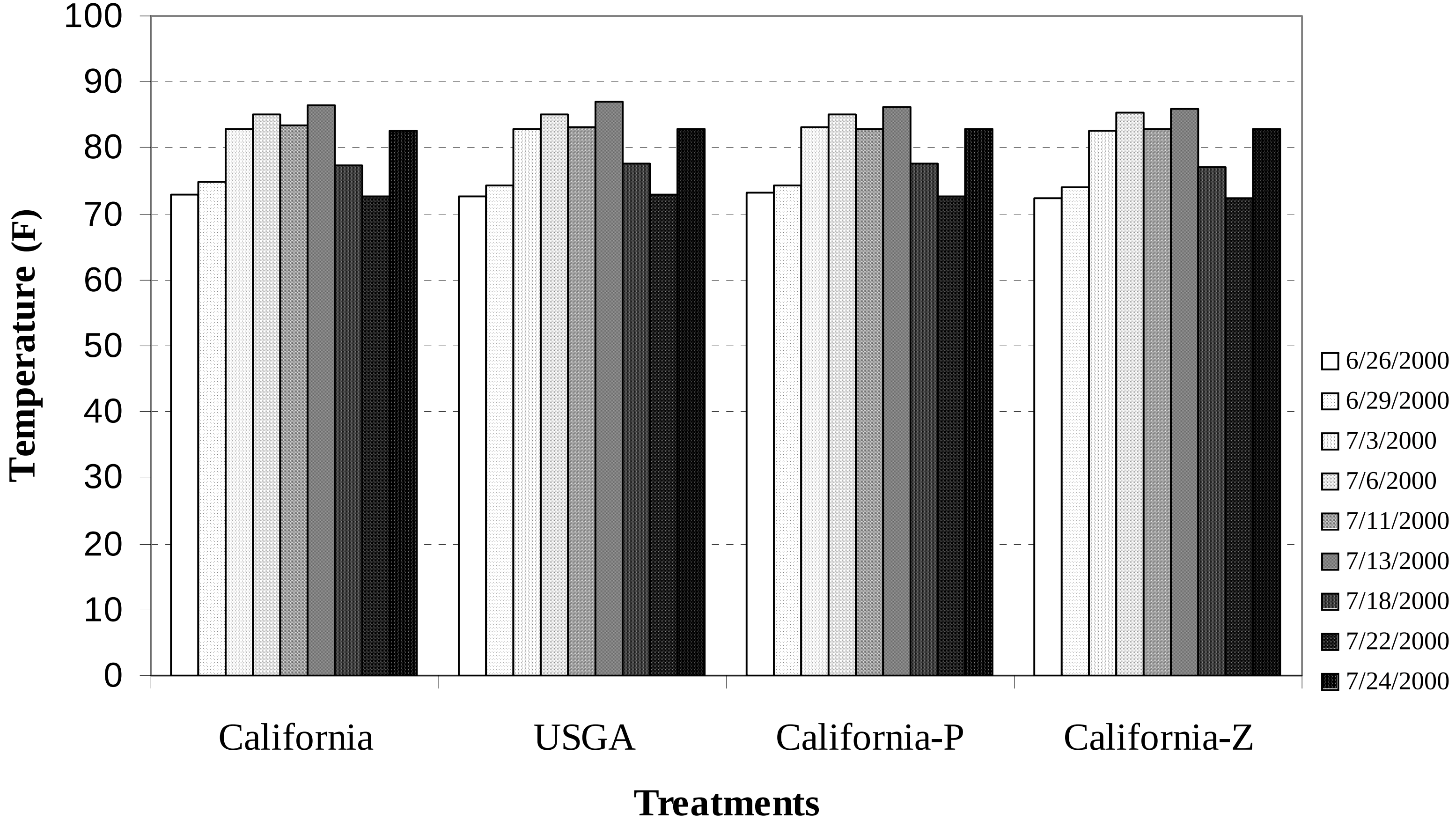

Figure 4.5. Temperatures in the sand-based root zone of 15 cm depth for the four treatments with AquaTerr at 12:00 pm during drought periods (from June 24 to July 24,2000).

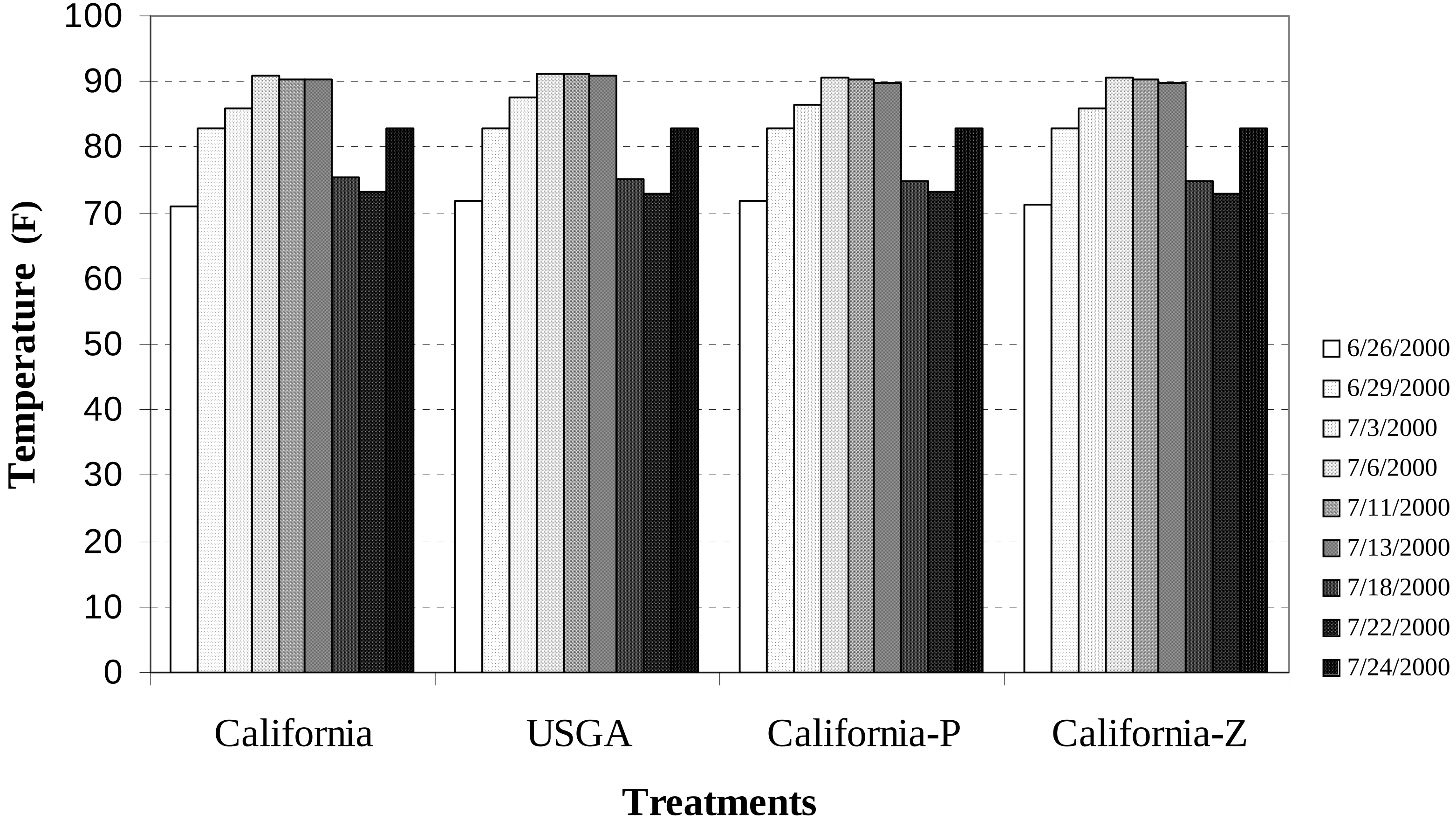

Figure 4.6. Temperatures in the sand-based root zone of 15 cm depth for the four treatments with AquaTerr at 4:00 pm during drought periods from June 24 to July 24, 2000).

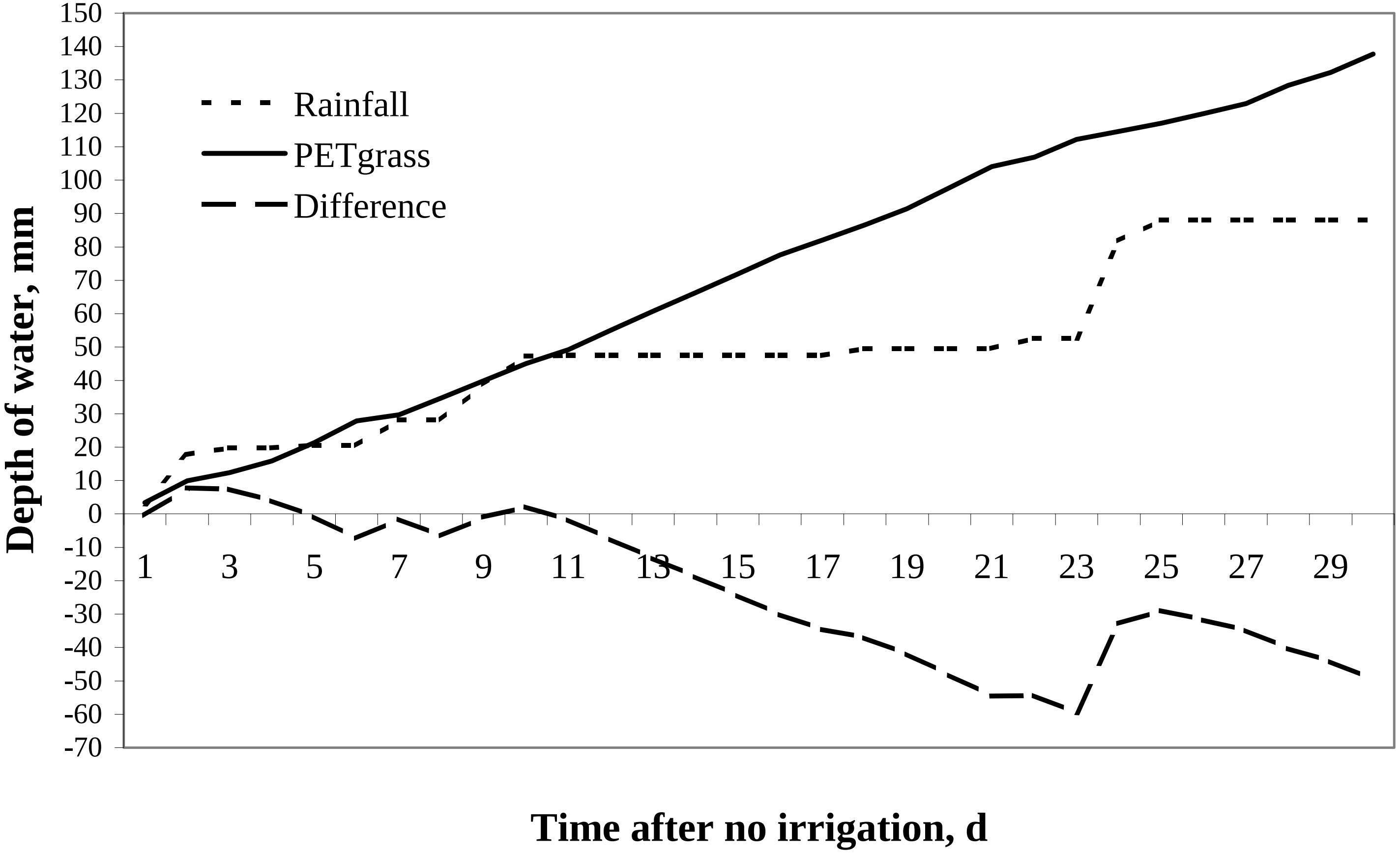

Figure 4.7. Cumulative rainfall, estimated potential ET of grass, and difference (rainfall – PET grass) for time periods after no irrigation: June 24 to July 24, 2000.

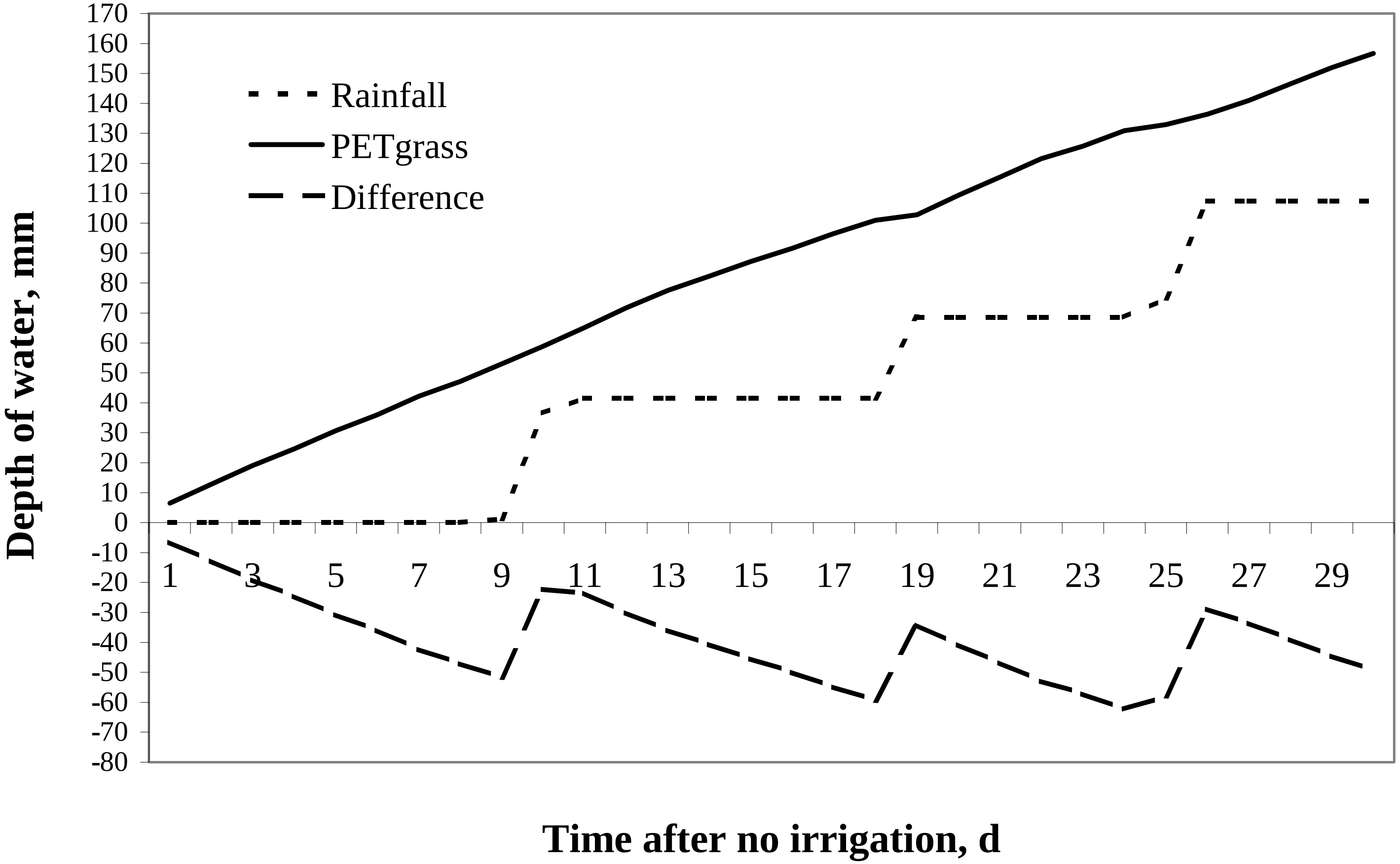

Figure 4.8. Cumulative rainfall, estimated potential ET of grass, and difference (rainfall – PET grass) for time periods after no irrigation: June 24 to July 24, 2001.

Figure 4.9 shows the average of root zone volumetric water content during the 2000 drydown period. The average includes measurements made at 8:00 am, 12:00 pm and 4:00 pm. Trends in root zone water content data for the treatments were similar: values remained higher during the first 10 days (7/4 measurement) and then dropped dramatically after 15 days (7/9 measurement). Root zone volumetric water content averaged about 22% at the beginning of the drydown period. Results indicate that the root zone volumetric water content for the California treatment were always higher for each measurement date when compared to the other treatments. This difference was not significant at the first date of measurement but was for all subsequent dates. Bigelow (2000) reported that sand size had a significant effect on porosity and water retention. Fine sand (0.1 to 0.25 mm) had a significantly higher available water holding capacity than either medium (0.25 to 0.5 mm) or coarse sand (0.5 to 1.0 mm). In this study, a higher content of fine and medium sand was used for the California treatments. The USGA treatment used sand with a higher percentage of medium to coarse sand. Results show that the highest water content that occurred in the California treatment was partially attributed to a higher fine sand content

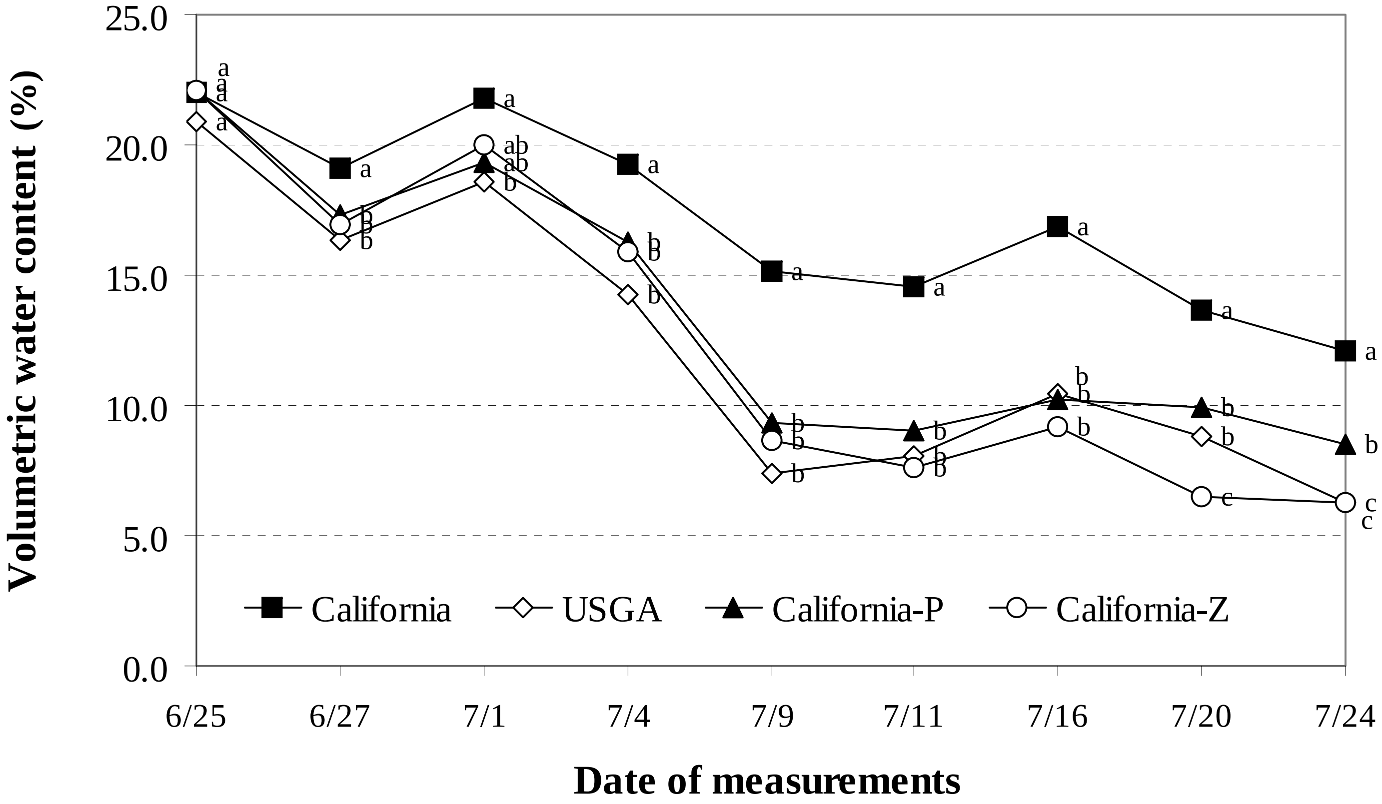

Figure 4.9. Average root zone volumetric water content (%) for the 0 to 10cm depth for the selected treatments. Average was determined for the 8:00 am, 12:00 pm, and 4:00 pm measurement times during the drought period (from June 24 to July 24, 2000). Means separation were determined by LSD $_{0.05}$ and indicated by letters at each measurement date.

(Table 3.1 and Figure 4.9). It is not understood why the California-Z treatment had a lower water content from 10 to 30 days after the beginning of the drydown period.

Figure 4.10 shows the difference in root zone volumetric water content from 8:00 am to 4:00 pm (value at 8:00 am minus value at 4 pm) during the drydown period. Larger differences between the morning and afternoon measurements were found during the beginning of the drydown period (except for the USGA treatment on the first date). The largest water content differences between the 8:00 am and 4:00 pm measurements were found three (6/27) to seven (7/1 measurement) days after no irrigation for all treatments. This implies that there were larger daily losses of water in the 0 to 0.1 m root zone depth when larger amounts of water were available in the root zones. There were only a couple of measurement dates that showed differences among the treatments.

For all treatments in 2001, root zone volumetric water content at the beginning of the drydown period averaged 28% and at the end averaged 7% (Figure 4.11). Root zone volumetric water content at the beginning of the drydown period was not significantly different among treatments.

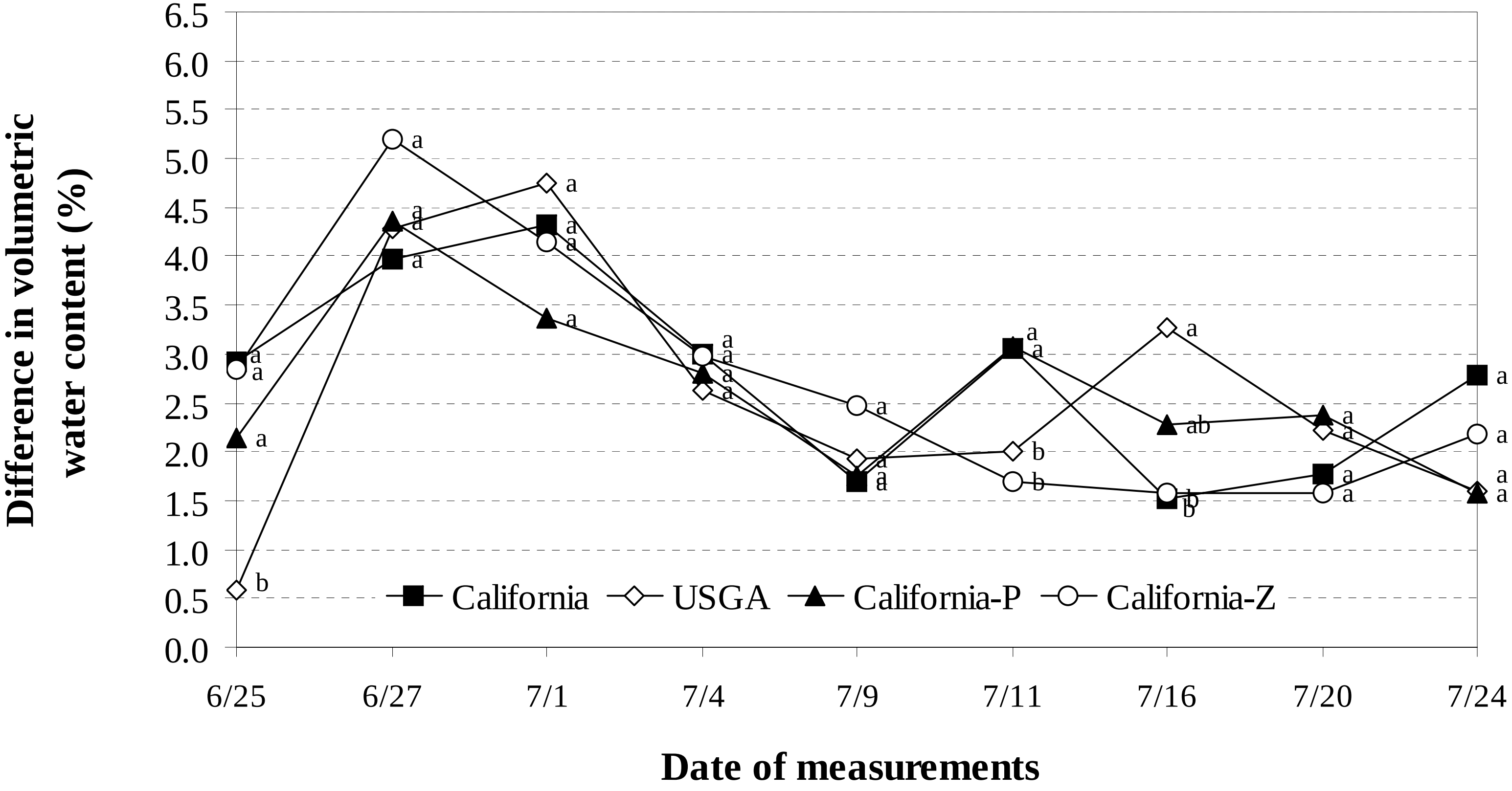

Figure 4.10. Difference in root zone volumetric water content (%) between 8:00 am and 4:00 pm (value at 8:00am – value at 4:00pm) during the drought period (from June 24 to July 24, 2000). Mean separation were determined by LSD $_{0.05}$ and indicated by letters at each measurement date.

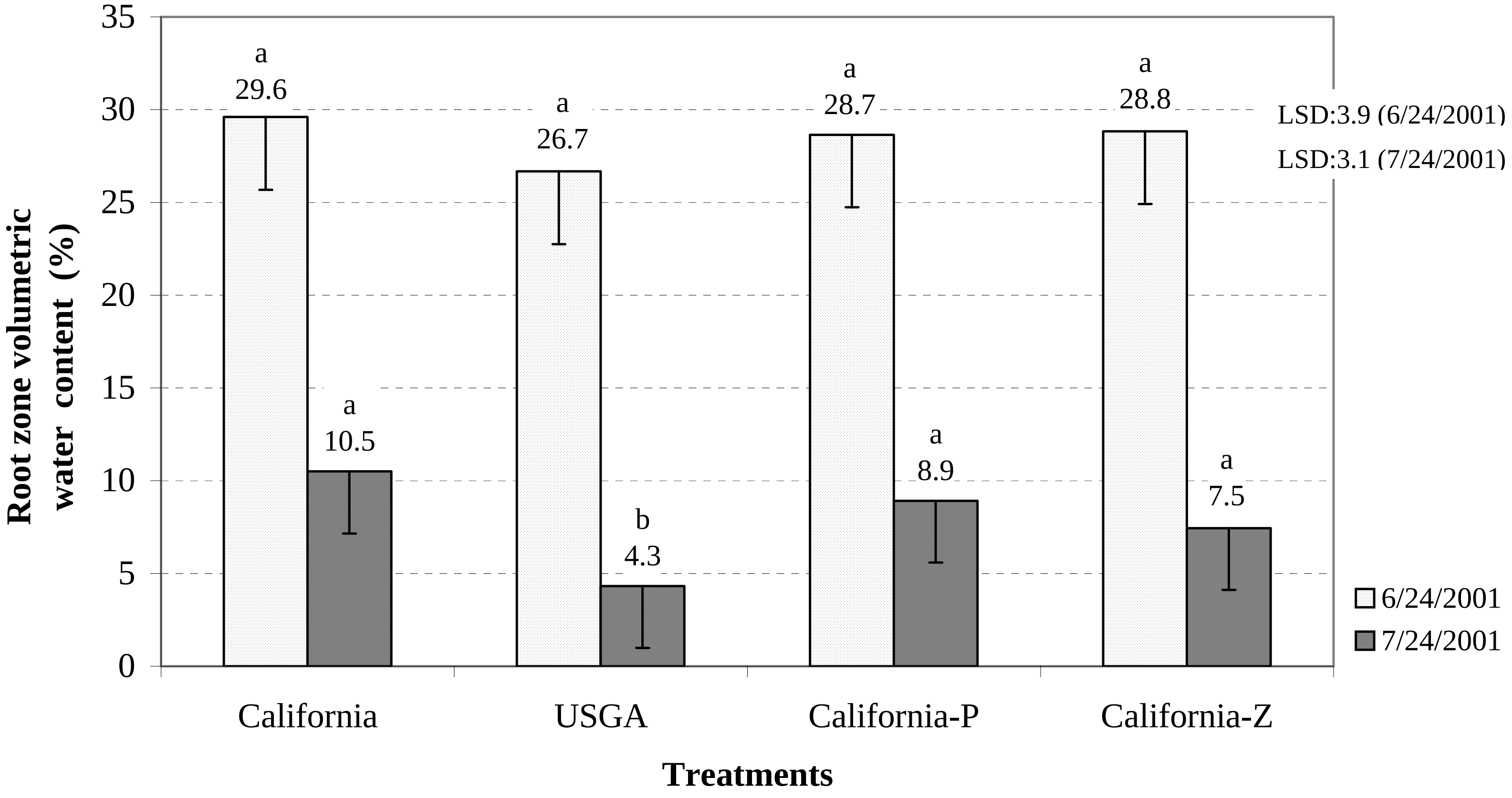

Figure 4.11. Root zone volumetric water content (%) among treatments at the beginning (6/24/01) and end (7/24/01) of the drought period. Means separation were determined by LSD $_{0.05}$ and indicated by letters at each measurement and vertical bars represent LSD $_{0.05}$.

At the end of the drought period, water content was not significantly different among the California treatments (California, California-P, and California-Z) while the USGA treatment had the lowest value of 4.3%. The higher root zone water content for the California treatments compared to the USGA treatment may have been partly due to these root zone mixtures having higher fine and medium sand content compared with medium to coarse sand content for the USGA treatment. Even though the USGA treatment contained peat as a root zone amendment, it did not retain more moisture during the drought stress period. In this study, differences in root zone water content among the treatments were probably also affected by the presence or absence of the pea gravel sub-layer. Bigelow (2001) reported that the presence or absence of a gravel sub-layer affected the root zone water retention. The presence of a gravel sub-layer significantly reduced root zone water retention. The gravel sub-layer treatment reduced root zone water roughly 50%. In our study, the California treatments (without gravel sub-layer) had higher root zone water content at the end of the drydown period in 2001 and only the California treatment had higher (0 – 10 cm) water content in 2000 when compared to the USGA treatment (with gravel sub-layer).

Results of the shoot water potential measurements at the beginning and end of the drydown period in 2001 are shown in Figure 4.12. The highest shoot water potential (least stress) occurred in the California-Z treatment at both the beginning and end of the drydown period. Only slight reductions (-0.08 MPa) in shoot water potential occurred in the California treatments during the drydown period. The shoot water potential for the USGA treatment was not significantly different from the California treatments at the beginning of the drydown period but had a large reduction (77%; -0.6 MPa) over the dry down period. The differences in the creeping bentgrass shoot water potentials (value at 6/24 minus 7/24, 2001) are shown in Figure 4.13. The USGA treatment had the largest shoot water potential difference between beginning and end of the drydown. Lehman (1993) reported that leaf water potential was associated with maintenance of growth under declining soil water content levels. Our results demonstrate that the greatest negative shoot water potential (-1.38 MPa) for the USGA treatment was associated with the lowest root zone volumetric water content after the drought stress period (Figures 4.11 and 4.12).

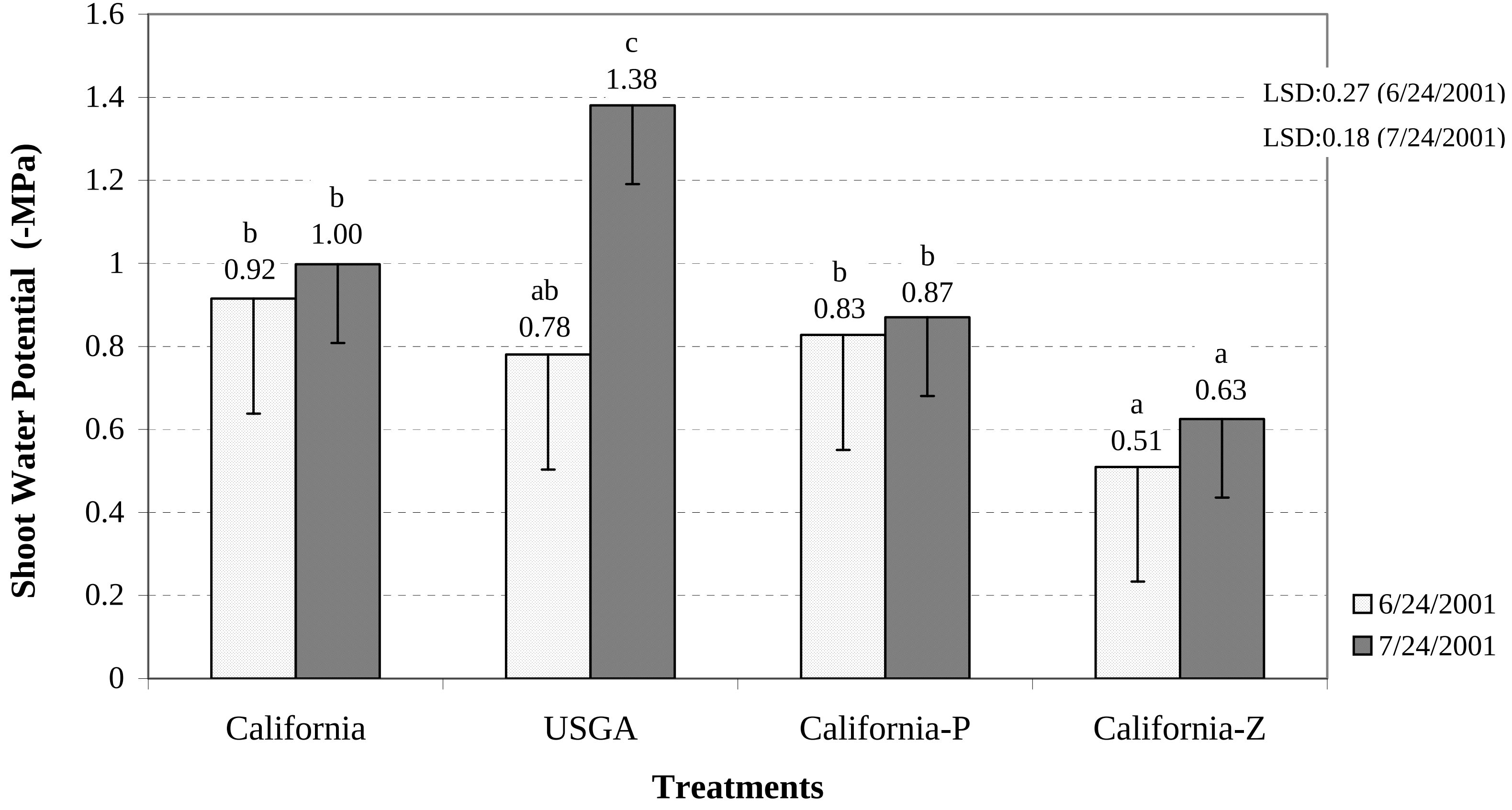

Figure 4.12. Shoot water potential (-MPa) among treatments at the beginning (6/24/01) and end (7/24/01) of the drought period. Means separation were determined by LSD $_{0.05}$ and indicated by letters at each measurement and vertical bars represent LSD $_{0.05}$.

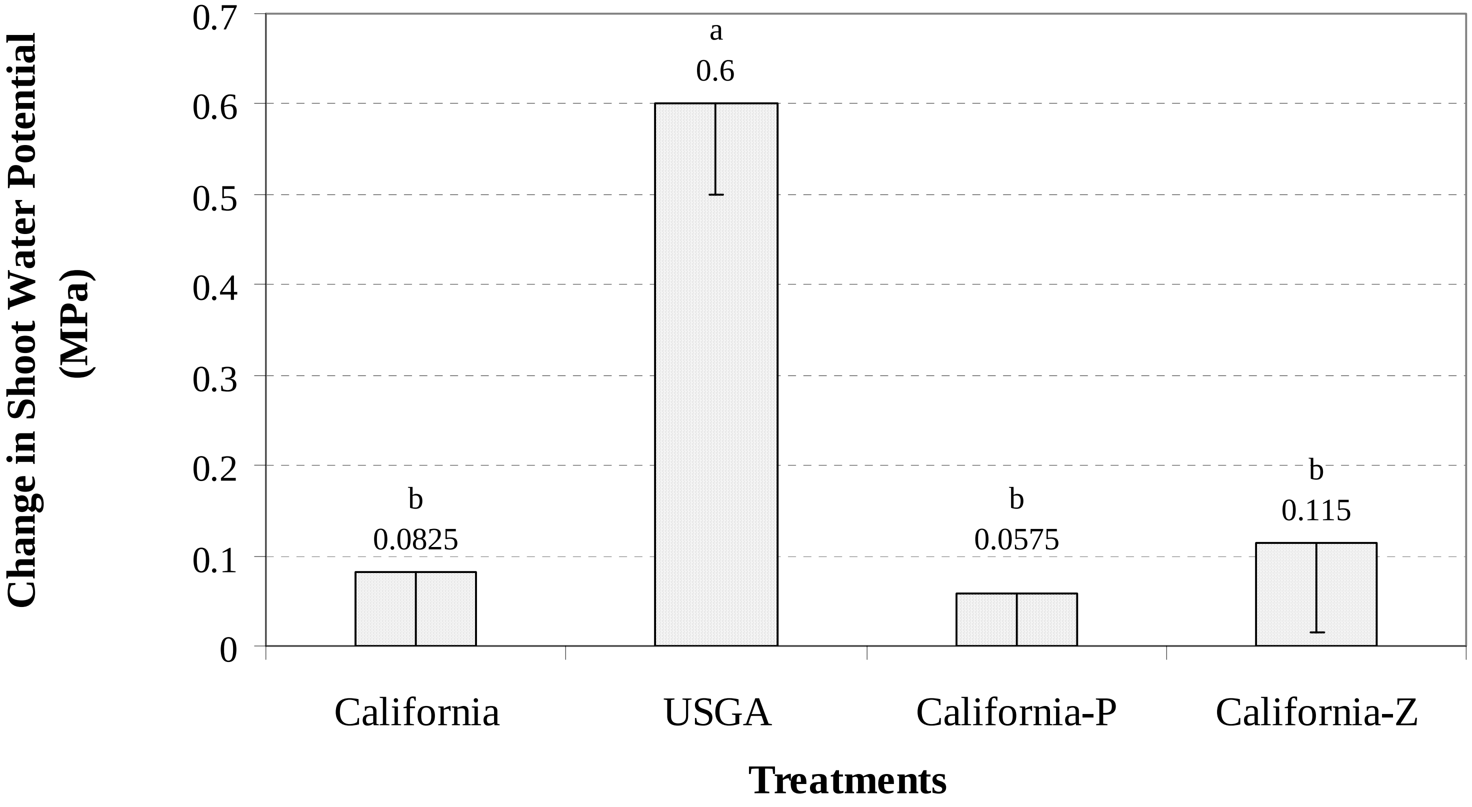

Figure 4.13. Change in the creeping bentgrass shoot water potential (value at 7/24 minus 6/24, 2001). Means separation were determined by LSD $_{0.05}$ and indicated by letters at each measurement and vertical bars represent LSD $_{0.05}$.

Bentgrass leaves on the USGA treatment were observed to have completely wilted at the end of the drought stress period and most of the grass in the plots had turned brown. This resulted from the fact that the USGA treatment experienced the highest bentgrass shoot water stress during the drydown period.

The results of the quality and color ratings for the four treatments at the beginning and end of the drydown periods for 2000 and 2001 are shown in Tables 4.1 and 4.2. The quality and color ratings of bentgrass for the California treatment were equal to or lower than the

Table 4.1. Quality and color ratings of bentgrass under irrigated conditions (6/25) and dry conditions (7/25) in 2000.

| Treatments | Quality rating+ | | Color rating+ | |
|---|---|---|---|---|
| | 6/25 | 7/25* | 6/25 | 7/25* |
| California | 4.8b | 4.4a | 5.3bc | 4.0a |
| USGA | 4.8b | 2.8b | 4.9c | 3.1b |
| California-P | 5.3b | 3.8ab | 5.6b | 4.3a |
| California-Z | 6.0a | 3.4ab | 6.1a | 3.3b |
| LSD $_{0.05}$ | 0.7 | 1.2 | 0.4 | 0.7 |

+Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal. *End of drydown (measured after no irrigation from June 24 to July 24, 2000). Letters following values within column indicate mean comparison.

Table 4.2. Quality and color ratings of bentgrass under irrigated conditions (6/25) and dry conditions (7/25) in 2001.

| Treatments | Quality rating+ | | Color rating+ | |
|---|---|---|---|---|
| | 6/25 | 7/25* | 6/25 | 7/25* |
| California | 5.9ab | 5.1a | 6.0ab | 5.6a |
| USGA | 5.8b | 2.5b | 5.9b | 2.6b |
| California-P | 6.1ab | 5.6a | 6.3a | 5.9a |
| California-Z | 6.4a | 5.6a | 6.1ab | 5.3a |
| LSD $_{0.05}$ | 0.5 | 1.3 | 0.4 | 1.3 |

+Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal. *End of drydown (measured after no irrigation from June 24 to July 24, 2001). Letters following values within column indicate mean comparison.

California-P and California-Z treatments and equal to the USGA treatment at the initiation of the drought period for both 2000 and 2001. However, the California treatment had equal to or better quality and color ratings compared with the California-P and California-Z treatments in 2000 at the end of the drydown period and had values in 2001 that were not significantly different than the California-P and California-Z treatments (which had the higher quality ratings that year). The USGA treatment had the lowest quality and color ratings at the end of the drydown period in 2001.

Greater nutrient content in the inorganic amended treatments (Tables 4.3 and 4.4) may have contributed to the higher bentgrass quality and color ratings at the beginning of the drydown periods in 2000 and 2001. The California-P treatment had the highest cation exchange capacity, and Ca and Mg levels in both 2000 and 2001. The California-Z treatment had the highest P and K levels for the four treatments. The quality and color ratings of the bentgrass for the California-Z treatment had the higher ratings under well irrigated conditions which were observed at the beginning of the drydown periods in 2000 (Table 4.1).

Table 4.3. Chemical properties in the root zone during the bentgrass mature green phase (June 2000).

| Treatments | pH | CEC | OM | P | Ca | Mg | K |
|---|---|---|---|---|---|---|---|
| | | cmol $kg^{-1}$ | % | mg $kg^{-1}$ | cmol $kg^{-1}$ | cmol $kg^{-1}$ | cmol $kg^{-1}$ |
| California | 6.8 | 2.22b | 0.45b | 18.74c | 1.75b | 0.30c | 0.16b |
| USGA | 6.9 | 2.74a | 0.70a | 19.49c | 2.20a | 0.37bc | 0.16b |
| California-P | 6.9 | 3.15a | 0.58ab | 25.47b | 2.44a | 0.46a | 0.23b |
| California-Z | 6.9 | 3.02a | 0.58ab | 35.73a | 2.18a | 0.39ab | 0.44a |
| $LSD_{0.05}$ | NS | 0.48 | 0.17 | 5.80 | 0.37 | 0.08 | 0.08 |

NS : Nonsignificant.

Table 4.4. Chemical properties in the root zone during the bentgrass mature green phase (May 2001).

| Treatments | pH | CEC | OM | P | Ca | Mg | K |
|---|---|---|---|---|---|---|---|
| | | cmol kg$^{-1}$ | % | mg kg$^{-1}$ | cmol kg$^{-1}$ | cmol kg$^{-1}$ | cmol kg$^{-1}$ |
| California | 6.9 | 2.76c | 0.18b | 21.90c | 2.12c | 0.41c | 0.18b |
| USGA | 6.8 | 3.72b | 0.33a | 23.75bc | 2.97b | 0.59b | 0.15b |
| California-P | 6.8 | 5.25a | 0.35a | 33.50ab | 4.06a | 0.79a | 0.38b |
| California-Z | 6.9 | 4.39b | 0.13b | 36.40a | 3.03b | 0.55bc | 0.81a |
| LSD $_{0.05}$ | NS | 0.80 | 0.11 | 11.00 | 0.57 | 0.14 | 0.28 |

NS : Nonsignificant.

However, the ratings for this treatment had the greatest decline during the drydown period in 2000 among the four treatments. This result may have been due to the California-Z treatment having the lowest root zone volumetric water content among the four treatments from 17 to 30 days after no irrigation (Figure 4.9). Figures 4.14 and 4.15 show the root zone water loss from the beginning to end of the drydown. The California-Z treatment had the highest root zone water loss in 2000 while root zone water loss among the treatments were not significantly different in 2001. The California-Z treatment did not decline in quality and color as much in 2001 compared with 2000. Also, the California-Z treatment had the highest shoot water

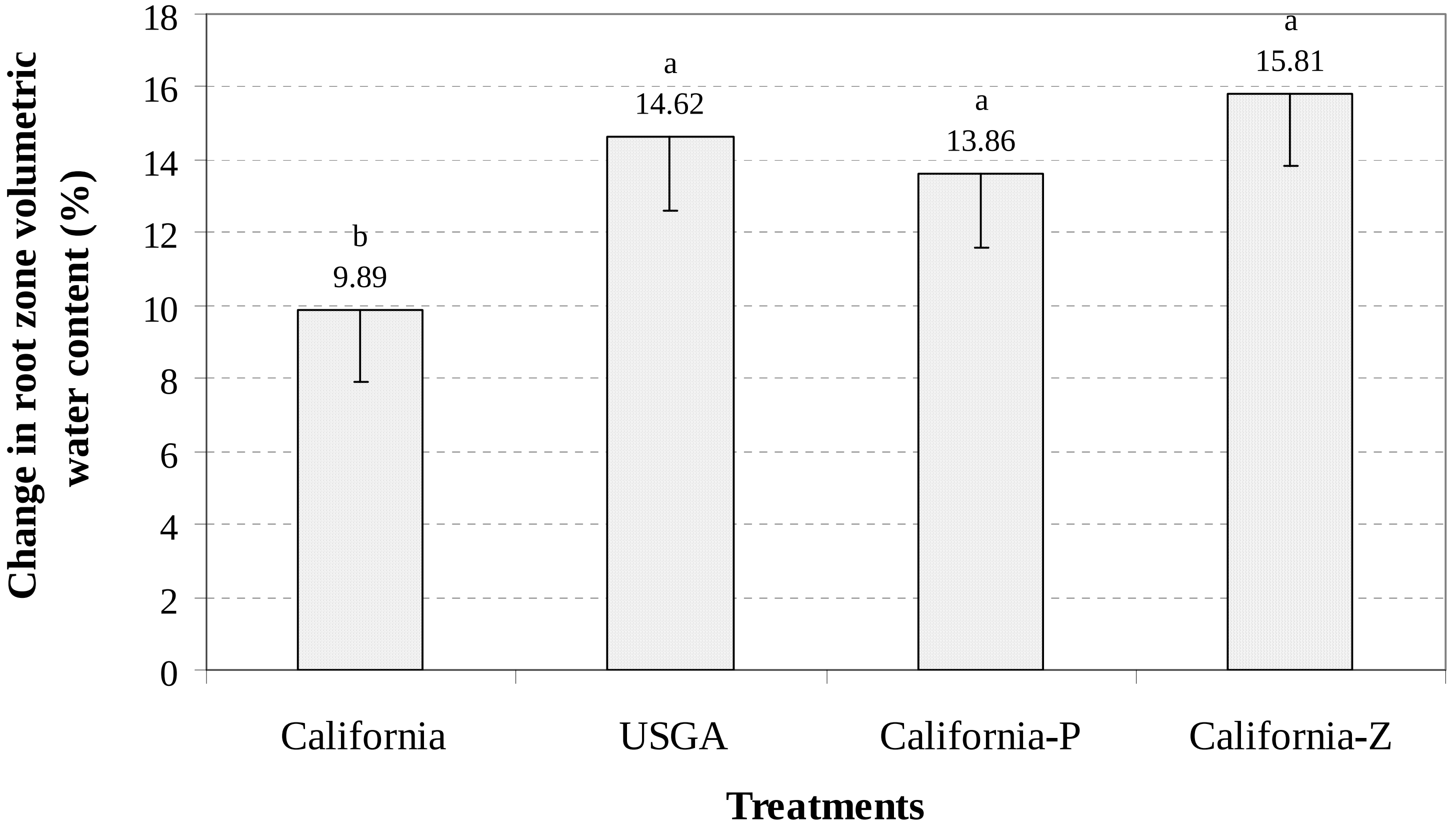

Figure 4.14. Change in the root zone water content (%) (value at 6/24 minus value at 7/24, 2000). Means separation were determined by LSD $_{0.05}$ and indicated by letters at each measurement and vertical bars represent LSD $_{0.05}$.

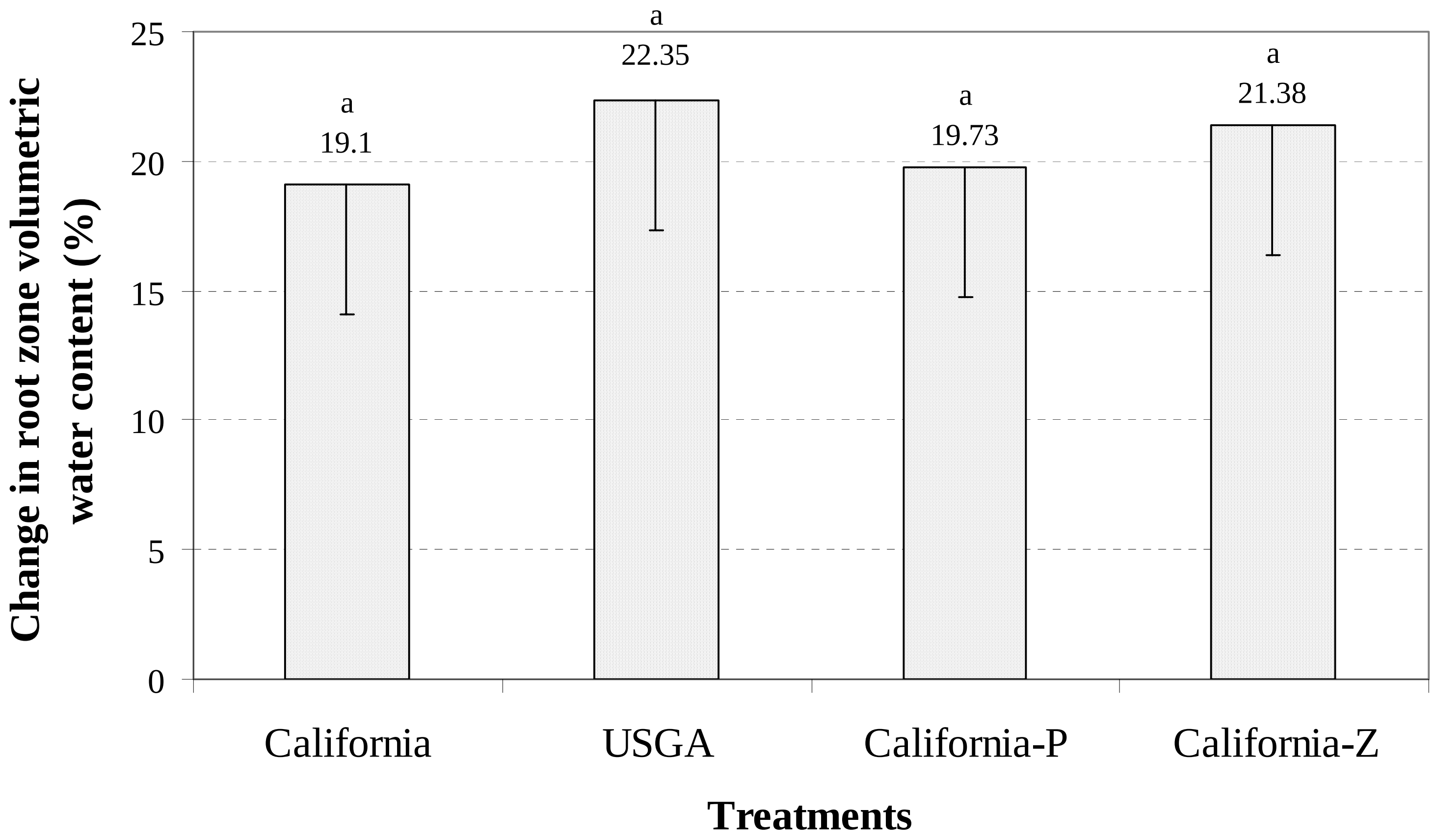

Figure 4.15. Change in the root zone water content (%) (value at 6/24 minus value at 7/24, 2001). Means separation were determined by LSD $_{0.05}$ and indicated by letters at each measurement and vertical bars represent LSD $_{0.05}$.

potential with highest creeping bentgrass quality when compared with other treatments after the drought stress period in 2001. Miller (2000) reported that turf grown in Profile and ZeoPro amended sand had the highest quality when compared with native soil, peat, and diatomaceous earth amended sand. These amendments had the potential to influence root zone water content, ultimately influencing transpiration response to drought stress. Although the peat amended USGA treatment had better nutrient levels (Ca and Mg) relative to the California treatment (Tables 4.3 and 4.4), color and quality at the beginning of the drydown period was similar to that of the California treatment. However, the USGA treatment showed significantly lower color and quality at the end of the drydown period for both years, probably due to higher plant water stress (Figure 4.12).

Huang and Petrovic (1996) reported that clinoptilotlite zeolite (ZeoPro) has a positive effect on turfgrass growth and quality. Zeopro exhibits selective retention of $NH_4^+$ and $K^+$, which may provide added benefits for turf growth. The California-Z treatment had the highest creeping bentgrass quality at the beginning of the drydown period which was probably due to greater nutrient content for this treatment (Tables 4.3 and 4.4). Lower root zone volumetric water content for the California-Z treatment at the end of the drydown period in 2000 may have been a result of higher water loss (Figure 4.9) due to greater transpiration. Since the plants in this plot had the highest quality rating (potentially more leaf area) at the beginning of the drydown, when compared to the other treatments, they may have had higher water transpiration which may reduce the quality for the California-Z treated plots. However in 2001, the California-Z treatment lost about the same amount of water during the drydown period as the other treatments. It also had the highest shoot water potential at the end of the drydown period.

This study showed that creeping bentgrass may perform differently when grown in four different root zone mixtures. The data suggest that the California putting green root zone system was the better treatment for maintaining bentgrass quality and color during drydown periods compared to the USGA construction system. The California construction system also resulted in the highest bentgrass shoot water potentials (least stress) during the drydown period. These results are attributed to the lack of a pea gravel sub-layer in the California system which results in higher plant available water in the root zone. The addition of Profile and zeolite to the sand for the California construction system was shown to offer some benefits during the drought period. These treatments were found to have a higher bentgrass shoot water potential (less stress) and nutrient content among the treatments. In this study, the California construction systems were found to provide better performance after a drydown period in 2001 than the USGA construction system.

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