CHAPTER IV

MINIMUM WATER REQUIREMENTS AND STRESS INDICATORS OF FOUR TURFGRASSES SUBJECTED TO DEFICIT IRRIGATION

ABSTRACT

Seasonal water requirements and stress indicators for 'Meyer' zoysiagrass (*Zoysia japonica* Steud.), 'Midlawn' bermudagrass (*Cynodon dactylon* L), 'Falcon II' tall fescue (*Festuca arundinaceae* Schreb.) and 'Brilliant' Kentucky bluegrass (*Poa pratensis* L.) were evaluated under a mobile rainout shelter at deficit irrigation levels of 20% to 100% of potential evapotranspiration (ET). Minimum annual irrigation amounts required to maintain a level of quality equal to turf receiving 100% ET ranged from 220 mm for bermudagrass to 552 mm for Kentucky bluegrass over the two year study. Kentucky bluegrass had less than acceptable quality even under the highest irrigation level during both years. Irrigation level (% of ET) where season-long acceptable turf quality was maintained in each year was 60% ET for tall fescue and bermuda, and 80% ET for zoysia. Irrigation at 20 and 40% ET resulted in a significant reduction in leaf relative water content (LRWC) in four species. Irrigation at 60% ET reduced LRWC of Kentucky bluegrass and zoysiagrass, but had no effect on that of tall fescue and bermudagrass. Leaf electrolyte leakage increased above that of well-watered turf when irrigation levels dropped to < 100% ET in Kentucky bluegrass, < 80% ET in tall fescue and zoysiagrass, and < 60% ET in bermudagrass.

ABBREVATIONS:

ET, evapotranspiration; LRWC, leaf relative water content; EL, electrolyte leakage; ND, The normalized difference vegetation index; IR/R, The ratio of reflectance at near infrared (935 nm) to red (661 nm) wavelengths.

INTRODUCTION

Turfgrass water use rates often exceed natural precipitation, and during extended periods without rainfall, restrictions may be imposed limiting water that can be applied to turf areas. As such, researchers have sought to identify turf species and cultivars that have good drought resistance (Aronson, 1987; Carrow, 1995; Fry and Butler, 1989), and irrigation management techniques to reduce water inputs.

In recent years, there has been increasing interest in deficit irrigation, returning water in amounts less than potential evapotranspiration (ET), as a water conservation technique (Feldhake et al., 1984; Fry and Butler, 1989; Qian and Engelke, 1999). Turf managers overseeing installation of new golf courses, housing developments, and other turf areas are commonly queried by government administrators as to how much irrigation water will be required to maintain an acceptable quality landscape. Sod producers also face growing concerns regarding water requirements to allow satisfactory harvest and sale of turf. However, the amount of water required to maintain acceptable quality of various turfgrass species throughout the growing season in the transition zone has not been well defined.

'Rebel' Tall fescue and 'Merion' Kentucky bluegrass visual quality were reduced by about 10% when irrigated at a 27% ET deficit in Colorado (Feldhake et al., 1984). In another Colorado test, tall fescue watered every 2 d at 50% ET exhibited only small reductions in turf quality (Fry and Butler, 1989). Qian and Engelke (1999) observed that irrigation required to maintain acceptable turf quality (expressed as % of ET) for respective grasses in Texas was: 'Rebel II' tall fescue (67%); 'Meyer' zoysiagrass 68%; 'Nortam' St. Augustinegrass (44%); and 'Tifway' bermudagrass (35%). Gibeault (1985) reported that turf quality in blends of Kentucky bluegrass and perennial ryegrass cultivars, and 'Kentucky-31' tall fescue, declined slightly when irrigation was reduced by 20% of ET in southern California.

More information is needed to determine deficit irrigation effects on plant stress indicators. For example, leaf relative water content, an indicator of leaf water status, decreases as drought stress progresses. Drought stress also causes cellular membrane modification, and increases leakage of ions and electrolytes (Kirnak et al., 2001); the degree of leakage can be measured. Leaf area index and the amount of green turf cover are also reduced during drought stress, and can be measured using a multispectral radiometer (Huang et al. 1998). No work has been done to determine how deficit irrigation influences plant stress as measured by one or more of the aforementioned techniques.

The objectives of this study were to: 1) determine minimum water required to maintain acceptable visual quality of zoysiagrass, bermudagrass, tall fescue, and Kentucky; and 2) evaluate effects of deficit irrigation on drought-related turfgrass stress indicators, leaf relative water content and leaf electrolyte leakage.

MATERIALS AND METHODS

Growing conditions and treatments

This 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 Sept., 2002. During dry weather, the shelter rested just to the north of the study area. The shelter was triggered by a minimum of 0.38 mm precipitation, and required approximately two minutes to move south on rails and completely cover the test area. One hour after precipitation ceased, the shelter returned to its resting position. A weather station was located within 2 km of the study area and was used to monitor temperatures (Appendix I)

The experimental design was a split-plot, with turfgrass species as the whole plot and irrigation level as the sub-plots. Whole plots measured 5.9 m x 1.83 m, and consisted of 'Meyer' zoysiagrass, 'Midlawn' bermudagrass 'Falcon II' tall fescue, and 'Brilliant' Kentucky bluegrass. All whole plots were established by sodding in spring, 2000 on a river-deposited silt loam (fine, montmorillonitic, mesic Aquic Arquidolls) soil. Sub-plots measured 1.18 x 1.83 m, and consisted of irrigation levels of 20, 40, 60, 80, and 100% of ET. Each plot was bordered by metal edging (set 15 cm deep) to minimize lateral movement of water upon application.

Water was applied twice weekly using a metered, hand-held hose with a fan spray nozzle attached. Deficit irrigation amounts were determined by taking the fraction of water use of lysimeter-grown turf receiving 100% ET. Pots (10.1 cm in diameter and 25 cm deep) constructed of PVC were planted with turf sampled in April, 2001using a 10.1-cm diam. cup cutter to remove a 25-cm deep soil core and accompanying turf. Cores were then placed into the pots to create lysimeters. Each lysimeter had a nylon screen on the bottom end taped with duct tape.

After planting, lysimeters were placed in holes that had been dug in the center of each sub-plot scheduled to receive 100% ET. Turf in lysimeters was maintained identically to that of the surrounding lysimeters.

The day before the study began each year, lysimeters were soaked until water was draining through the bottom of each. 24 h later, each was sealed on the bottom end with two plastic bags and weighed to determine its reference weight, and then returned to respective holes in the plot area.

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: 562 and 598 mm for tall fescue, 390 and 449 mm for zoysia, 552 and 364 mm for Kentucky bluegrass and 407 and 412 mm for bermuda.

Turf was mowed twice weekly at 5-6 cm using a walk-behind rotary mower, and clippings were collected. 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. Severe decline of Kentucky bluegrass in 2002 precluded collection of data.

Measurements

Data were collected on ET, turf quality, canopy reflectance, leaf relative water content (LRWC), and leaf electrolyte leakage (EL).

Evapotranspiration rate was measured twice weekly by measuring change in mass of lysimeters using the water balance method described previously.

Turf quality was rated visually on the scale of 0 (brown, dead turf) to 9 (optimum color, density, and uniformity). Turf receiving a rating of 6 was deemed to have acceptable quality.

Canopy reflectance at eight wave-lengths (from 435 to 1080 nm) was measured at 1200 h on sunny days with a multispectral radiometer (MSR) (CROPSCAN, Rochester, Minn.). The normalized difference vegetation index (ND) and the ratio of reflectance at near infrared (935 nm) to red (661 nm) wave-lengths (IR/R) were calculated based on canopy reflectance (Asrar et al., 1984):

$$ND=(R_{935} - R_{661})/(R_{935} + R_{661})$$

$$IR/R=R_{935}/R_{661}$$

Where R_{935} = reflectance at 935 nm (790-1080 nm) and R_{661} = reflectance at 661 nm (648-674 nm). Normalized difference vegetation index is correlated with canopy green leaf biomass. The ratio of IR/R is correlated with leaf area index (LAI) (Hatfield et al., 1983).

Leaves to provide ~ 1.0 g fresh weight were sampled randomly at two locations in each plot in order to measure leaf relative water content. Leaf relative water content was calculated as LRWC = (FW-DW)*100/(TW-DW), where FW is leaf fresh weight, DW is leaf dry weight, and TW is the weight of leaves at full turgor after soaking in water for 24 h at room temperature (22 °C).

Leaf electrolyte leakage was determined by taking a 0.5 ~ 1.0 g sample of leaves from two locations in each sub-plot, rinsing with water, immersing in 20 ml deionized water, and subjecting to a vacuum of 48 kPa for 15 min. Samples were then shaken in flasks containing deionized water on a shaker table (Lab-Line Instruments, Inc., Melrose Park, IL) for 24 h. The conductivity of the solution ($C_{initial}$) with fresh tissues was measured using a conductivity meter (YSI Model 32, Yellow Spring, OH). Leaves then were killed by autoclaving at 140 °C for 20 min, and the conductivity of the solution with killed tissues (C_{max}) was measured. Relative EL was calculated as: ($C_{initial}$ / C_{max}) x 100.

Data analysis

Treatment effects were determined by analysis of variance according to the mixed procedure of Statistical Analysis System (SAS Institute Inc., 1988). Variation was partitioned into grass species, deficit irrigation level, and treatment duration (sampling time). Analyses showed a significant difference in the corresponding interaction between grass species and deficit irrigation level. Therefore, the comparison of deficit irrigation treatments within a grass species was statistically analyzed. Differences among treatment means within a species were separated by a least significant difference mean separation test ($P < 0.05$). Multiple linear regression was used to determine the critical values of LRWC, EL, ND, and IR/R below which unacceptable turf quality was observed. Initial ET, ND and the IR/R ratio were considered as covariants to analyze covariance effects according to the general linear models of the Statistical Analysis System. Then, ET, ND and the IR/R ratio were adjusted as if each treatment had the same initial value.

RESULTS

Visual quality

In 2001, Kentucky bluegrass quality was lower than that of turf receiving 100% ET beginning at 10 DOT at 20% ET, at 22 DOT at 40% and 60% ET and at 51 DOT at 80% ET in 2001 (Fig. 1). Severe decline in Kentucky bluegrass prevented acquisition of good data in 2002. All irrigation levels led to unacceptable quality throughout the study period (Fig. 2).

Tall fescue subjected to deficit irrigation in 2001 had poorer quality than well-watered turf beginning at 44 DOT at 20% ET and 51 DOT at 40% ET (Fig. 1). Tall fescue receiving 60% to 80% of ET exhibited quality equivalent to well-watered turf. In 2002, tall fescue experienced a reduction in quality compared to well-watered turf beginning at 38 DOT at 20% and 40% ET and at 81 DOT at 60% ET (Fig. 2). At 80% ET, tall fescue quality was similar to well-watered turf throughout the summer.

Bermudagrass quality declined below that of well-watered turf beginning at 51 DOT at 20% ET in 2001 (Fig. 1). At all other irrigation levels, bermudagrass quality was equivalent to that of well-watered turf. In 2002, bermudagrass receiving 20% or 40% ET had lower quality than that of well-watered turf beginning 38 DOT (Fig. 2).

In 2001, Zoysiagrass quality began to decline relative to well-watered turf beginning at 22 DOT at 20%, 40% and 60% ET (Fig. 1). Likewise, in 2002, irrigation at 60% ET led to a decline in zoysia quality relative to well-watered turf beginning at 23 DOT (Fig. 2).

Canopy reflectance

Normalized difference vegetation index (ND) and the ratio of reflectance at near infrared to red wavelengths (IR/R) decreased below that of turf irrigated at 100% ET beginning at 12 DOT for Kentucky bluegrass receiving 20% ET and 23 DOT for turf irrigated at 40%, 60% or 80% ET in 2001 (Fig. 3 and Fig. 5). Poor turf performance in 2002 precluded collection of ND and IR/R ratio data in Kentucky bluegrass (Fig. 4 and Fig. 6).

The ND and IR/R ratio of tall fescue irrigated at 20% ET in 2001 dropped below that of turf receiving 100% ET at 51 DOT (Fig. 3 and Fig. 5). In 2002, tall fescue irrigated at 20% and 40% ET had lower ND and IR/R ratio compared to well-watered turf starting at 24 DOT (Fig. 4 and Fig. 6).

The ND and IR/R ratio of bermudagrass irrigated at 20% ET in 2001 dropped below that of turf receiving 100% ET at 23 DOT and 80 DOT (Fig. 3 and Fig. 5). Dollar spots (*Sclerotonia homeocaxpa*) led the decline in the ND and IR/R ratio at all irrigation levels. In 2002, bermudagrass irrigated at 20% and 40% ET exhibited a similar decline beginning at 24 DOT (Fig. 4 and Fig. 6).

The ND and IR/R ratio of zoysiagrass in 2001 dropped below that of turf receiving 100% ET beginning at12 DOT at 20 and 40% ET and at 23 DOT at 60% ET. However, The ND and IR/R ratio at 60% ET recovered the same level as that of turf receiving 100% ET at the end of experiment (Fig. 3 and Fig. 5). In 2002, The ND and IR/R ratio of zoysia receiving 20 and 40% ET was reduced relative to well-watered turf at 24 DOT

(Fig. 4 and Fig. 6). 60% ET reduced the ND and IR/R ratio of zoysia, beginning at 51 and 38 DOT, respectively (Fig. 4 and Fig. 6).

Leaf relative water content

Leaf relative water content of Kentucky bluegrass receiving 20%, 40% and 60% ET was equivalent to that of well-watered turf until 9, 22, and 38 DOT in 2001, respectively (Fig. 7). Poor turf performance in 2002 precluded collection of LRWC data in Kentucky bluegrass.

Tall fescue irrigated at 20% and 40% ET in 2001 had a significantly lower LRWC compared to w ell-watered turf beginning at 22 a nd 66 DOT, respectively (Fig. 7). In 2002, tall fescue irrigated at 20% and 40% ET had lower LRWC compared to well-watered turf starting at 36 DOT (Fig. 8).

Bermudagrass LRWC in 2001 dropped below that of well-watered turf beginning at 66 DOT at 20% ET (Fig. 7). In 2002, bermudagrass irrigated at 20 and 40% ET exhibited a similar decline beginning at 36 DOT (Fig. 8).

Zoysia LWRC was lower than that of well-watered turf beginning at 22 DOT in plots receiving 20% and 40% ET. Irrigation at 60%ET reduced LRWC of zoysiagrass at 38 DOT and 66 DOT in 2001 (Fig. 7). In 2002, LRWC of zoysia receiving 20, 40, and 60% ET was reduced relative to well-watered turf at 22, 36, and 36 DOT, respectively (Fig. 8).

Electrolyte leakage

In Kentucky bluegrass, any reduction in irrigation below 100% ET resulted in higher levels of EL in 2001 (Fig. 9). Poor Kentucky bluegrass performance in 2002 precluded collection of EL data.

In tall fescue any reduction in ET below 60% caused significantly higher levels of EL in 2001 (Fig. 9). Irrigation at 20% and 40% ET increased the EL of tall fescue, beginning at 37 DOT in 2002 (Fig. 10). Tall fescue at 60 ET had significantly higher EL than well-watered turf at 37 and 64 DOT.

Irrigation had to drop to 40% ET in bermudagrass before EL was higher than that of turf receiving irrigation at 100% ET in 2001 (Fig. 9). In 2002, irrigation at 20% ET resulted in higher EL of Bermuda at 23 and 37 DOT (Fig. 10).

Like tall fescue in 2001, reducing zoysia irrigation to 60% ET or below resulted in higher EL levels, beginning at 36 DOT for 20% and 40% ET and at 64 DOT for 60% ET (Fig. 9). In 2002, irrigation at < 80% ET resulted in higher EL levels than observed in well-watered turf, beginning at 23 DOT for 60 % ET or below and at 37 DOT for 80% ET (Fig. 10).

DISCUSSION

Minimum deficit irrigation levels required to maintain acceptable season-long quality for respective grasses were: Kentucky bluegrass, 100% ET (evaluated 2001 only), zoysia, 80% ET, bermuda, 60% ET; and tall fescue, 60% ET. In 2001, minimum irrigation amounts required to maintain a level of quality equal to turf receiving 100% ET for the 102-day study period ranged from 220 mm for bermudagrass to 552 mm for Kentucky bluegrass. In 2002, required irrigation amounts required to maintain quality ranged from 286 mm for bermudagrass to 395 mm for zoysia (Kentucky bluegrass was left out).

Fry and Butler (1989) observed that when every 2 d, irrigation at 50% ET resulted in only small reductions in visual turf quality in tall fescue in Colorado. The average water requirements to maintain acceptable turf quality for turfgrass species in Georgia were: 'Tifway' bermudagrass (66 % ET), 'Meyer' zoysiagrass (80%), and 'Rebel II' tall fescue (78% ET) (Carrow, 1995). Our values for water requirements of grasses we evaluated were similar to those reported for tall fescue in Colorado (Fry and Butler, 1989), and slightly lower than values reported for tall fescue, bermuda, and zoysia in Georgia (Carrow, 1995). Differences among locations in respective deficit irrigation levels required to maintain quality likely result due to differences in soil types, weather conditions, duration of drought events, and the length of growing seasons.

Generally, turfgrass species that have exhibited good drought resistance are able to tolerate lower levels of deficit irrigation. For example, earlier work in Kansas indicated that 'Midlawn' bermudagrass and 'Mustang' tall fescue exhibited greatest drought resistance, followed by 'Meyer' zoysiagrass (Qian et al., 1997). A similar superiority of bermudagrass and tall fescue to tolerating deficit irrigation levels < 60% ET was observed herein. Kentucky bluegrass had unacceptable quality when irrigation levels dropped below 100% ET. It is likely that the interactive effects of heat with drought stress lead to bluegrass decline.

The present study indicated that turf quality was acceptable until LRWC dropped to 76% for Kentucky bluegrass, 77% for tall fescue, 65% for bermudagrass, and 76% for zoysia. This suggests that bermuda had a greater ability to tolerate desiccation before a visible decline in quality occurred. Sinclair and Ludlow (1985) proposed that LRWC was a good indicator of water status. Reduction in leaf water content results in reduced photosynthetic competence in many plants (Baker, 1993), and led to a decline in tall fescue and zoysia canopy net photosynthesis as reported in Chapter V.

Drought stress resulting from low levels of deficit irrigation may cause dysfunction of leaf cellular membranes, resulting in an increased permeability for ions and electrolytes. The present study indicated that turf quality was acceptable until leaf EL increased to 22% for Kentucky bluegrass, 24% for tall fescue, 38% for bermuda, and 26% for zoysia, suggesting that membranes of cells in Bermuda were least affected by low levels of deficit irrigation. Trenholm et al. (1999) confirmed that ND and IR/R ratio were highly correlated with visual turf quality, shoot density, and shoot tissue injury ratings. In this study, respective ND and IR/R ratio thresholds for acceptable turf quality were 0.74 and 6.68 for bermudagrass, 0.77 and 7.67 for Kentucky bluegrass, 0.79 and 8.53 for tall fescue, and 0.73 and 6.65 for zoysia grass. This indicated that deficit irrigation had more effect on leaf area index of tall fescue and Kentucky bluegrass than on that of zoysia and bermuda. The ND and IR/R ratio were highly correlated with visual turf quality (Hatfield et al., 1983), again indicating these are a valuable quantitative measurement of turfgrass response to stress.

In summary, deficit irrigation can be used as a strategy to minimize water requirements in turfgrass systems. Selection of species, however, is important to assure good turf quality through periods of deficit irrigation. Relative water content and electrolyte leakage are good indicators of water status.

REFERENCES

Aronson, L.J., A.J.Gold, and R.J. Hull. 1987. Cool-season turfgrass response to drought stress. Crop Sci. 27: 1261-1266.s

Asrar, G., M.Fuchs, E.T.Kanemsau, and J.L.Hatfield. 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. Agron. J. 76:300-306.

Baker, N.R. 1993. Light-use efficiency and photoinhibition of photosynthesis in plants under environmental stress, p.221-235. In: J.A.C.Smith and H.Griffiths (eds.). Water deficits-Plant response from cell to community. Bios Scientific Publishers, Oxford, U.K.

Carrow, R.N. 1995. Drought resistance aspects of turfgrasses in the southeast: ET and crop coefficients. Crop Sci. 35:1685-1690.

Feldhake, C.M., R.E. Danielson, and J.D.Butler. 1984. Turfgrass evapotranspiration. II. Responses to deficity irrigation. Agronomy J. 76:85-89.

Fry, J.D. and J. D. Butler. 1989. Response of tall and hard fescue to deficit irrigation. Crop Sci. 29:1536-1541.

Gibeault, V.A., J.L. Meyer, V.B. Youngner, and S.T. Cockerham. 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: Performance of commonly used turfgrasses. P. 347-356. In F.Lemaire (ed) Proc. 5th Int. Turfgrass Res. Conf., Avignon, France. 1-5 July. INRA Publ., Versailles, France.

Hatfield, E., T.Kanemasu, G.Asrar, R.D.Jackson, P.J.Pinter, Jr. R.J. Reginato, and S.B.Idso. 1983. Leaf area estimates from spectral measurements over various planting dates of wheat. . International Journal of Remote Sensing. 6:167-175

Huang, B., J. Fry and B. Wang. 1998. Water relations and canopy characteristics of tall fescue cultivars during and after drought stress. HortScience. 33 (5):837-1998.

Kirnak H. , C. Kaya, I. Tasi and D. Higgs. 2001. The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. Blulg. J. Plant Physiol. 27: 34-46.

Qian,Y.L. and M.C. Engelke. 1999. Turfgrass selection: comparing three turfgrasses for minimum irrigation requirements, drought resistance and long-term performance. Turf-grass-trends. Turf Grass Trends. 8 (1): 4-8.

Qian, Y.L., J.D. Fry, S.C. Wiest, and W.S. Upham. 1996. Estimating turfgrass evapotranspiration using atmometers and the Penman-Monteith model. Crop Sci. 36 (3): 699-704.

Qian, Y.L., J.D.Fry, and W.S.Upham. 1997. Rooting and drought avoidance of warm-season turfgrasses and tall fescue in Kansas. Crop Science 37:905-910.

Sinclair, T.R. and M.M.Ludlow. 1985. Who taught plants thermodynamics? The unfulfilled potential of plant water potential. Aust. J.Plant Physiol. 33:213-217.

Siddique, M.R.B., A.Hamid and M.S.Islam. 2000. Drought stress effects on water relations of wheat. Bot. Bull. Acad. Sin. 41:35-39.

Trenholm, L.E., R.N.Carrow and R.R.Duncan. 1999. Relationship of multispectral radiometry data to qualitative data in turfgrass research. Crop Sci. 39 (3): 763-769.

Waddington, D.V., R.N.Carrow, and R.C.Shearman. 1992. Turfgrass. Amer. Soc. Of Agron., Madison, Wis.

White,R.H., A.H. Bruneau, and T.J. Cowett. 1993. Drought resistance of diverse tall fescue cultivars. Int. Turf. Soc. Res. J. 7:607-613

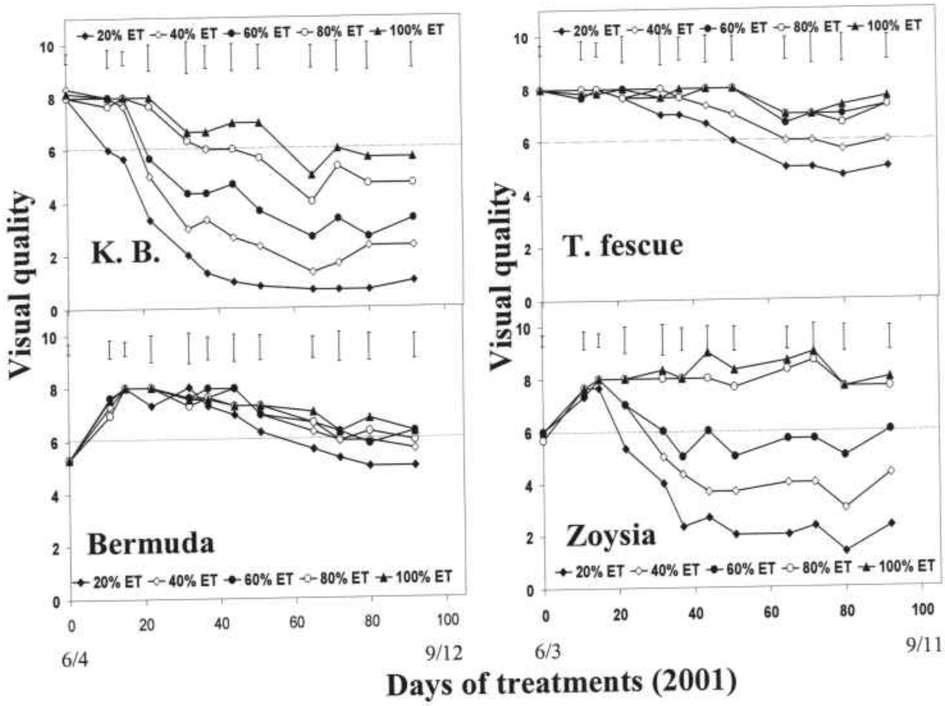

Fig. 1. Visual quality of four species in response to deficit irrigation in 2001. Vertical bars indicate LSD values (*P*=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.

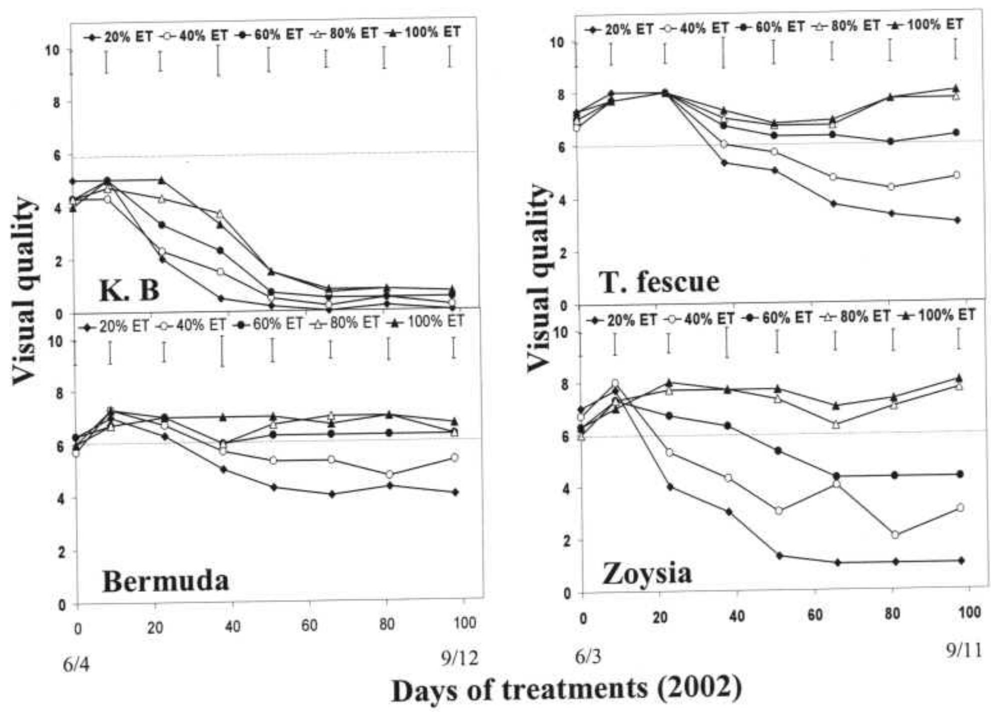

Fig. 2. Visual quality of four species in response to deficit irrigation in 2002.Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.

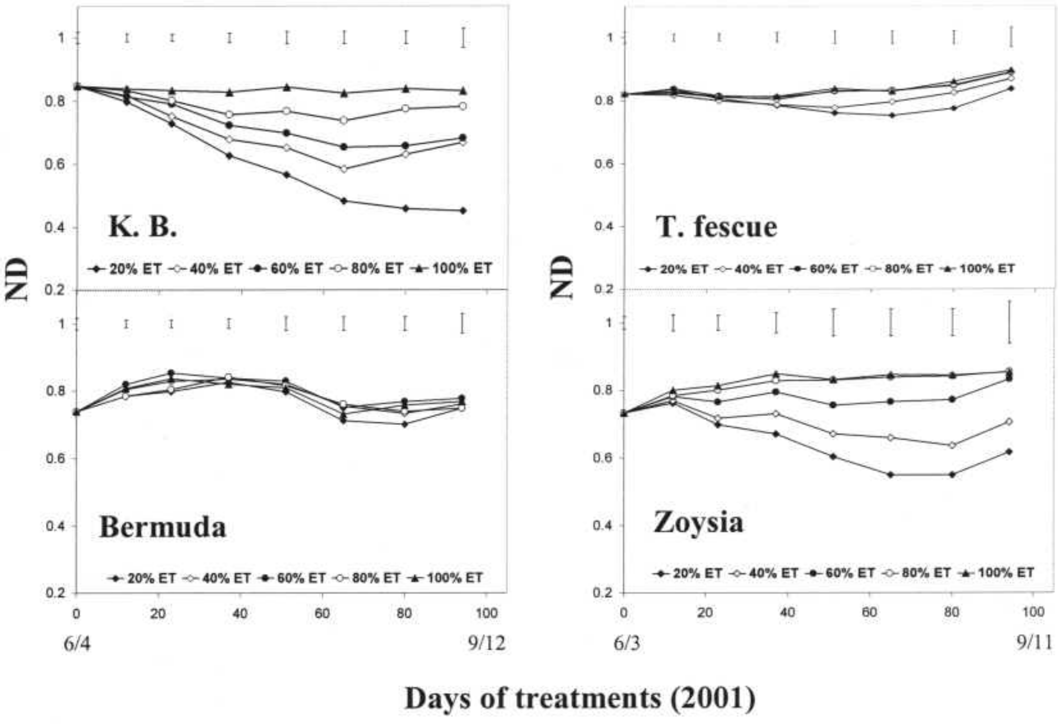

Fig. 3. The normalized difference vegetation index (ND) of four species in response deficit irrigation in 2001. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.

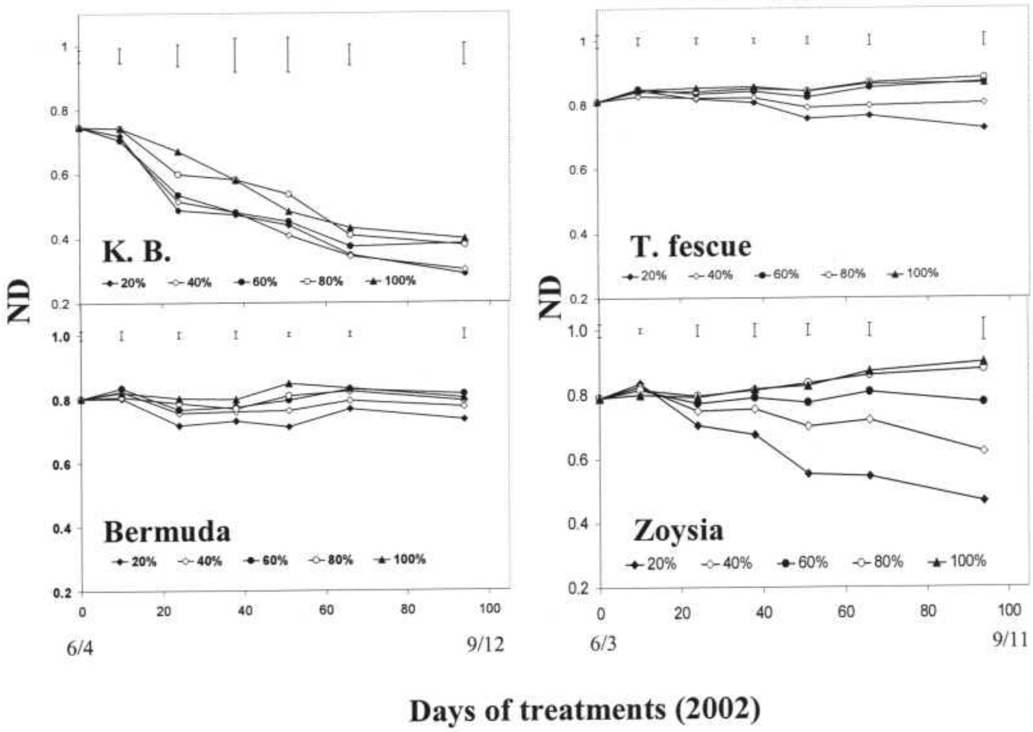

Fig. 4. The normalized difference vegetation index (ND) of four species in response to deficit irrigation in 2002.Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.

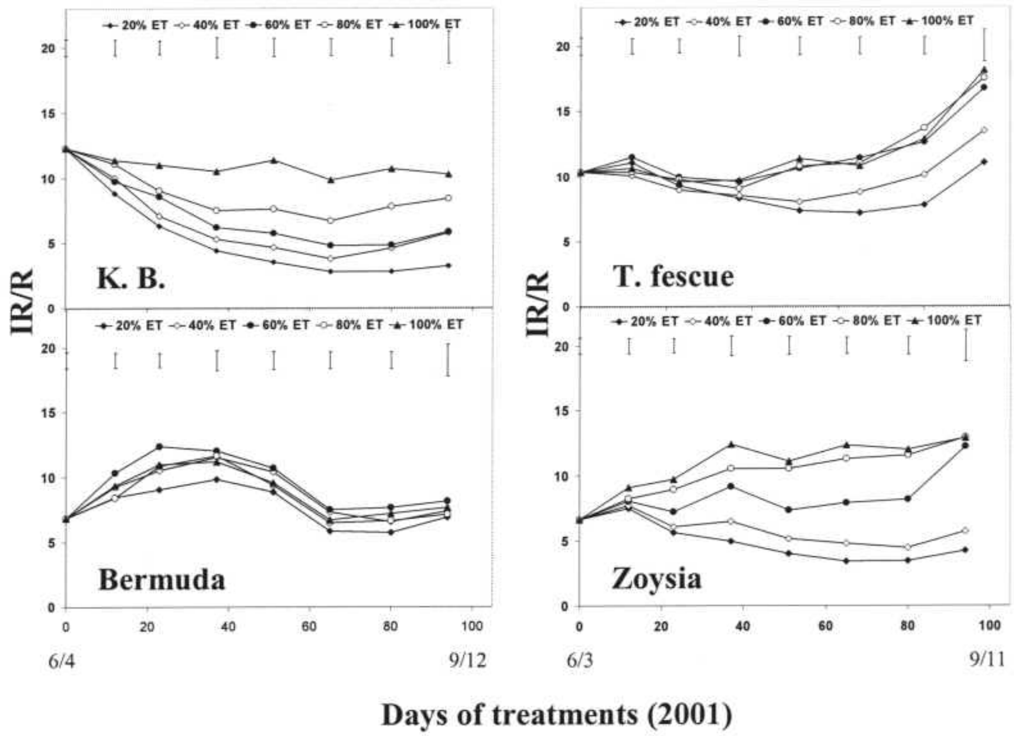

Fig. 5. The IR/R ratio of four species in response to deficit irrigation in 2001. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.

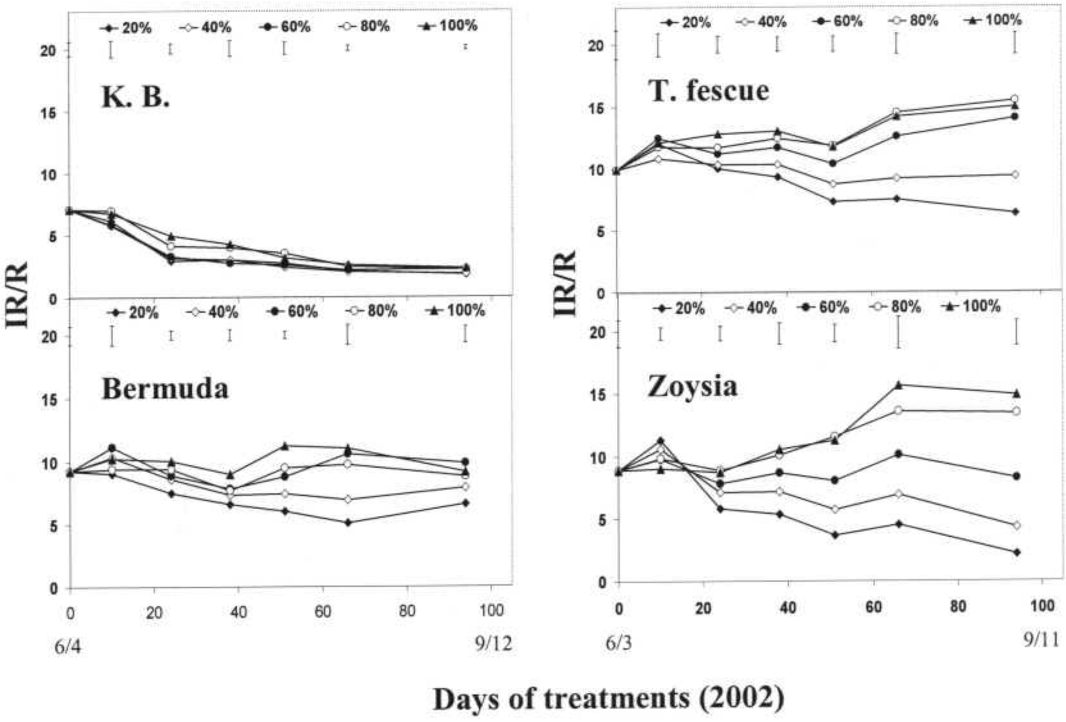

Fig. 6. The IR/R ratio of four species in response to deficit irrigation in 2002. Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.

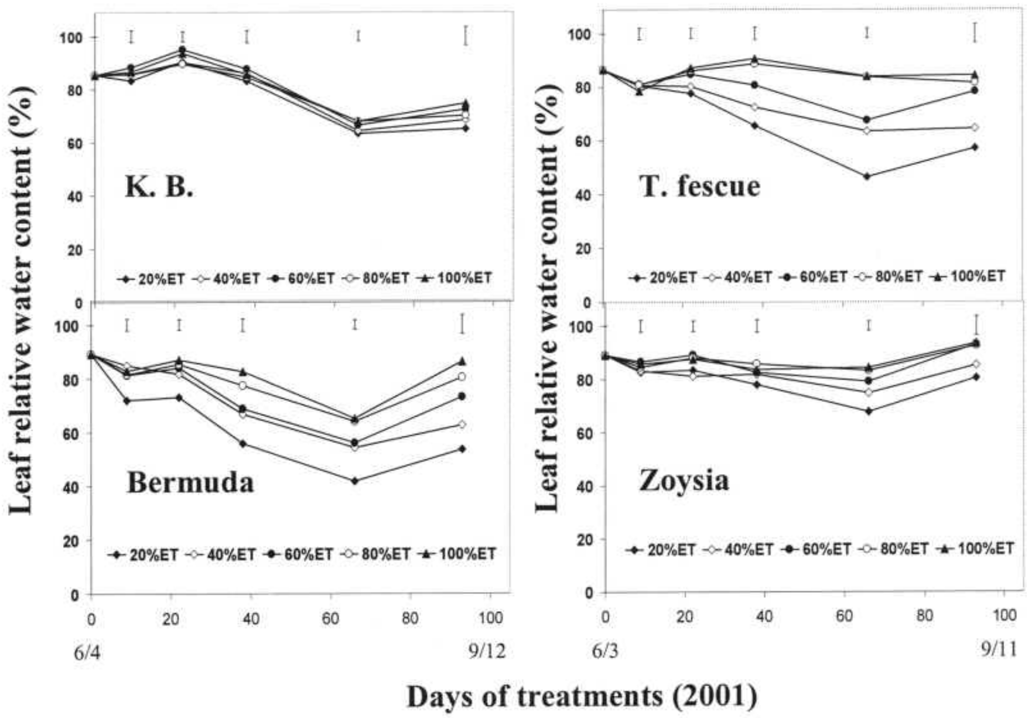

Fig. 7. Leaf relative water content of four species in response to deficit irrigation in 2001.Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment.

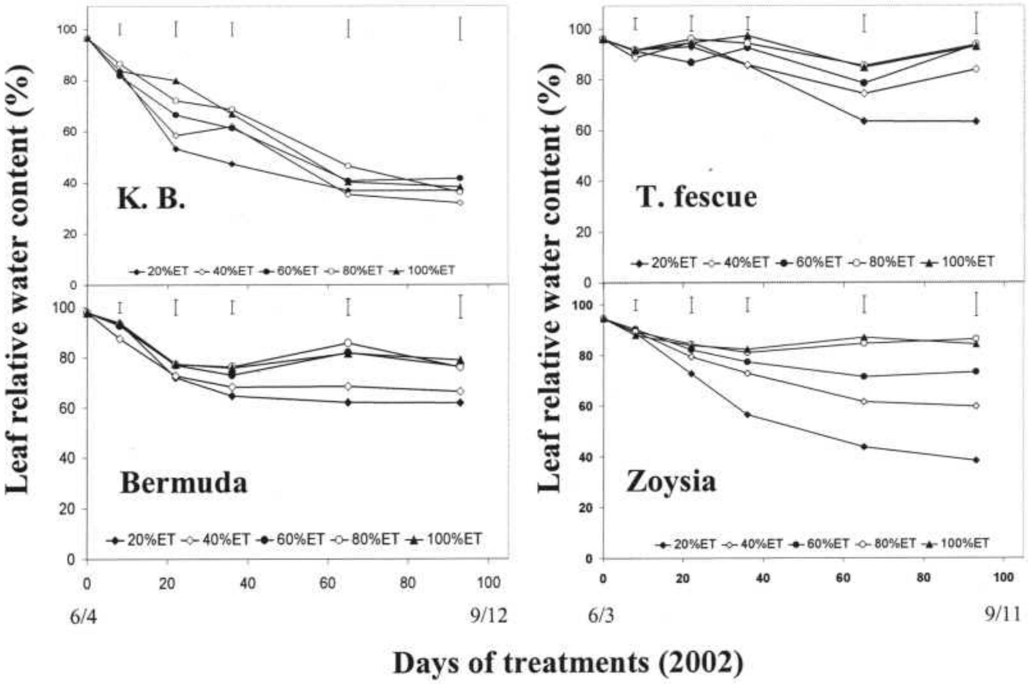

Fig. 8. Leaf relative water content of four species in response to deficit irrigation in 2002.Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue-tall fescue.

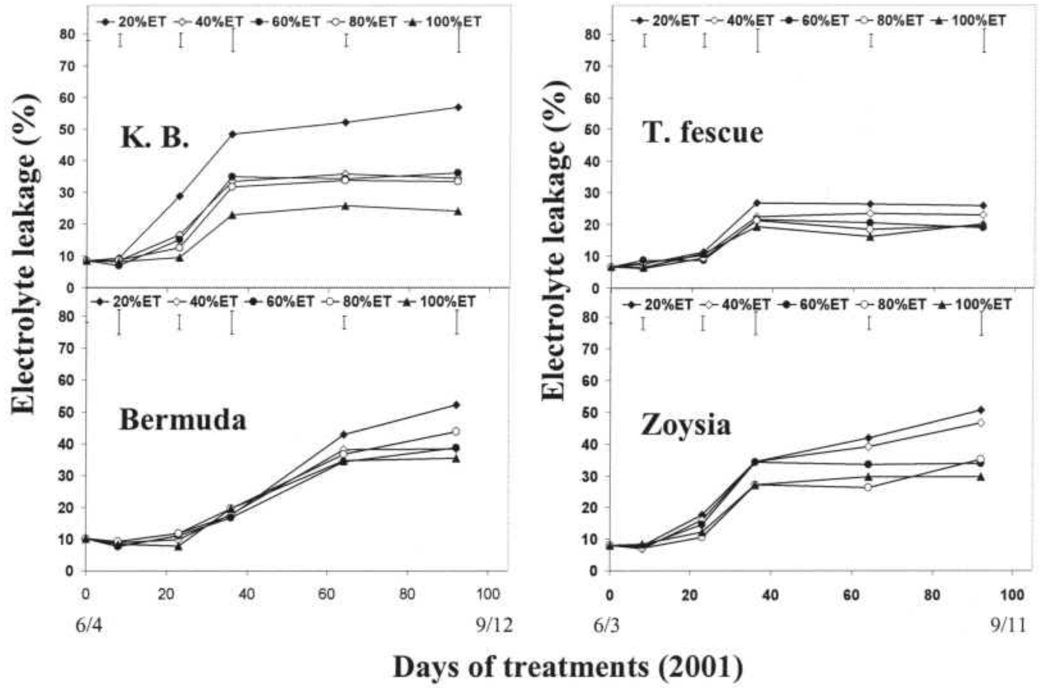

Fig. 9. Leaf electrolyte leakage of four species in response to deficit irrigation in 2001.Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.

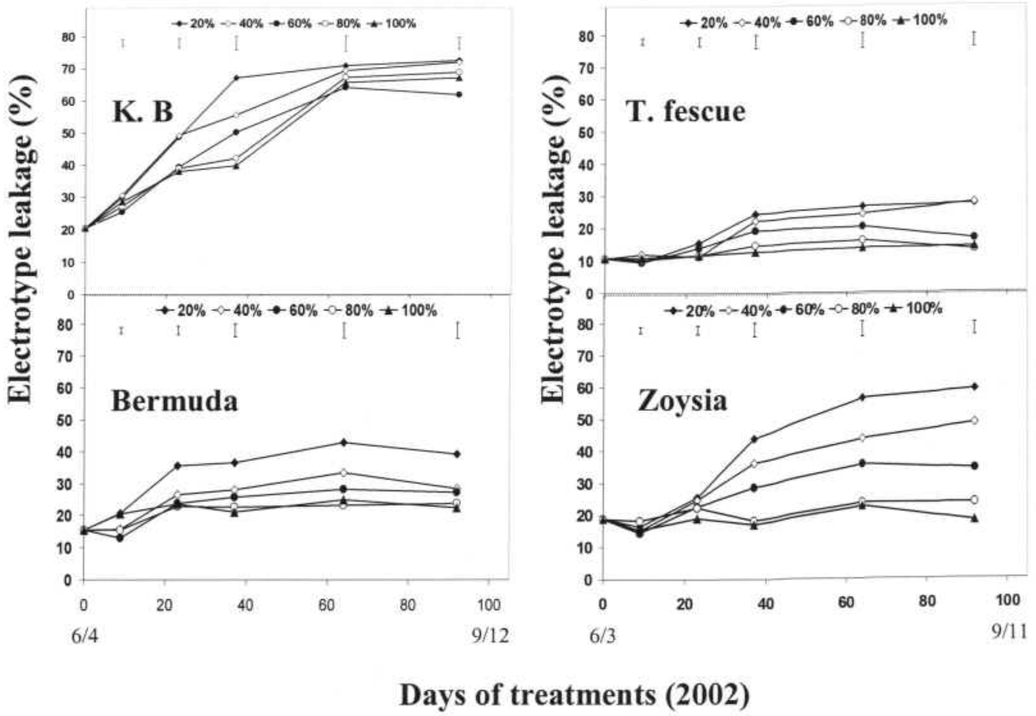

Fig. 10. Leaf electrolyte leakage of four species in response to deficit irrigation in 2002.Vertical bars indicate LSD values (P=0.05) for treatment comparisons at a given day of treatment. K.B. - Kentucky bluegrass; T.fescue- tall fescue.