CHAPTER V

CARBON METABOLISM AND WATER USE EFFICIENCY OF ZOYSIAGRASS AND TALL FESCUE DURING DEFICIT IRRIGATION

ABSTRACT

Little is known about the influence of deficit irrigation on turfgrass growth and physiology. Growth and physiological responses of 'Falcon II' tall fescue and 'Meyer' zoysiagrass were evaluated for two summers under a mobile rainout shelter at deficit irrigation levels of 20% to 100% of potential evapotranspiration (ET). Tall fescue and zoysiagrass irrigated at 20% and 40% ET had significantly lower canopy net photosynthesis (CNP), whole-plant respiration (WPR), canopy vertical growth rate (CVGR), tiller density and underlying soil water content than turf receiving 100% ET (well-watered turf). Irrigation at ≤ 40% ET in zoysia reduced CNP to a greater extent than WPR; a similar response occurred in tall fescue at 40% ET in one year, and at 20% ET in both years. Water use efficiency was generally higher over all irrigation regimes in zoysia compared to tall fescue. Deficit irrigation did not affect water use efficiency (WUE) in tall fescue until the end of each summer at 20% and 40%. Irrigation at 20% and 40% ET reduced WUE for zoysiagrass during most of each study period in both years. By reducing CNP to a greater extent than WPR, deficit irrigation may influence plant responses to subsequent abiotic and biotic stresses; this deserves further investigation.

ABBREVATION

ET, evapotranspiration (ET); CNP, canopy net photosynthesis; WPR, whole-plant respiration; CVGR, canopy vertical growth rate; WUE, water use efficiency (WUE).

INTRODUCTION

Water availability for use in irrigating green spaces becomes limited when concerns over water shortages arise. Researchers have investigated the effects of drought on turf quality and water relations (Carrow, 1996; Qian and Fry, 1997; Huang and Fu, 2000). Deficit irrigation, or application of water at levels less than potential evapotranspiration (ET), can be used as one strategy to minimize water demand for turfgrasses. The influence of deficit irrigation on carbon metabolism, water use efficiency, and turfgrass growth has not been reported.

Researchers evaluating response of turfgrasses to drought reported that clipping production, verdure, density, and turf quality declined, whereas wilt, leaf firing, and canopy temperature increased with drought (Minner and Butler, 1985, Aronson et al., 1987; Carrow, 1996.).

Although turfgrass growth is dependent upon water absorption and maintenance of positive plant turgor pressures, drought stress may also have immediate and long term effects on plant growth by influencing carbon metabolism. Photosynthesis and respiration may be differentially affected by drought (Pande and Singh, 1981). Such responses could influence reserve carbohydrate levels. A negative whole-plant carbon balance could occur as a result of reduced photosynthetic capacity during drought, unless simultaneous and proportionate reductions in growth and carbon consumption take place. Carbon metabolism has not been evaluated during deficit irrigation in turf.

Water use efficiency is an indicator of the amount of water lost through ET relative to the amount of carbon fixed. The effects of drought on water use efficiency vary, depending on the species, and duration and intensity of drought. Read (1991) reported that drought resulted in higher WUE in wheat (*Triticum aestivum* L.). However, Mastrorilli (1999) verified that a temporary soil water stress reduced WUE in sweet sorghum [*Sorghum bicolor (L.) Moench*]. Tall fescue and zoysia are widely used in the transition zone; however, little is known about the influence of deficit irrigation on their water use efficiency.

To date, experiments done to evaluate turfgrass physiological responses to drought have been done under controlled conditions in the laboratory (Hays et al., 1991). Such short-term approaches may not best represent real world conditions that can be evaluated over months or years in the field.

Our objectives were to evaluate the effects of deficit irrigation on carbon metabolism, WUE, and growth of tall fescue and zoysia.

MATERIALS AND METHODS

Plant material and growing conditions

The experiment was conducted using an automated, mobile rainout shelter (180 m^2) at the Rocky Ford Turfgrass Research Center at Manhattan, KS from 4 June to 14 September, 2001 and from 3 June to 13 September, 2002. The shelter was set on rails, and a rainfall event of 0.4 mm triggered its movement over the study area. Time required for the plots to be completely covered was approximately two minutes. A weather station , located within 2 km of the study area, was used to monitor temperatures (Appendix I).

The study was set up as a split-plot design, with turfgrass species as the whole plots and irrigation levels as the sub-plots. 'Meyer' zoysia and 'Falcon II' tall fescue were sodded in spring, 2000 in 5.9 m x 1.83 m whole plots on a river-deposited silt loam soil (fine, montomorillonitic, mesic Aquic Arquidolls). Irrigation levels were 20, 40, 60, 80, and 100% of ET applied twice weekly to sub-plots measured 1.18 x 1.83 m. Each plot was bordered by metal edging (set 15 cm deep) to minimize lateral movement of water after application.

Turf was mowed twice weekly at 5-6 cm using a rotary mower. Nitrogen was applied at 49 kg ha^{-1} to tall fescue and Kentucky bluegrass in May 3, September 19 and November 8 in 2001 and May 3, September 18 and November 15 in 2002. Zoysia and bermudagrass received an equivalent level of N in May 3 and June 29 in 2001 and May 3 and August 5 in 2002. Lysimeters were maintained identically to field plots.

Amounts of water to deliver respective deficit irrigation levels were determined based on ET measured in well-watered lysimeters using the water balance method (Qian et al., 1996). Lysimeters were constructed of PVC pipe (10.1 cm in diameter and 25 cm deep) that had a nylon screen on the bottom end taped with duct tape. Intact soil cores and accompanying turf were sampled from the actual plots in April, 2001 using a 10-cm diam. cup cutter. Lysimeters were then set into holes slightly larger than the lysimeters that were located in the center of plots of each species receiving irrigation at 100% ET. The day before the study began each year, lysimeters were soaked until water was draining through the bottom of each. When drainage had ceased, each was sealed on the bottom end with plastic bag and weighed to determine its reference weight, and then returned to respective holes in the plot area.

To determine ET, lysimeters were removed from the field and weighed between 0100 h and 0200 h on Monday and Friday of each week. The mass of water lost from each was recorded and converted to ET. Water was then added to lysimeters using a graduated cylinder to return each to its reference weight before returning to the field.

Deficit irrigation amounts for field plots were calculated as: Deficit irrigation level x ET x an area adjustment factor. Total water applied to turf receiving 100% ET during the study period in 2001 and 2002, respectively, was as follows: tall fescue, 562 and 598 mm and zoysia, 390 and 449 mm.

Measurements

Data were collected on carbon metabolism, water use efficiency (WUE), canopy vertical growth rate (CVGR), tiller density, and soil water content.

Carbon metabolism was measured every 4 weeks, beginning on 4 June, 2001 and 3 June, 2002, using a LI-6400 portable gas exchange system (Licor Inc., Lincoln, NE). Measurements were made between 0900 and 1500 h. Canopy net photosynthesis (CNP) and whole plant respiration (WPR) were determined by enclosing the turf canopy (81 cm^2) in a transparent plexiglass chamber (15 × 10 × 10 cm) attached to the CO_2 analyzer. Data for CNP and WPR were expressed as CO_2 uptake and evolution per unit area.

Water use efficiency was determined on the same dates CNP and WPR were measured, and was calculated as the photosynthetic rate (μmol CO_2 s^{-1} m^{-2}) over evapotranspiration (mmol H_2O s^{-1} m^{-2}) using a LI-6400 portable gas exchange system (LI-COR Inc. Lincoln, NE).

Canopy vertical growth rate (CVGR) and tiller density were determined every 4 weeks by calculating the difference in turf canopy height before and after cutting on three-day intervals. A sheet of paper was rested on the canopy surface to measure canopy height as the distance from the paper to the soil surface at eight arbitrary locations in each sub-plot. Tiller density was determined by dropping a 5.1-cm diam. template at two locations in each plot and counting tillers.

Soil water content was measured using a time domain reflectometer (Soil Moisture Equipment Corp., Santa Barbara, CA). Two steel probes, measuring 0.63 cm in diam. by 25-cm long were set at an arbitrary location in each sub-plot in April, 2001, and they remained in place until removed at the end of the study period in September, 2002. A small block of wood, with appropriate holes drilled to accommodate probes, was used to protect the probes in the period between measurements.

Data analysis

Treatment effects were determined by analysis of variance according to the mixed model of Statistical Analysis System (SAS Institute, Inc., 1988). Variation was partitioned into grass species, deficit irrigation level, and treatment duration (sampling time). Results indicated a significant species x deficit irrigation level interaction; therefore, results and discussion focus on responses to deficit irrigation within a grass species. Treatment means were separated by a least significant difference test ($P < 0.05$). Initial ET and SWC measurements were considered covariants to analyze covariance effects using the general linear models procedure (SAS Institute Inc., 1988).

RESULTS

Canopy net photosynthesis

Zoysia had a higher CNP than tall fescue on nearly all evaluation dates in 2001 and 2002 at irrigation levels of 60 % ET and above. Beginning at 44 DOT in 2001, tall fescue CNP was lower than that of well-watered turf when irrigated at 20% ET (Fig. 1). In 2002, CNP of tall fescue irrigated at 20% or 40% ET was lower than that of well-watered turf beginning 73 DOT.

Zoysia irrigated at 20, 40 or 60% ET had a lower CNP than well-watered turf during most of the study period in each year (Fig. 1).

Whole-plant respiration

Irrigation at 20% and 40% ET reduced tall fescue WPR compared to well-watered turf beginning at 44 DOT in 2001 and 2002 (Fig. 2).

Zoysia WPR was reduced to below levels of well-watered turf at 60% ET beginning at 44 DOT in 2001, and at 20 and 40% ET beginning at 30 DOT in 2001 and at 44 DOT in 2002 (Fig. 2).

Water use efficiency

Zoysia had higher WUE than tall fescue, especially at irrigation levels ≥ 60% ET (Fig. 3). Deficit irrigation had no effects on water use efficiency of tall fescue during most of each study period in both years.

Irrigation at 20% and 40% ET reduced WUE for zoysiagrass during most of each study period in both years (Fig. 3).

Canopy vertical growth rate

Tall fescue receiving 20% and 40% ET had a significantly lower CVGR than that receiving 100% ET, beginning at 31 DOT in 2001 and at 46 DOT in 2002 (Fig. 4).

The CVGR of zoysia receiving 20% ET was lower than that of well-watered turf beginning at 18 DOT in 2001 and 2002 (Fig. 4). Irrigation at 40% ET reduced zoysia CVGR relative to well-watered turf beginning at 18 DOT in 2001 and at 31 DOT in 2002. Zoysia irrigated at 60% ET had a lower CVGR than well-watered turf at 31 and 46 DOT in 2001. In 2002, however, growth rate of zoysia irrigated at 60% ET was similar to well-watered turf.

Turf density

In both years, irrigation at 20% and 40% ET reduced tall fescue tiller density to below the level of well-watered turf beginning at 44 DOT (Fig. 5).

Zoysia receiving 20% and 40% ET had significantly lower tiller densities than well-watered turf during most of the study period in 2001. In 2002, irrigation at 20% and 40% ET did not reduce tiller density until 73 DOT.

Soil water content

Compared to zoysia, tall fescue had higher soil water contents at 25 cm depth at a given irrigation level on all measurement dates in both years. Soil water content at 25 cm depth was lower under tall fescue receiving 20% and 40% ET than under well-watered turf beginning at 8 DOT in 2001 and at 7 DOT in 2002 (Fig. 6).

Compared to well-watered turf, irrigation at 60% ET reduced SWC under zoysia during most of the study in 2001 (Fig. 6). All deficit irrigation levels reduced SWC under zoysia during most of the study period in 2002.

DISCUSSION

Tall fescue and zoysia CNP, WUE, WPR, CVGR, and tiller density were generally unaffected when irrigated at 80% ET. This suggests that a moderate level of deficit irrigation has little effect on tall fescue or zoysia carbon metabolism or growth. Others have observed similar, positive responses to moderate deficit irrigation levels in tall fescue and zoysia. Tall fescue quality was similar to well-watered turf when irrigated every 2 or 4 d at 75% ET in Colorado (Fry and Butler, 1989). In Nevada, tall fescue color and coverage were unaffected at a deficit irrigation level of 80% (Dean et al., 1996). Zoysia remained the same level of turf quality as that of control (100% ETp), when irrigated at 34% ET on 2 day intervals and mowed at 1.6 cm from 18 July to 17 August (McSuker et al., 1987).

At deficit irrigation levels ≤ 60% ET, differences between tall fescue and zoysia in carbon metabolism and growth, and within each species relative to well-watered turf, were more evident. Irrigation at 60% ET reduced CNP for zoysia during the latter stages of each study period, but did not affect tall fescue. At 40% and 20% ET, tall fescue and zoysia CNP, WPR, CVGR, and tiller density were all reduced compared to well-watered turf.

Qian et al. (1997) reported that 'Meyer' zoysia exhibited earlier, and more extended symptoms of wilting during summer dry down in the field compared to 'Mustang' tall fescue. My results indicated a similar superiority of tall fescue to zoysia in tolerance to deficit irrigation levels of ≤60% ET. It is likely that tall fescue was able to tolerate lower deficit irrigation levels by relying upon extensive rooting to extract water deep in the soil for growth. Qian et al. (1997) reported that 'Meyer' zoysia had 78% of its roots in the surface 30 cm, whereas tall fescue had 65% of its roots in the same region. At 30 to 60 cm, tall fescue root length density was over 10 times greater than that of zoysia. In the same test, tall fescue consistently extracted more water than zoysia at a 90 cm depth. Herein, soil water content at a 0 to 25 cm depth under tall fescue was consistently higher than that under zoysia regardless of irrigation level. It seems that the drier 0 to 20 cm soil depth under zoysia compared to tall fescue in our test occurred because that is the region where zoysia absorbs most of its water.

Sub-soil water that contributed to the positive performance of tall fescue at irrigation levels < 80 % ET may not have been delivered through our irrigation treatments; rather, precipitation falling in the fall, winter, and spring may have been present and available to deep-rooted tall fescue throughout most of the summer.

It should also be noted that some grasses, such as buffalograss [*Buchloe dacyloides* (Nutt.) Engelm.] are capable of absorbing water deep in the soil with long roots, and transporting and depositing it nearer the soil surface, a phenomenon known as hydraulic lift (Huang, 1998). Although the potential for hydraulic lift exists in tall fescue, it has not been documented.

The decline in tall fescue and zoysia CNP at deficit irrigation levels < 80% ET could be explained by the effects of drought on these processes. Photosynthesis is sensitive to drought, and stomatal conductivity is first affected. Huang and Fu (2000) also observed a decline in CNP rate beginning at 9 DOT of tall fescue when the water content of entire soil profile inside a 40-cm long PVC tube was dried to about 5% (v/v) in the greenhouse. The effects of drought stress on CNP has also been reported in other plant species, including bell pepper (*Capsicum annuum L.*) (Delfine et al., 2001), and maize (*Zea mays L.*)(Nissanka et al., 1997).

Whole-plant respiration did not decline until irrigation levels were reduced to 40% ET in both species. Hence, at 60% ET in zoysia, CNP was reduced, but not WPR. In tall fescue, irrigation at 20% ET caused a greater reduction in CNP than in WPR. The imbalance between CNP and WPR could lead to limited carbohydrate availability (Huang and Fu, 2000; Schmidt and Blaser, 1967; Huang and Gao, 2000), and exacerbate the near-term declines in CVGR and tiller density brought about by drought stress alone. In addition, a long-term imbalance between CNP and WPR could lead to greater susceptibility to injury from biotic or abiotic stresses, such as temperature extremes, for nonstructural carbohydrate levels can influence survivability (Fry et al., 1993).

Crops considered to have high WUE continue to fix carbon, and produce good biomass, while using relatively low amounts of water. In turfgrass systems, an efficient water user is one that is able to maintain higher CNP rates while transpiring less water. The present study indicated that zoysia had a significantly higher level of WUE than tall fescue at irrigation levels > 40% ET. This difference was likely due to the more efficient C_4 photosynthetic ability in zoysia compared to the C_3 pathway in tall fescue (Tung, 1999). The C_4 plants have ability to continue fixing carbon even when stomata are temporarily closed in response to drought. In C_3 plants, such as tall fescue, stomata closure leads to a rapid reduction in CNP. According to the results of previous researchers, and mine, tall fescue maintains higher photosynthesis even when soil surface moisture becomes depleted, as long as water is available deeper in the profile.

Irrigation at 20% and 40% ET reduced WUE for zoysiagrass during most of each study period in both years, indicating that zoysiagrass photosynthesis was reduced to a greater extent than ET.

Tall fescue WUE was unaffected regardless of deficit irrigation level. This was likely due to relatively high CNP and ET levels measured across all irrigation levels.

In summary, the results suggested that tall fescue and zoysiagrass were able to tolerate water deficit to a certain extent though physiological adjustment. Irrigation at ≤ 40% and ≤ 60% ET had detrimental effects on growth and physiological processes for tall fescue and zoysiagrass, respectively. By reducing growth and carbon metabolism, deficit irrigation may influence plant response to subsequent abiotic and biotic stress. This deserves further investigation.

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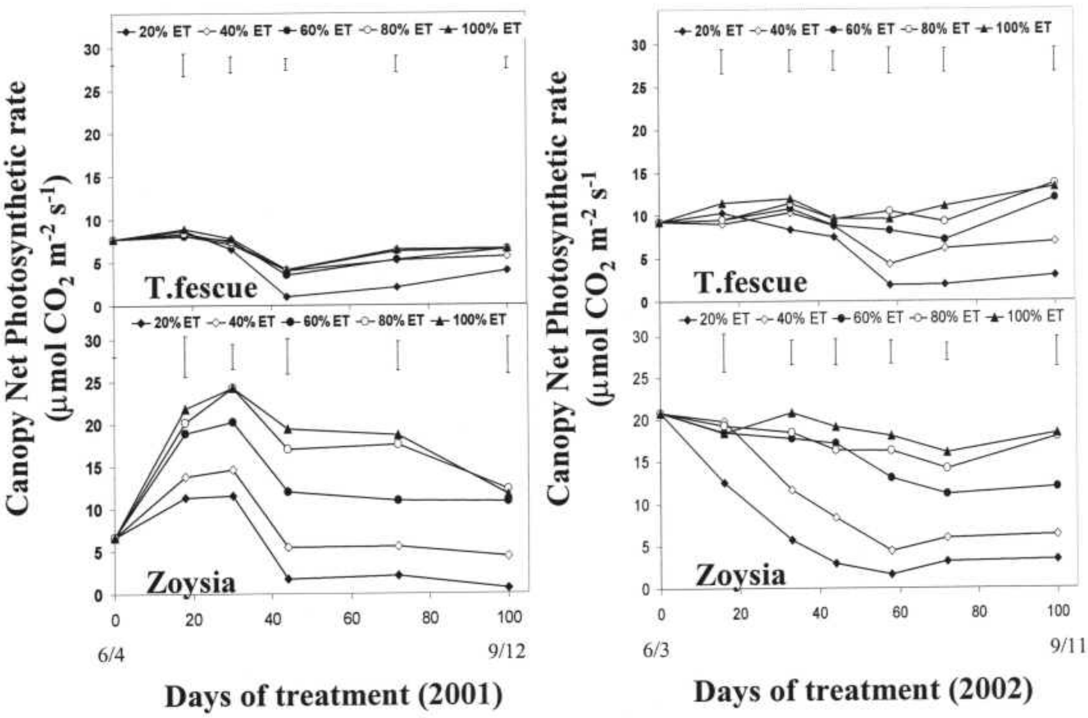

Fig. 1. Canopy net photosynthetic rate of tall fescue and zoysia in response to deficit irrigation. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. T.Fescue-tall fescue.

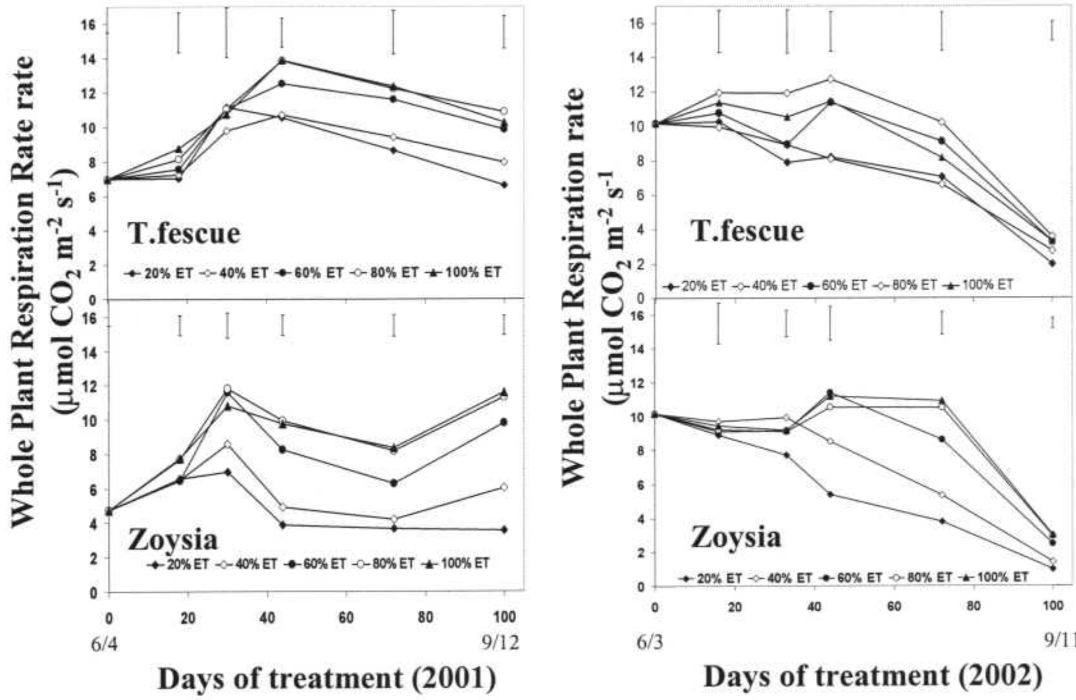

Fig. 2. Whole plant respiration rate of tall fescue and zoysia in response to deficit irrigation. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. T.fescue-tall fescue.

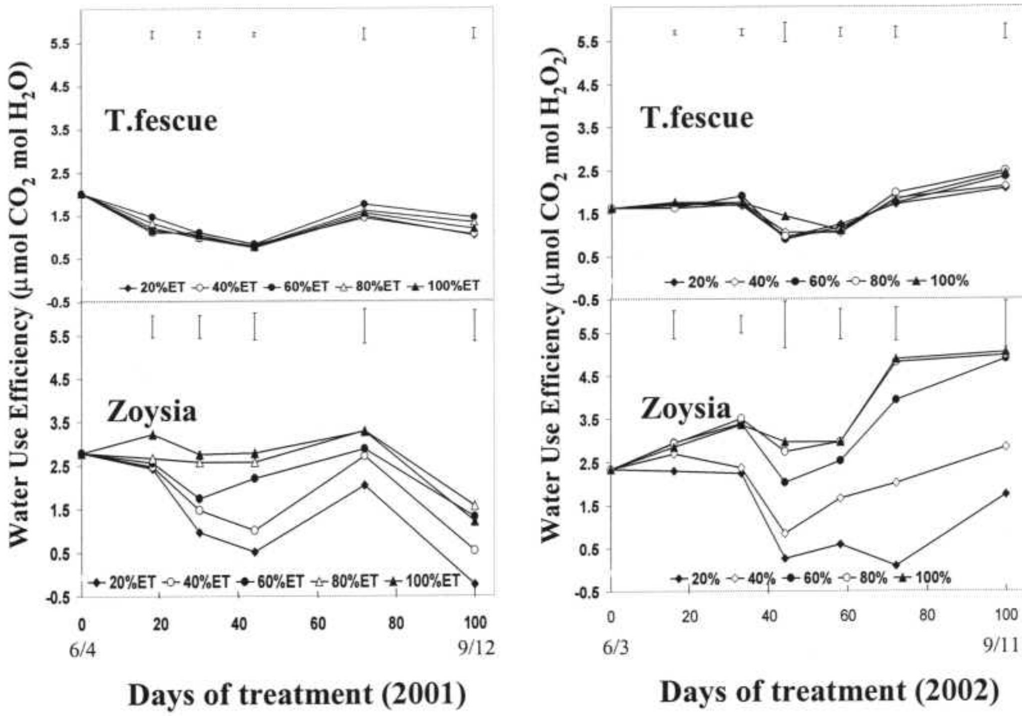

Fig. 3. What use efficiency of tall fescue and zoysia in response to deficit irrigation. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. T.fescue - tall fescue.

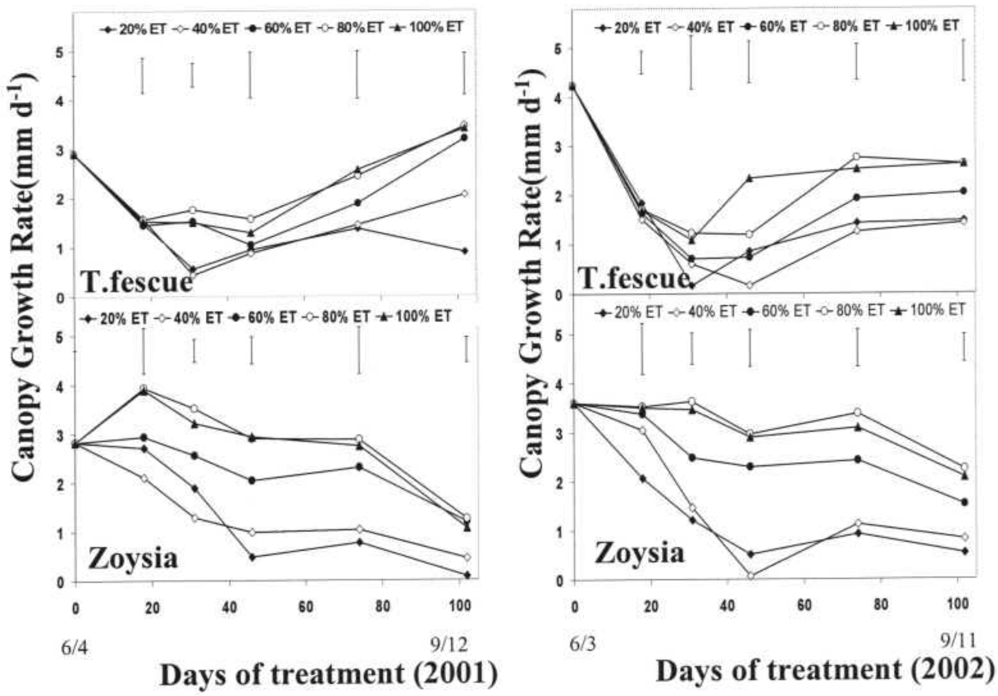

Fig. 4. Canopy growth rate of tall fescue and zoysia in response to deficit irrigation.Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. T.fescue - tall fescue.

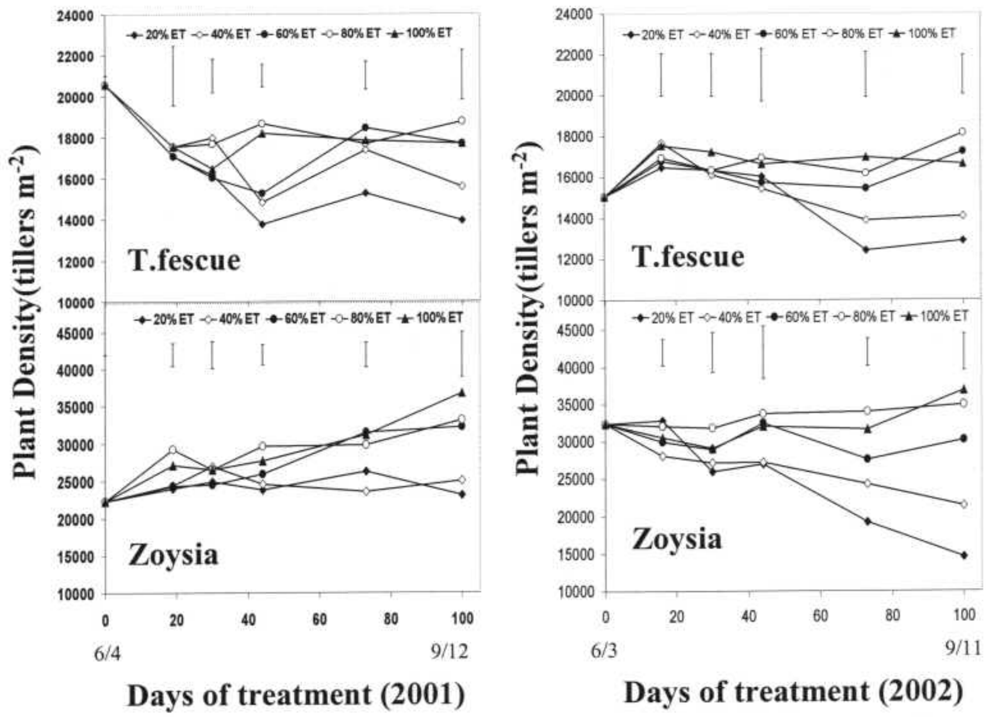

Fig. 5. Plant density of tall fescue and zoysia in response to deficit irrigation. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment.

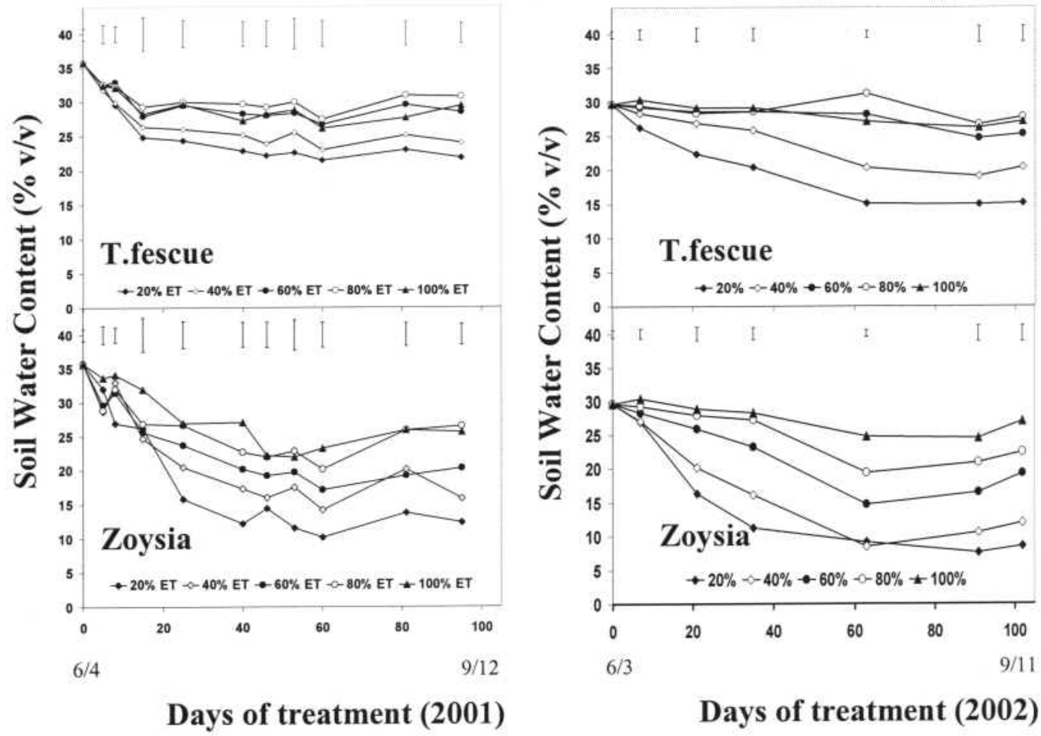

Fig. 6. Soil water content of tall fescue and zoysia in response to deficit irrigation. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. T.fescue - tall fescue.