Cool-Season Turfgrass Responses to Drought Stress[1]

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ABSTRACT

As the supply of water available for turf irrigation becomes limited, it is important to identify water-efficient and drought-tolerant turfgrasses. To establish the critical soil water potential at which cool-season turfgrasses begin to experience drought stress, the growth and quality responses of *Poa pratensis* L. 'Baron', *Lolium perenne* L. 'Yorktown II', *Festuca rubra* var. *commutata* Gaud. 'Jamestown' and *Festuca ovina* var. *duriuscula* (L.) Koch 'Tournament' to drought stress were compared in a greenhouse study. Evapotranspiration (ET) rates were measured using weighing lysimeters containing undisturbed cores of mature turf growing in a silt loam soil. Tensiometers and electrical resistance blocks were installed in a separate set of eight lysimeters containing *L. perenne* to determine the relationship between water loss due to ET and soil water potential. The ET rates of all grasses were unaffected until the soil water potential reached -50 to -80 kPa. During further soil water depletion, ET rates declined and drought stress symptoms became apparent. Leaf water potential of *P. pratensis* and *L. perenne* decreased by 50 to 75% when soil water potential declined to -80 kPa, while that of *Festuca* species remained relatively constant to a soil water potential of -400 kPa. Based on the parameters measured, *P. pratensis* and *L. perenne* exhibited a more rapid decline in ET rate, quality, and leaf growth under moisture stress than the two *Festuca* species, which demonstrated greater ability to thrive with limited soil moisture.

Additional index words: ***Festuca ovina*** **var.** ***duriuscula*** **(L.) Koch,** ***Festuca rubra*** **var.** ***commutata*** **Gaud.,** ***Lolium perenne*** **L.,** ***Poa pratensis*** **L., Soil water potential, Leaf water potential, Water use, Lysimeter, Evapotranspiration.**

INCREASED competition for water has fostered interest in water conservation practices for both warm- and cool-season turfgrasses. Responses of turfgrass to drought can be viewed in a number of ways. Drought stress will affect visual quality, growth rate, evapotranspiration (ET) rate, and recuperative ability following drought-induced dormancy (Beard, 1973). The manifestation of these responses to drought stress may vary with each turfgrass. Grass species and cultivars have been found to respond differently to drought stress (Levitt, 1980; Minner and Butler, 1985).

The rainfall pattern in southern New England can produce periods of summer drought even though annual precipitation exceeds annual ET. Irrigation should be withheld until drought symptoms are imminent to utilize summer precipitation most efficiently. Biran et al. (1981) found that delaying irrigation until the onset of temporary wilting resulted in a significant decrease in water consumption by turf. Clear indicators of impending drought stress must be identified to minimize unnecessary application of irrigation water. In addition, grass species need to be selected which can maintain acceptable visual quality during lengthy rain-free periods.

Many researchers have found that drought stress does not occur to plants growing in a drying soil until a critical soil water potential is reached (Penman, 1948; Holmes, 1961; Richards and Marsh, 1961). Based on this concept, tensiometer systems have been used widely to initiate irrigation when a predetermined threshold soil water tension occurs. Augustin and Snyder (1984) used a threshold of 10 kPa to initiate irrigation of bermudagrass, *Cynodon dactylon* (L.) Pers., in Florida. The tensiometer-scheduled system generated water savings of 42 to 95% compared to an irrigation system based on maximum expected daily ET.

The soil-water potential that corresponds to the onset of plant drought stress varies with crop species, soil type, and evaporative demand (Hillel, 1980). Denmead and Shaw (1962) demonstrated that the rate of potential evapotranspiration (PET), the ET rate that would occur under well-watered conditions, will affect the relationship between soil moisture potential and drought stress. Regional differences in the atmospheric water saturation deficit should alter the critical soil water potential for a given species. Mean summer PET for Kentucky bluegrass (*Poa pratensis* L.) in the arid West has been found to exceed PET in the humid Northeast by 30 to 65% (O'Neil et al., 1979; Feldhake et al., 1983; Aronson et al., 1987). Threshold soil water potentials that result in drought stress occur at less negative soil water potentials in the West than in the Northeast.

Varying climatic conditions will influence relative drought tolerance of cool-season turfgrasses, necessitating regional evaluations. Beard (1973) ranked hard fescue (*Festuca ovina* var. *duriuscula* L. Koch) and red fescue (*F. rubra* L.) as more drought tolerant than Kentucky bluegrass, while Minner and Butler (1985) found the opposite to be true under field trials in Colorado.

The objectives of the study presented here were: (i) to compare the drought responses of four cool-season turfgrasses under moderate evaporative conditions, and (ii) to determine if a soil water threshold potential could be used to identify the onset of a variety of drought stress responses.

MATERIALS AND METHODS

The response of four turfgrass species to drought stress was investigated in a controlled greenhouse environment during the winter of 1984 to 1985. The grasses were 'Baron' Kentucky bluegrass, 'Yorktown II' perennial ryegrass (*Lolium perenne* L.), 'Jamestown' Chewings fescue (*F. rubra* var. *commutata* Gaud.) and 'Tournament' hard fescue.

Culture Conditions

Evapotranspiration rates were measured using weighing lysimeters as described by Feldhake et al. (1983) and modified by Aronson et al. (1987). Undisturbed cores of sod and soil, 150 mm deep and 250 mm in diameter, were taken in 1984 from turf swards seeded in 1980. The sod was grown on an Enfield silt loam (coarse-silty over sandy or sandy-skeletal, mixed, mesic Typic Dystrochrepts). Soil cores representing the first 150 mm soil depth below the thatch and the 150 to 300 mm depth were taken from mature field plots of the four grass species studied and washed to remove the

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soil. The upper 150 mm of soil contained at least 85% of the dry mass of roots for all the grasses. Lysimeters were placed in a greenhouse and maintained for 80 days under well-watered conditions before drought tests were begun.

Supplemental lighting (180 W/m^2) was provided 14 h day^{-1} from a combination of fluorescent tubes and sodium vapor lamps to ensure adequate light. The uniformity of light distribution was measured at the start of the study using a LiCor Radiometer (LI-170 Quantum/Radiometer/Photometer, Lambda Instruments Corp., Lincoln, NE). Supplemental radiation was measured over each lysimeter at night to insure uniform light distribution. Incoming solar radiation was measured over each lysimeter four times over the course of a test day to insure all areas of the bench received the same daily solar radiation.

Liquid fertilizer (4.8, 1.2, and 3.7 g N,P,K/m^2) was applied to each lysimeter 8 days before each stress period. Contact fungicides were applied before the measurement periods and no disease was observed during the study. The greenhouse temperature was maintained between 15 and 24°C. Dew-point temperatures ranged from 12 to 18°C.

Six lysimeters of each grass and six well-watered control lysimeters containing Baron Kentucky bluegrass were arranged on a greenhouse bench in a randomized block design. The grasses were exposed to two consecutive drought stress periods. The first stress interval was continued until the grasses showed visible signs of stress (quality scores below 6.5). The grasses were then allowed to recuperate under well-watered conditions for 3 weeks by which time all the lysimeters had returned to their initial turf quality scores. The second drought period was continued until plant death.

Drought Stress Measurements

Each lysimeter was weighed at 24-h intervals to determine water loss due to ET. The balance used (O'Haus 20 kg solution balance, O'Haus Scale Co., Florham Park, NJ) provided accuracy to the nearest gram (equivalent to a 0.02 mm depth of water). Although different species may transpire at different rates when water is not limited, the relative ET rates between crops have been shown to be at a constant ratio for a given growth stage and height regardless of weather conditions (Gates and Hanks, 1967; Eagleman and Decker, 1965). Within the greenhouse, daily weather and evaporative demand fluctuated noticeably during the course of the 10 weeks of measurement, due largely to changes in radiation from varying cloudiness and day length. To highlight the influence of soil water potential on ET, daily crop coefficients were computed as the ratio of mean ET from a given species to the mean ET from a well-watered reference crop. Crop coefficients are used routinely to isolate the influence of individual variables such as crop growth stage on ET (Burman et al., 1980; Doorenboos and Pruitt, 1977).

Predictive methods such as the Penman or Jenson-Haise equation are often used to estimate a reference crop ET (Penman, 1948; Jensen and Haise, 1963). In this study, actual measurements of ET from well-watered plants were used to represent a reference ET, since lysimeter estimates can more accurately reflect the climatic variables that influence ET than do equations. Well-watered Baron Kentucky bluegrass was arbitrarily selected as the reference crop to isolate the influence of soil moisture on the comparative ET between species. To insure well-watered conditions, the reference lysimeters were watered every fourth day with the measured amount of water lost since the previous watering.

Quality scores were recorded every 3 days before mowing. Scores ranged from a perfect rating of 9, representing dense, green, turgid grass, to a low of 1 when the grass appeared dead. A score of 6.5 or above was considered acceptable turf quality.

The grass in each lysimeter was mowed to a height of 50 mm every 3 days. Clippings were harvested and both wet weights (WW) and dry weights (DW) were determined. Leaf growth rate was calculated and expressed as grams DW clippings/m^2/day. The water content of the clippings (g WW $-$ g DW) was divided by the water content of clippings from the same grass determined earlier at full turgor to provide a relative leaf water content (RLWC).

During the second stress period, leaf water potential of the grasses was measured using a pressure bomb (SoilMoisture Corp. Model 3000, with a Model 3015G4 specimen holder, SoilMoisture Equipment Corp., Santa Barbara, CA), employing the technique developed by Scholander et al. (1964). Apical segments of fully expanded leaves 3 cm long were excised and immediately sealed into the pressure bomb for measurement. Three leaf samples from three different locations in each lysimeter were measured prior to mowing every 3 days during the second stress period. Leaf water potential of the well-watered Baron Kentucky bluegrass control was measured at the same time to provide the means for computing a ratio between drying and well-watered grasses which would account for environmental variation between sampling times.

Soil Moisture Characteristic Curve

Tensiometers (Irrometer Co., Riverside, CA) were placed vertically at a 10 cm depth in six additional lysimeters containing the same perennial ryegrass sod and soil used in the drought stressed lysimeters to establish a soil moisture characteristic curve of cumulative water loss vs. soil water potential. The lysimeters were weighed at 24-h intervals to determine the relationship between change in soil water content (water loss due to ET) and decline in soil water potential to -80 kPa through three dry-down periods. When -80 kPa was reached, the lysimeters were irrigated to saturation to begin a new dry-down period.

To extend the soil moisture characteristic curve below the -80 kPa range, electrical resistance blocks were installed at a depth of 10 cm in another set of eight lysimeters constructed as before. The relationship between change in soil water content and soil water potential between -100 and -400 kPa was determined. The blocks were calibrated prior to placement in the soil using ceramic pressure plate moisture extractors (SoilMoisture Equipment Corp.). These lysimeters were also weighed at 24-h intervals at the same time electrical resistance measurements were taken.

Data Analysis

For each grass investigated, no statistical differences were observed between the first and second stress periods for any plant response measured based on Student's T Test ($P \leq 0.05$). Therefore, data for the two dry-down periods were combined for graphical presentation. Based on measured cumulative water loss and the soil moisture characteristic curve, a daily soil water potential was calculated for each lysimeter. In order to generate statistical parameters, the daily observations were rounded to one of 16 selected soil water potential values. Plant responses are plotted against these soil water potentials with all points representing a mean based on at least two observations with the standard error of the mean indicated.

RESULTS AND DISCUSSION

Evapotranspiration Rate

Changes in the ratio of actual ET of the four turfgrasses to the well-watered reference ET followed a similar trend (Fig. 1). The crop coefficients remained unaffected by declining soil water potential until a potential of -50 to -80 kPa occurred. Below this potential, the crop coefficients declined, indicating a decrease in ET in response to limiting soil water. This trend was similar to the models proposed by Gardner and Ehlig (1963). They proposed that transpiration was governed mainly by meteorological factors when soil water is available, but declined linearly with soil water potential after a critical soil water level is reached.

Above -60 kPa, hard fescue transpired significantly less than the other grasses as evidenced by a consistently lower crop coefficient. The relatively lower ET observed for hard fescue is consistent with previous research into comparative water use rates of cool-season grasses under well-watered conditions (Beard, 1973 & 1986; Partridge, 1941; Peterson, 1985), but observed in only 1 of 2 years under field conditions in Rhode Island (Aronson et al., 1987). Below -60 kPa, Chewings fescue generally sustained the highest crop coefficient and greatest ET of the four grasses. Hard fescue was intermediate while the ET from Kentucky bluegrass and perennial ryegrass declined the most under drought-stressed conditions.

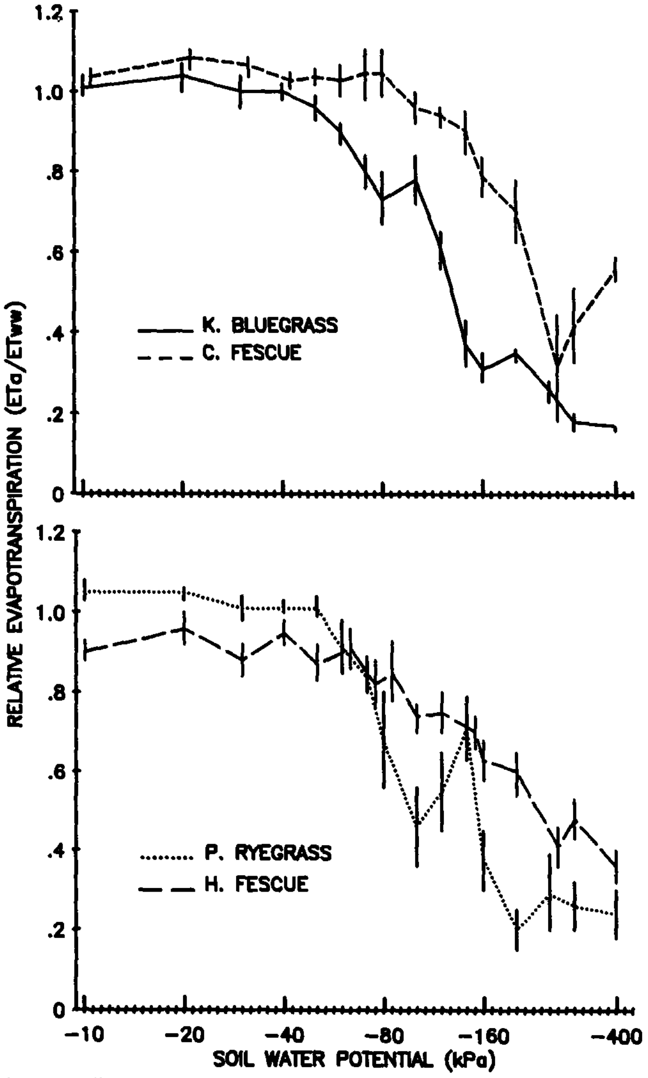

Fig. 1. Effect of soil water potential on the relative ET of four cool-season turfgrasses. ETa = actual ET; ETww = ET of well watered reference grass. Vertical bars = SE of the means. Coincident data offset for clarity.

Turf Quality

The impact of drought stress on turf quality mirrored the trends observed for ET (Fig. 2). The visual quality of Kentucky bluegrass and perennial ryegrass declined when soil water potential fell below -60 kPa, while the quality of the fine-leaved fescues declined more slowly. Lowered quality scores have been reported for cool-season grasses exposed to drought stress (Feldhake et al., 1984) although no threshold soil water potential was correlated with this decline. Neither Kentucky bluegrass nor perennial ryegrass maintained acceptable turf quality (a score of 6.5 or above) after

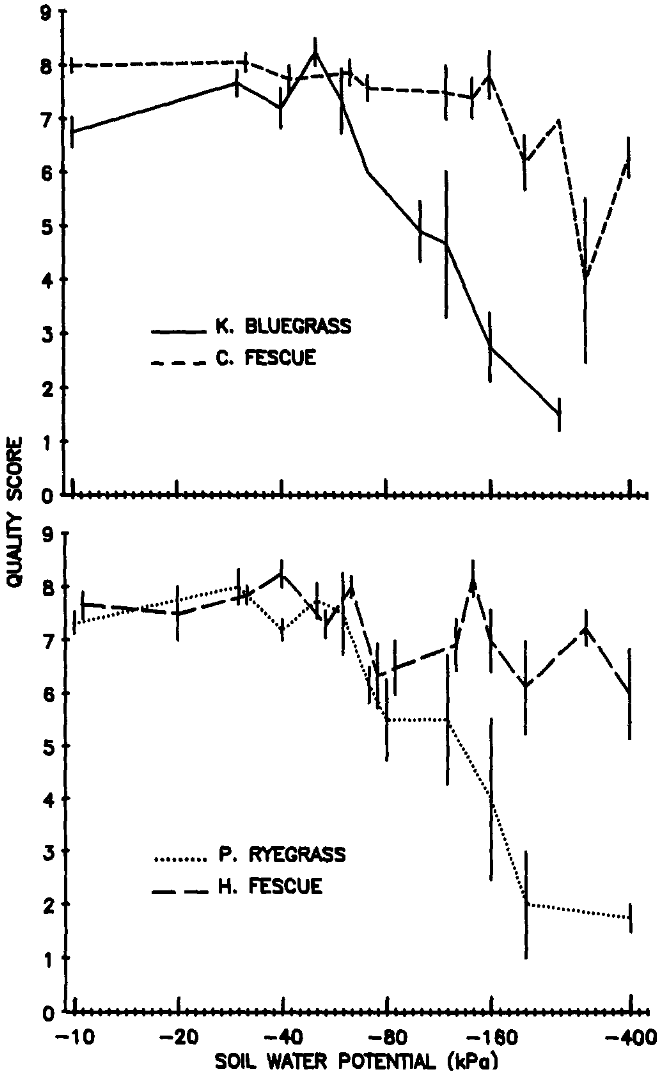

Fig. 2. Effect of soil water potential on the turf quality of four cool-season turfgrasses. Vertical bars = SE of the means. Coincident data offset for clarity.

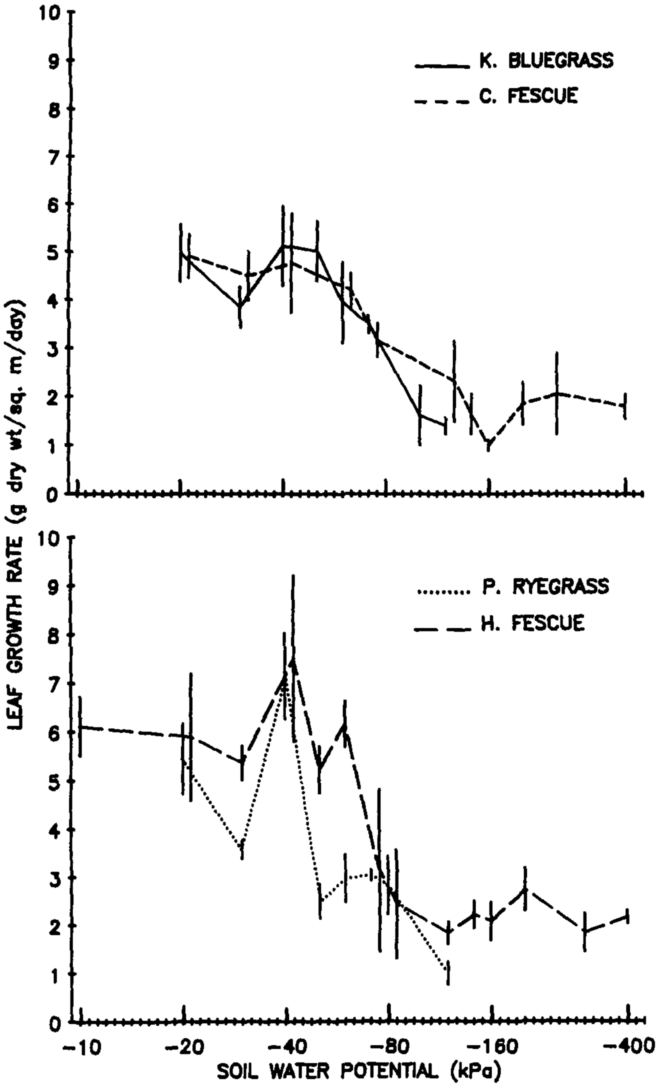

Fig. 3. Effect of soil water potential on leaf growth rate of four cool-season turfgrasses. Vertical bars = SE of the means. Coincident data offset for clarity.

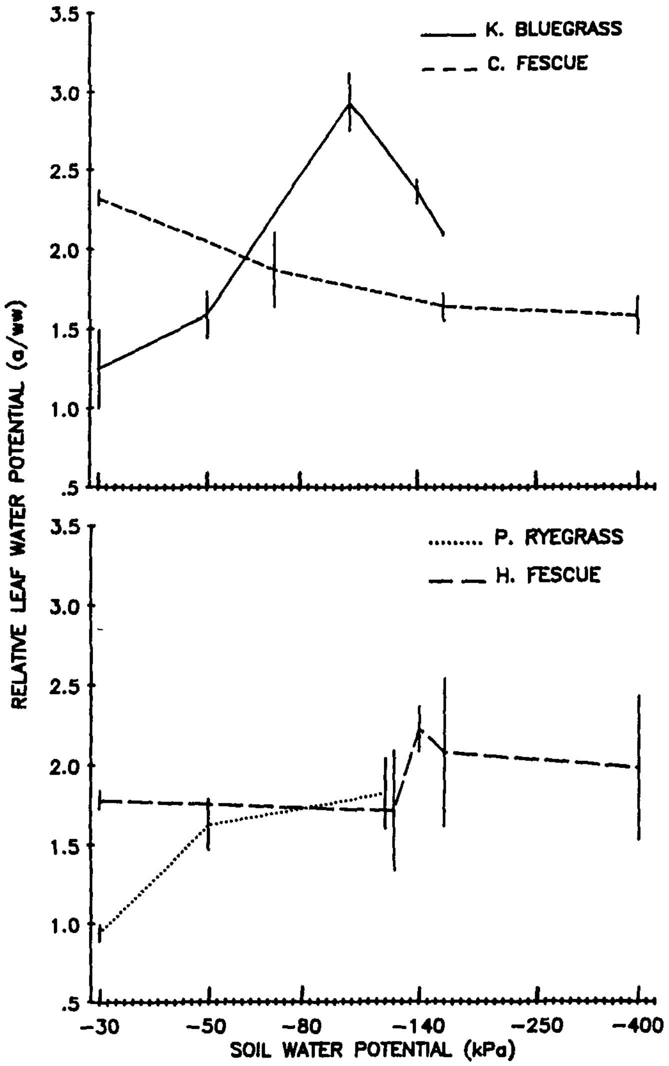

Fig. 4. Effect of soil water potential on the relative leaf water potential (RLWP) of four cool-season turfgrasses. a = actual leaf water potential; ww = leaf water potential of well watered reference grass. Vertical bars = SE of the means. Coincident data offset for clarity.

soil water potential declined to -60 kPa. In contrast, the fescues maintained acceptable quality to -400 kPa. Depending on soil type, this difference in sensitivity to low soil water potential could give the fescues a substantial additional period of acceptable quality during an episode of drought.

The relative responses of visual quality to decreasing soil water are in agreement with those of Beard (1973) rather than those of Minner and Butler (1985). The latter authors rated fine fescues less drought tolerant than Kentucky bluegrass and perennial ryegrass. Of the 42 fescue cultivars they studied, several demonstrated greater drought tolerance. These included Jamestown and Tournament, the Chewings fescue and hard fescue cultivars we used.

Leaf Growth Rate

Reduced leaf growth of turfgrasses during drought stress has been reported often (Beard, 1973; Doss et al., 1962; Feldhake et al., 1984). A decline in leaf growth rate of Kentucky bluegrass and perennial ryegrass occurred at about -50 kPa (after approximately 8 days of drying), before ET rate or turf quality declined (Fig. 3). At a soil water potential of -125 kPa (at about 10 days of drying), Kentucky bluegrass and perennial ryegrass exhibited no leaf growth while the fine-leaved fescues continued to grow to -400 kPa (at 21 days of drying). Continued leaf growth during soil drying may contribute to the maintenance of turf quality by the fescues under drought conditions (Fig. 2).

Leaf Water Potential

Relative leaf water potential of the fescues remained relatively constant (Fig. 4) throughout the drought stress period (to -400 kPa). Kentucky bluegrass and perennial ryegrass experienced a decline in leaf water potential of 50 to 75% as soil water potential approached -125 kPa, and leaf growth stopped. The change in relative leaf water potential with an increase in soil water potential was described best as a negative exponential relationship and was significant for Kentucky bluegrass and perennial ryegrass ($r = -0.75$ and -0.65, respectively—data not shown). Similar curves

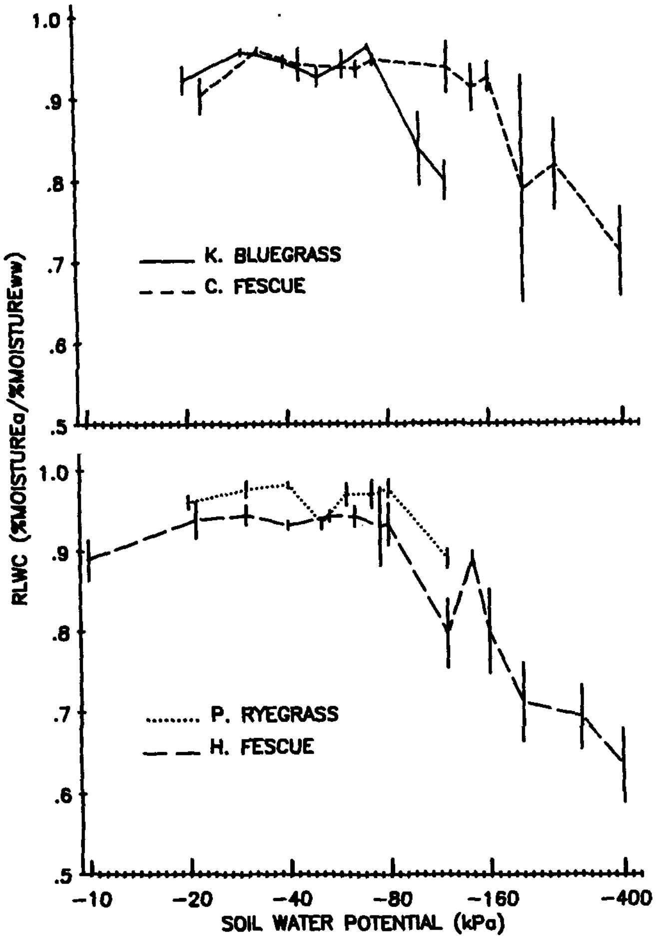

Fig. 5. Effect of soil water potential on the relative leaf water content (RLWC) of four cool-season turfgrasses. % moisture$_a$ = actual % moisture; % moisture$_{ww}$ = % moisture of well-watered control grass. Vertical bars = SE of the means. Coincident data offset for clarity.

for Chewings and hard fescues were positive or not significant (r = 0.72 and -0.14, respectively). Relative leaf water potential was less responsive to declining soil water content than other parameters measured. These results are in agreement with the findings of Sheffer (1979), who noted that leaf water potential in cool-season turfgrasses was not as sensitive to drought stress as ET and growth rates.

Relative Leaf Water Content

As with most other parameters investigated, RLWC of the grasses declined under drought stress when soil water potential decreased below -80 kPa (Fig. 5). Chewings fescue retained more water in its leaf tissue than hard fescue throughout the drought periods. Kentucky bluegrass and perennial ryegrass lost only 20 and 10% of their leaf water, respectively, when soil water potential was -125 kPa and leaf growth ceased.

CONCLUSIONS

Based on visual quality, ET, growth rate, and RLWC of turfgrasses under greenhouse conditions, the fescues were the most drought tolerant of the four grasses studied. The perennial ryegrass and Kentucky bluegrass tested were decidedly less drought tolerant and sustained substantial injury when the soil water potential declined to less than -125 kPa. These findings substantiate Beard's (1973) categorization of drought resistance in cool-season turfgrasses. He rated hard fescue and red fescue 'good', Kentucky bluegrass 'medium', and perennial ryegrass 'fair' in overall resistance to drought stress.

Most of the plant characteristics monitored in this study displayed marked changes when soil water potential decreased to a range of -50 to -80 kPa. It appears that this moisture potential range may represent a threshold level of drought stress for cool-season grasses growing in southern New England. Tensiometers can reliably measure soil water potential to -80 kPa and represent an inexpensive method for monitoring soil water status to minimize application frequency and increase water conservation.

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