HortScience 33(5):837–840. 1998.

Water Relations and Canopy Characteristics of Tall Fescue Cultivars during and after Drought Stress

Bingru Huang[1], Jack Fry[2], and Bin Wang[3]
Department of Horticulture, Forestry and Recreation Resources, Kansas State University, Manhattan, KS 66506

Additional index words. canopy green leaf biomass, chlorophyll fluorescence, *Festuca arundinacea*, leaf area index, leaf water potential

Abstract. **Understanding factors associated with drought resistance and recovery from drought stress in tall fescue (*Festuca arundinaces* Schreb.) is important for developing resistant cultivars and effective management strategies. Our objective was to investigate water relations, photosynthetic efficiency, and canopy characteristics of tall fescue cultivars (forage-type 'Kentucky-31', turf-type 'Mustang', and dwarf-type 'MIC18') in responses to drought stress and subsequent recovery in the field and greenhouse. During drought stress under field conditions, 'MIC18' had lower turf quality, more severe leaf wilting, and higher canopy temperature than 'Mustang' and 'Kentucky-31', indicating that 'MIC18' was more drought-sensitive. The greenhouse study comparing 'K-31' and 'MIC18' showed that leaf water status, chlorophyll fluorescence, canopy green leaf biomass, and lead area index of both cultivars declined as soil dried. Reductions in relative water content, leaf water potential, chlorophyll fluorescence, canopy green leaf biomass, and leaf area index were more severe and occurred sooner during dry down for 'MIC18' than for 'Kentucky-31'. After rewatering following 14 days of stress, leaf water deficit and turf growth recovered, to a greater degree for 'Kentucky-31' than for 'MIC18'. However, soil drying for 21 days caused long-term negative effects on leaf photosynthetic efficiency and canopy characteristics for both cultivars.**

Tall fescue is a popular cool-season turfgrass for use in home and commercial landscapes throughout the transition zone of the United States. It produces a relatively deep root system and has better ability to avoid drought than perennial ryegrass (*Lolium perenne* L.) or Kentucky bluegrass (*Poa pratensis* L.) (Sheffer et al., 1987). Forage-type cultivars (e.g., 'Kentucky-31') have a relatively fast rate of vertical elongation, coarse leaf texture, and poor density. Improved, turf-type cultivars have been developed that exhibit improved density and a finer leaf texture. 'Bonsai' was the first "dwarf" tall fescue developed that has been marketed as a slow-growing variety. The proposed advantages of dwarf tall fescue cultivars are a slower shoot growth rate and, consequently, less frequent mowing and reduced clippings. Slow shoot growth might allow shifting carbohydrate supplies from shoot to root production, resulting in a deeper-rooted, more drought-resistant plant.

Limited available data, however, suggest that slow-growing turfgrass cultivars actually may exhibit reduced drought resistance compared with nondwarf turf-type or forage-type cultivars (Carrow, 1996; White et al., 1993), although other characteristics such as low water use (Kopec et al., 1988), darker green color, high density, and finer texture make slow-growing cultivars desirable for use in home lawns. Carrow (1996) found that 'Bonsai' had poorer visual quality and more severe leaf firing compared to forage-type and turf-type cultivars during dry down in a Georgia field study. White et al. (1993) suggested that, based upon rooting characteristics, drought resistance may decrease as more dwarf characteristics are selected for in breeding programs.

More detailed information is needed on drought stress responses and recuperative capability of genetically diverse tall fescue cultivars. Tall fescue performance during and after drought may be associated with the occurrence and severity of leaf water deficit, a reduction in leaf chlorophyll fluorescence, the amount of green leaves, and leaf area index for photosynthesis. Chlorophyll fluorescence as expressed with a calculated Fv/Fm ratio is proportional to a leaf's photosynthetic efficiency (Baker, 1993). Measuring Fv/Fm provides a rapid method for determining the integrity of the photosynthetic apparatus following exposure to environmental stresses (Krause and Weis, 1991). Leaf area index and the amount of green leaves in a turf canopy are major components of turf quality evaluation (Waddington et al., 1992). Understanding these physiological and canopy characteristics of genetically diverse tall fescue cultivars during and after drought could help identify criteria for breeding resistant cultivars.

The objectives of the present study were to 1) compare growth, water relations, and canopy characteristics of tall fescue cultivars differing in shoot growth rate during and after drought stress and 2) determine growth and physiological factors that might contribute to variability in turf quality under drought stress conditions.

Received for publication 27 Aug. 1997. Accepted for publication 29 Jan. 1998. Publication no. 97-461-J of the Kansas Agricultural Experiment Station. We thank Alan Zuk and Ward Upham for their assistance, and thank Steve Keeley and Paul Jennings for reviewing the manuscript. This research was partially supported by Kansas Turfgrass Foundation. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
[1]Assistant professor.
[2]Associate professor.
[3]Visiting scientist.

Materials and Methods

Field study. Field plots of three tall fescue cultivars, 'Kentucky-3' (forage-type cultivar), 'Mustang' (a turf-type cultivar), and 'MIC18' (a dwarf-type cultivar), were established at a seeding rate of 245 $kg \cdot ha^{-1}$ in Sept. 1991 at the Rocky Ford Turfgrass Research Center in Manhattan, Kans. Plots measuring 6 × 6 m were arranged in a randomized complete block with four replications. Soil was a Chillum silt loam (fine, montmorillonitic, mesic, Aquic, Arquidolls). Turf was maintained at a 7.6-cm height during the growing season and received a total of N at 150 $kg \cdot ha^{-1} \cdot year^{-1}$ split equally in September, November, and May. Irrigation was applied during turf establishment in 1991; thereafter, no irrigation was applied. The first turf drought stress was observed in early Aug. 1994. Turf was rated visually for quality on 23 Aug., 30 Sept., and 18 Oct. and for leaf wilting on 30 Sept. Turf quality was rated on a 0 to 9 scale where 0 = brown, dead turf; 6 = acceptable quality for a home lawn; and 9 = optimum color, density, and uniformity. Leaf rolling was evaluated on a similar scale where 0 = severe wilt and 9 = no observable leaf rolling. Canopy minus air temperature for each cultivar was determined at three random locations in each plot using an infrared thermometer (Everest Interscience, Tustin, Calif.).

Greenhouse study. 'Kentucky-31' and 'MIC18' were examined in a greenhouse. Established sods 30 cm in diameter were collected from field plots in Oct. 1996. Sods were scraped and washed free of soil before planting in 30-cm-diameter × 40-cm-deep plastic pots filled with a mixture of 1 coarse river sand : 2 top soil (by volume) collected from the field.

Plants were grown in a greenhouse with temperatures of 24 °C day/15 °C night and a photoperiod of 14 h. The light regime in the greenhouse was supplemented with 1-kW metal halide lamps. Light intensity on a horizontal plane just above the canopy at 12:00 AM averaged 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Plants were watered twice weekly to bring soil to field capacity for 3 months before dry down began. Controlled-release fertilizer (17N–6P–10K) was topdressed twice to provide N at 171 $g \cdot m^{-2}$ per application. Turf was hand clipped biweekly at a 6-cm height.

The experiment consisted of three soil moisture treatments: 1) well-watered control:

plants were irrigated every other day until drainage occurred; 2) drought stress: irrigation was withheld, allowing soil to dry down for 28 d; and 3) recovery: some turf grown under drought stress for 14 and 21 d was resupplied with water to allow for recovery. Volumetric soil water content was measured every 2 d using time-domain reflectometry (TDR) (Topp et al., 1980). A pair of stainless steel probes (spaced at 5.0 cm) 20 cm long and 3.1 mm in diameter were inserted vertically into the soil profile. Trase TDR (Soil Moisture Equipment, Santa Barbara, Calif.) provided a digital readout.

Several shoot characteristics, including leaf relative water content (RWC), leaf water potential, leaf chlorophyll fluorescence, and canopy reflectance at eight wavelengths, were determined at various times after the dry-down treatment and rewatering. Leaf water potential was measured on four young, fully expanded leaves in each pot at 11:00 AM with a pressure chamber (Soil Moisture Equipment). Leaf chlorophyll fluorescence (Fv/Fm; Fv is variable fluorescence; Fm is the maximal level of fluorescence) was determined on five young, fully expanded leaves in each pot with a fluorescence induction monitor (Dynamax, Houston). Canopy reflectance at eight wavelengths (from 435 to 1080 nm) was measured at 12:00 AM 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) wavelengths (IR/R) were calculated based on canopy reflectance (Asrar et al. 1984):

$$ND = (R935 - R661)/(R935 + R661)$$
$$IR/R = R935/R661$$

where R935 = reflectance at 935 nm (790–1080 nm) and R661 = reflectance at 661 nm (648–674 nm). Normalized difference vegetation index is often correlated with canopy green leaf biomass. The ratio of IR/R is often correlated with leaf area index (LAI) (Hatfield et al., 1983).

The greenhouse experiment consisted of two factors (two cultivars and three soil moisture treatments) with four replications arranged in a completely randomized design. Treatment effects were determined by analysis of variance according to the general linear models procedure of the Statistical Analysis System (SAS Institute, Cary, N.C.). Variation was partitioned into cultivar and soil moisture as main effects and their corresponding interactions. Differences ($P = 0.05$) among soil moisture treatment means within each grass were separated by a protected least significant difference (LSD) test.

Results

Field study

'MIC18' had a significantly lower visual ranking for turf quality than other cultivars on 23 Aug. and 18 Oct. 1994 during a drought period (Table 1). On 30 Sept., quality of 'MIC18' was significantly lower than that of 'Mustang' but not of 'Kentucky-31'. Canopy minus air temperature was significantly ($P < 0.10$) greater for 'MIC18' than other cultivars. 'MIC18' exhibited more severe leaf rolling than other cultivars.

Greenhouse study

Changes in soil moisture. Soil volumetric water content (SWC) under well-watered conditions averaged 31% over the experimental period (Fig. 1). Soil water content in the dry-down treatment declined below that in the well-watered control after 8 d. Soil dryness under drying conditions was not significantly different between 'Kentucky-31' and 'MIC18'. The SWC declined to 20% by 8 d, 12% by 14 d, and dropped below 10% by 18 d of dry down and thereafter.

Water relations. Relative leaf water content (RWC) declined significantly with soil drying, starting at 12 d for both cultivars (Fig. 2, top). Severe leaf wilting was observed at 12 d for 'MIC18' and 16 d for 'Kentucky-31'. After 16 d into dry down, 'Kentucky-31' maintained significantly higher RWC than 'MIC18'. Leaves were completely wilted, desiccated, and brown at 21 d into dry down for both cultivars. However, by 6 d after watering following 14 d of dry-down, RWC was similar to well-watered plants for both cultivars.

A significant decline in leaf water potential (Ψ_{leaf}) occurred beginning 10 d into dry down for both cultivars (Fig. 2, bottom). Leaf water potential decreased to 2.7 MPa for 'Kentucky-31' and 3.6 MPa for 'MIC18' by the end of dry down. After 14 d of soil drying, 'Kentucky-31' maintained higher Ψ_{leaf} than 'MIC18'. After 6 d of rewatering following 14 d of soil drying, Ψ_{leaf} increased significantly for both cultivars but to a larger degree for 'Kentucky-31' than for 'MIC18'. Leaf water potential did not rise to a level equivalent to that of well-watered turf by 6 d, but did recover to the control values for both cultivars by 14 d of rewatering.

Leaf photosynthetic efficiency. Soil drying caused a significant decline in leaf photosynthetic efficiency as indicated by the Fv/Fm ratio, beginning 16 d after dry down for 'MIC18' and 18 d for 'Kentucky-31' (Fig. 3). The decline in the Fv/Fm ratio under drying conditions was more dramatic for 'MIC18' than for 'Kentucky-31'. By 6 d of rewatering following 14 d of dry down, the Fv/Fm ratio was restored to a level similar to that of a well-watered turf for both cultivars. The Fv/Fm ratio never recovered when rewatering followed 21 d of dry down.

Canopy characteristics. Normalized difference vegetation index (ND) was reduced with soil drying beginning at 11 d for 'MIC18' and at 16 d for 'Kentucky-31' (Fig. 4, left). The decline in ND was greater for 'MIC18' than for 'Kentucky-31'. Recovery in ND occurred after rewatering following 14 d of dry down for both cultivars but not until 14 d for

Table 1. Turf quality, leaf rolling, and canopy minus air temperature of tall fescue cultivars at Manhattan, Kans., in 1994.

Cultivar	Turf quality 23 Aug.	Turf quality 30 Sept.	Turf quality 18 Oct.	Leaf rolling 30 Sept.	ΔT^z (°C) 23 Aug.
Kentucky-31	5.5 a[y]	5.8 ab	6.5 a	7.0 a	2.5 a
Mustang	6.0 a	6.5 a	6.5 a	7.3 a	2.6 a
MIC18	4.5 b	5.0 b	5.0 b	5.3 b	3.9 b

[z]Canopy minus air temperature.
[y]Means followed by the same letter within a column are not significantly different based on an LSD test.

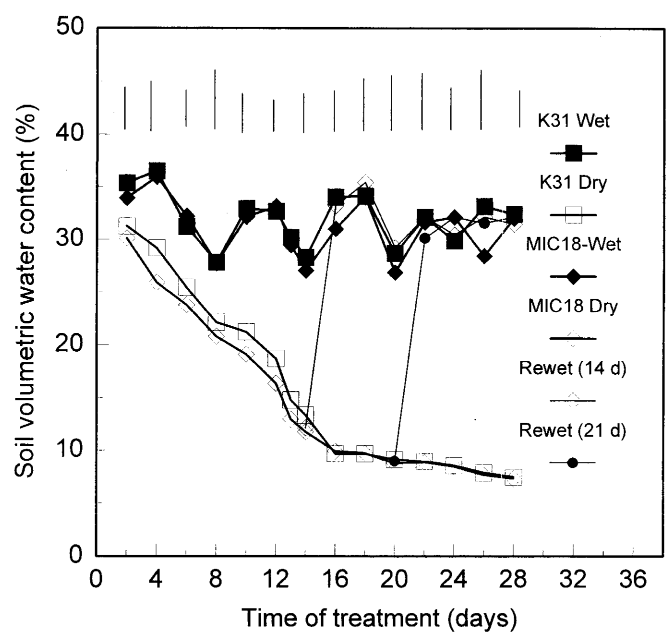

Fig. 1. Changes in soil moisture during and after dry down.

'MIC18' and 10 d for 'Kentucky-31'. The ND value also increased after rewatering following 21 d of dry down, but did not return to levels of well-watered turf in either cultivar.

The IR/R ratio also was not affected by soil drying until 11 d for 'MIC18' and 16 d for 'Kentucky-31' (Fig. 4, right). The ratio increased after rewatering following 14 d of dry down, but it never reached levels of well-watered turf in either cultivar. However, IR/R recovery was greater for 'Kentucky-31' than for 'MIC18'. Leaf area index never recovered to the level of well-watered turf after rewatering following 21 d of dry down for either 'Kentucky-31' or 'MIC18'.

Discussion

Under drought conditions, turf quality was lower, canopy minus air temperature was higher, and leaf rolling was more severe for 'MIC18' than for 'Kentucky-31' and 'Mustang' in the field. These results indicate that the dwarf-type 'MIC18' is more sensitive to drought stress than the forage-type 'Kentucky-31' and turf-type 'Mustang'. These results are consistent with results discussed by White et al. (1993) and Carrow (1996).

Leaf water deficit, as indicated by relative leaf water content (RWC) and leaf water potential (Ψ_{leaf}), was also greater for 'MIC18' than for 'Kentucky-31' with soil drying. However, water status recovered after rewatering to a greater extent for 'Kentucky-31' than for 'MIC18'. These different responses of 'Kentucky-31' compared to 'MIC18' could be related to its development of a more extensive root system and maintenance of turgid and viable roots during drought stress (Huang, unpublished results). Carrow (1996) reported that tall fescue cultivars with a greater root length density at a depth of 2 feet (0.6 m) are less prone to leaf firing and wilting during drought periods. Better performance and delayed leaf rolling of tall fescue cultivars during drought stress has also been attributed to low basal osmotic potential before stress, osmotic adjustment, and prolonged turgor maintenance (White et al., 1992).

Reduction in leaf water content results in reduced photosynthetic competence in many plants under drought conditions (Baker, 1993). Under mild drought stress, decreases in photosynthesis generally are considered to be the result of reduced availability of CO_2 because of stomatal closure (Kaiser, 1987; Schulze, 1986). Leaf water deficit also can have effects on chloroplast biochemistry or chlorophyll fluorescence (Fv/Fm) that would contribute to depressions in photosynthetic performance (Baker, 1993; Krause and Weis, 1991). Reduction in the Fv/Fm ratio occurred when the soil volumetric water content dropped below 10% and RWC declined below 60% with severe leaf wilting, suggesting that severe drought stress caused damage to chloroplasts and, therefore, limited photosynthetic efficiency of tall fescues. Leaves of 'MIC18' experienced more severe damage to photosynthetic efficiency than 'Kentucky-31' under drying conditions, which could account for its severe decline in

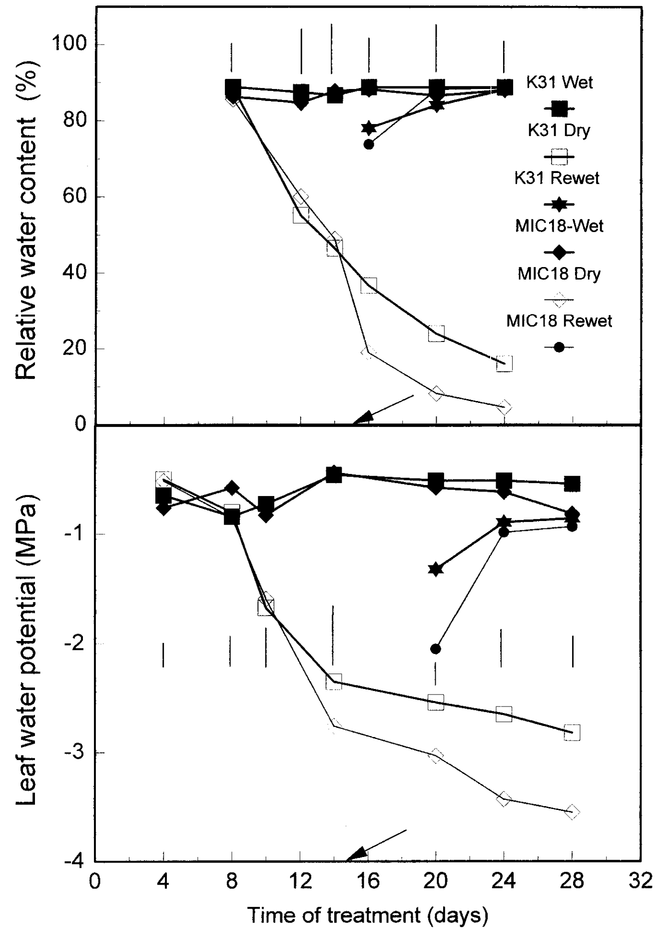

Fig. 2. (**Top**) Relative leaf water content and (**bottom**) leaf water potential in response to soil drying and rewatering following 14 d of dry down for 'Kentucky-31' and 'MIC18'. Arrows indicate when rewatering started. Bars indicate LSD values for treatment comparisons within a given day of treatment ($P = 0.05$).

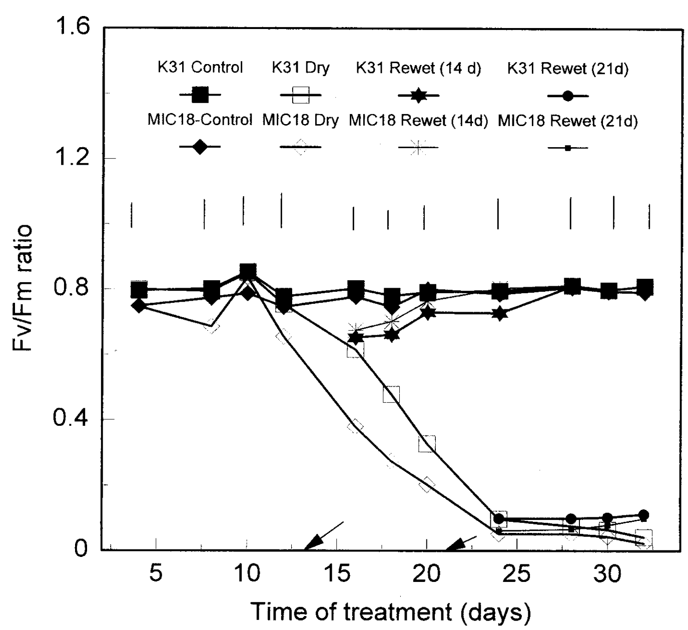

Fig. 3. Chlorophyll fluorescence (Fv/Fm) in response to soil drying and rewatering following 14 d of dry down for 'Kentucky-31' and 'MIC18'. Arrows indicate when rewatering started. Bars indicate LSD values for treatment comparisons within a given day of treatment ($P = 0.05$).

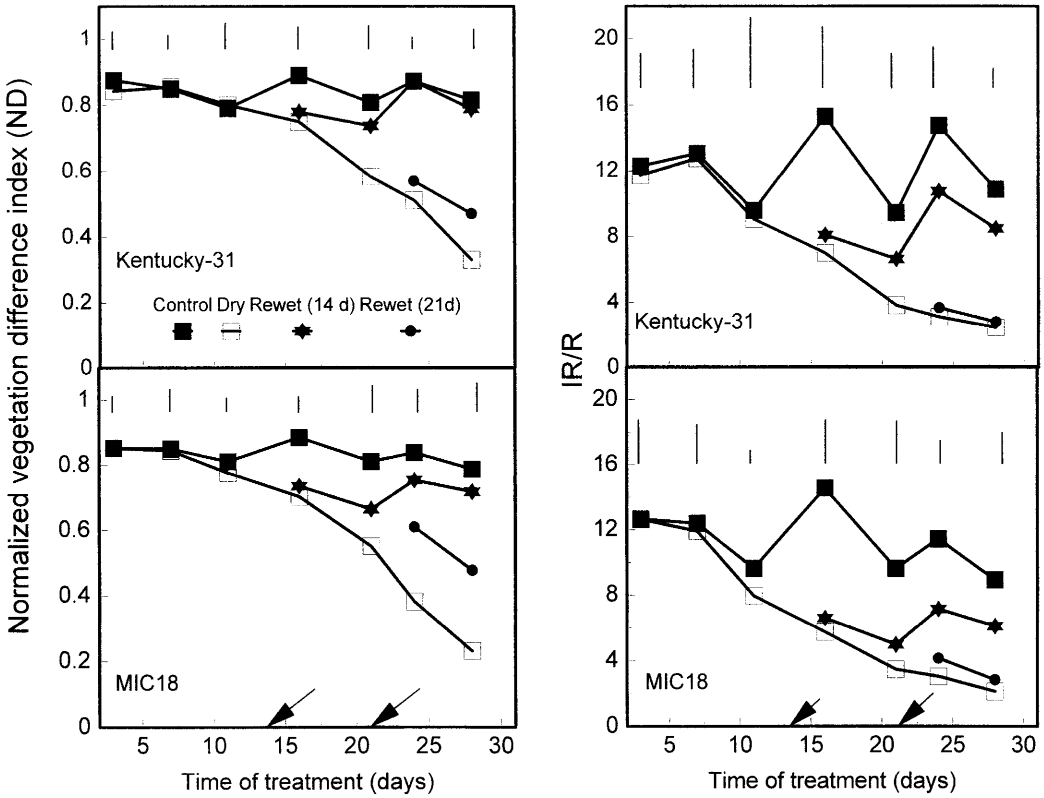

Fig. 4. (**Left**) Canopy green leaf biomass as indicated by normalized vegetation index (ND) and (**right**) leaf area index as indicated by IR/R ratio in response to soil drying and rewatering following 14 d of dry down for 'Kentucky-31' and 'MIC18'. Arrows indicate when rewatering started. Bars indicate LSD values for treatment comparisons within a given day of treatment ($P = 0.05$).

growth and turf quality. The Fv/Fm ratio resumed to the control value 6 d after watering following 14 d of dry down. However, Fv/Fm never recovered after rewatering following 21 d of drought when soil moisture declined below 10% and RWC was below 30%, indicating that permanent damage to chloroplasts in some leaves occurred, despite the complete recovery of leaf water content after rewatering. Kaiser (1987) indicated that an irreversible decrease in plant photosynthetic capacity occurs as RWC drops below 30%, leading to cell death from membrane damage in chloroplasts.

Turf quality evaluation based on visual scoring is subjective (Waddington et al., 1992). The multispectral radiometer (MSR) technique enables quantification of canopy characteristics. Asrar et al. (1984) and Hatfield et al. (1983) suggested that leaf area can be estimated best from the IR/R ratio. The quantity of photosynthetically active radiation (*PAR*) captured by the plant canopy estimated from spectral reflectance measured with MSR and ND indicates canopy green leaf biomass (Asrar et al., 1984; Hatfield, 1983; Hipps et al., 1983). After 16 d of soil drying, canopy green leaf biomass, as indicated by ND, and leaf area index, as indicated by IR/R, were reduced to a greater extent for 'MIC18' than 'Kentucky-31'. These greater declines could contribute to the lower overall turf quality of 'MIC18' observed in the field under drying conditions.

In summary, our results demonstrated that a dwarf-type tall fescue cultivar ('MIC18') had inferior drought resistance and recuperative capability compared to a forage-type ('Kentucky-31') or turf-type cultivar ('Mustang'). The variations in drought responses between 'MIC18' and 'Kentucky-31' were demonstrated by differential responses in leaf water status, photosynthetic efficiency, and canopy characteristics. The results also indicated that watering after 14 d of dry down resulted in physiological recovery with minimal loss in turf quality for tall fescue cultivars. However, 21 d of dry down resulted in long-term negative effects on physiological activity and quality of turf.

Literature Cited

Asrar, G., M. Fuchs, E.T. Kanemasu, 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 responses from cell to community. Bios Scientific Publishers, Oxford, U.K.

Carrow, R.N. 1996. Drought avoidance characteristics of diverse tall fescue cultivars. Crop Sci. 36:371–377.

Hatfield, J.L., E.T. Kanemasu, G. Asrar, R.D. Jackson, P.J. Pinter, Jr., R.J. Reginato, and S.B. Idso. 1983. Leaf area estimaters from spectral measurements over various planting dates of wheat. Intl. J. Remote Sens.

Hipps, L.E., G. Asrar, and E.T. Kanemasu. 1983. Assessing the interception of photosynthetically active radiation in winter wheat. Agr. Meteorol. 28:253–259.

Kaiser, W.M. 1987. Effects of water deficit on photosynthetic capacity. Physiol. Plant. 71:142–149.

Kopec, D.M., R.C. Shearman, and T.P. Riordan. 1988. Evapotranspiration of tall fescue turf. HortScience 23:300–301.

Krause, G.H. and E. Weis. 1991. Chlorophyll fluorescence and photosynthesis: The basics. Ann. Rev. Plant Physiol. Plant Mol. Biol. 42:313–349.

Schulze, E.-D. 1986. Carbon dioxide and water vapor exchange in response to drought in the atmosphere and the soil. Ann. Rev. Plant. Physiol. 37:247–274.

Sheffer, K.M., J.H. Dunn, and D.D. Minner. 1987. Summer drought responses and rooting depth of three cool-season turfgrasses. HortScience 22:296–297.

Topp, G.C., J.L. Davis, and A.P. Annan. 1980. Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. Water Resource Res. 16:574–582.

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. Intl. Turf. Soc. Res. J. 7:607–613.

White, R.H., M.C. Engelke, S.J. Morton, and B.A. Ruemmele. 1992. Competitive turgor maintenance in tall fescue. Crop Sci. 32:251–256.