# WATER RELATIONS OF SELECTED BERMUDAGRASS (*Cynodon dactylon*) GENOTYPES

By

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WATER RELATIONS OF SELECTED BERMUDAGRASS

(Cynodon dactylon) GENOTYPES

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# INTRODUCTION

Bermudagrass is used in a wide variety of management schemes in the southern United States. Its adaptation to warm humid and warm sub-humid regions make it an excellent choice for recreational sites, pastures and erosion control.

Turf is used as an integral part of home and business landscapes to improve aesthetical and property values. Recreational activities, ranging from backyard play to professional sports, use turfgrasses as a playing surface and added safety cushion. Businesses involving sales, installation, maintenance, equipment, and consulting for turf provide a high amount of economic stimulation.

Bermudagrass is used as a forage crop on thousands of acres of improved pasture land. Its dense growth of high quality plant material makes it a favorite choice for grazing and hay production. Management practices utilizing this characteristic provide a year-round diet for livestock.

This grass species is used extensively along roadsides, waterways, and other potential erosion areas. The stoloniferous and rhizomatous growth habit and fibrous root system of bermudagrass forms an excellent sod which enables soils to become virtually resistant to the erosion process.

Water requirements of turfgrasses are important in their

selection, adaptation, and use. Water availability is often the most limiting environmental factor to consider when growing bermudagrass. Grasses require water for growth and transpiration. Evapotranspiration has been defined as the total amount of water lost through transpiration and evaporation from plant and soil surfaces (Beard, 1973).

Evapotranspiration (ET) rates are expressed quantitatively as mg $m^{-2}$ $s^{-1}$ or mm $day^{-1}$. Since the amount of water retained for plant growth is less than 1 to 2% of the total transpired, water use rates are essentially equal to ET rates (Jensen, 1968). Factors that influence the water use rate of turfgrasses are: length of growing season, growth rate, species or cultivar, intensity of culture, intensity of traffic, soil type, rainfall, and available soil moisture (Doss et al., 1964).

Recent studies have examined interspecific responses to deficit irrigation (Feldhake et al., 1984, and Gibeault et al., 1984). Gibeault et al. (1984) determined that in order to maintain non-limiting soil moisture for ET, cool-season turfgrasses required about 1,100 mm of irrigation, versus 850 mm for warm-season turfgrasses in 1982. They observed a 36 to 50% potential water savings by using warm-season turfgrasses with deficit irrigation rather than cool-season species maintained at a higher irrigation level. Kneebone and Peeper (1982) noted no differences between bermudagrass and zoysiagrass, but tall fescue and St. Augustinegrass used more water than bermudagrass and

zoysiagrass. With the exception of the study by Biran et al. (1981), no published information on intraspecific comparisons in consumptive water use is available for either cool or warm-season species.

Turf managers use water for more than maintaining turfgrass turgor and growth. Water is commonly used in turf maintenance to leach pesticides, wash in fertilizers, and syringing turf for heat stress protection. As water constraints increase, more emphasis needs to be placed on water conservation. With today's technology in plant breeding, opportunities exist to breed cultivars which have the potential to utilize water more efficiently.

Although development of cultivars with the ability to use less water will help in the area of water conservation, there remains to be a problem when managers are faced with periods of little or no rainfall. Drought describes a condition when growth is limited due to a prolonged period of water stress (Beard, 1973). Plants use varying mechanisms for drought resistance. Resistance can occur through tolerance, avoidance, and escape mechanisms.

Drought tolerance mechanisms allow the plant to survive during periods of water stress. Drought tolerant plants have adaptations to tolerate low internal water potentials. Tolerance occurs when the plant maintains turgor pressure as internal water potential declines or protoplasm has the ability to survive under severe desiccation (Younger, 1985).

Drought escape is another resistance mechanism. Some

annual grasses escape soil drought by means of a short life cycle that is completed during the rainy season. Annual bluegrass (Poa annua) has this escape capability (Beard, 1973). It can germinate, mature, and set seed during a short period of cool, moist weather. This escape mechanism allows it to complete its life cycle before periods of low soil moisture. Seed dormancy during dry periods is an escape mechanism which delays germination until more favorable growth conditions prevail.

Plants with drought avoidance capabilities not only survive periods of water stress, they maintain growth and productivity during a drought. The ability of the plant to avoid drought is accomplished by anatomical and morphological adaptations that allow for sufficient water uptake, reduction in water use, or both. Decreasing soil moisture can increase rooting in the lower portion of the soil profile (Beard, 1973). Doss et al. (1960) observed that the effective rooting depth of five warm-season forage species decreased as soil moisture increased, while Bennett and Doss (1960) noted similar results on cool-season forage species. This implies that greater rooting depth during soil water stress is a drought avoidance mechanism and/or that roots grow within a limited soil water potential range (Peacock and Dudeck, 1985). Avoidance can also involve a combination of morphological characteristics including leaf rolling, thickened cuticle, and stomatal closure.

Water shortages not only affect plants by causing

morphological changes, but physiological changes may also occur which are not as visible. Turfgrass plants grown under conditions of drought stress generally have a higher osmotic pressure and a lower tissue water content. A water deficit causes an overall reduction in physiological activity, noticeably decreasing the photosynthetic rate. Dehydration decreases respiration in seeds and certain mature tissues but stimulates respiration in actively growing tissues (Beard, 1973).

Associated with the metabolic changes are increased soluble carbohydrates, free amino acids, amides, and bound water content (Kemble and Macpherson, 1954). Carbohydrates are the primary source of reserve energy stored in the vegetative organs of biennial and perennial forage plants. Reserves are essential for survival and producing plant tissues when carbohydrate utilization exceeds photosynthetic activity (Smith, 1969). Total nonstructural carbohydrate concentration is an estimate of the carbohydrate energy readily available to the plant. This term refers to carbohydrates available as energy to the plant (Smith, 1969 and Weinmann, 1947). An area which renders further investigation is the role, if any, that the total nonstructural carbohydrate content has in drought avoidance capabilities of plants.

This thesis is divided into two chapters. The first will report on an experiment which determined water use rates of twelve bermudagrass genotypes, as well as a comparison of

two methods used to measure water use rates. Chapter two will examine an experiment designed to test for differences in root distribution in response to drought stress among ten bermudagrass genotypes. It will also report on the effect that nonstructural carbohydrates have on the ability of bermudagrass to maintain productivity during an extended drought period.

# LITERATURE CITED

Beard, J.B. 1973. Turfgrass science and culture. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Bennett, O.L. and B.D. Doss. 1960. Effect of soil moisture level on root distribution of cool season forage species. Agron. J. 52:204-207.

Biran, I., B. Bravdo, I. Bushkin-Harav, and E. Rawitz. 1981. Water consumption and growth rate of 11 turfgrasses as affected by mowing height, irrigation frequency, and soil moisture. Agron. J. 73:85-90.

Doss, B.D., D.A. Ashley, and O.L. Bennett. 1960. Effect of soil moisture regime on root distribution of warm-season forage species. Agron. J. 52:569-572.

Doss, B.D., D.A. Ashley, and O.L. Bennett. 1964. Moisture use by forage species as related to pan evaporation and net radiation. Soil Sci. 98:322-327.

Ekern, P.S. 1966. Evapotranspiration by bermudagrass sod in Hawaii. Agron. J. 58:387-390.

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

Gibeault, V.A., J.L Meyer, R. Strohman, R. Autio, M. Murphy, and D. Monson. 1984. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation. Univ. of Calif., Riverside.

Jensen, M.E. 1968. Water consumption by agricultural plants. p. 1-22. In T.T. Kozlowski (ed.) water deficits and plant growth. Vol. 2. Academic Press, Inc., New York.

Kemble, A.R. and H.T. Macpherson. 1954. Liberation of amino acids in perennial ryegrass during wilting. Biochemical J. 58:46-49.

Kneebone, W.R. and I.L. Peeper. 1982. Consumptive water use by sub-irrigated turfgrasses under desert conditions. Agron. J. 74:419-423.

Peacock, C.H. and A.E. Dudeck. 1985. Effect of irrigation interval on St. Augustine rooting. Agron. J. 77:813-815.

Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. Wisconsin Agric. Exp. Stn. Report 41.

Weinmann, H. 1947. Determination of total available carbohydrates in plants. Plant Physiology. 22:279-290.

Younger, V. 1985. Physiology of water use and water stress. p. 37-44. In V.A. Gibeault and S.T. Cockerham (ed.) Turfgrass Water Conservation. Publ. 21405. Univ. of Calif.

# CHAPTER I

# COMPARISON OF TWO METHODS FOR MEASURING WATER USE RATE OF TWELVE BERMUDAGRASS GENOTYPES

## INTRODUCTION

Efficient water management has become a pressing issue across arid and semi-arid regions. Nearly half of the water treated annually in the western USA for municipal use was applied to outdoor vegetation (Linaweaver et al., 1967). Similar practices were observed for northern Colorado (Danielson et al., 1979). Turfgrass is a major component of the urban vegetation, and considerable work has been done to measure its water use rate (Feldhake et al., 1983). There remains a need to continue research in the area of water useage to ensure efficient use in the future.

In turf water use studies, water use rate is defined as the total amount of water required for turfgrass growth plus the quantity lost by transpiration and evaporation from plant and soil surfaces (Beard, 1973). Evapotranspiration (ET) is water loss to the atmosphere through evaporation from plant and soil surfaces plus transpiration from plants. The amount of water retained for plant growth is less than 1 to 2% of

the total transpired. Therefore, water use rates are essentially equal to ET rates (Jensen, 1968).

Several methods, such as water balance or hydrologic, micrometeorological, and empirical, have been employed to estimate ET. These methods differ in short and long-term accuracy and in convenience and cost (Tanner, 1967). A lysimeter is an isolated block of soil and vegetation in which gain or loss of water is monitored. Lysimeters have been reported to be the the only practicable method for measurement of evapotranspiration rates with adequate precision (van Bavel, 1961). The large weighing lysimeters and micrometeorological methods are accurate but expensive. Empirical methods are good to approximate only long-term ET losses and need accurate measurements for calibration (Tomar and O'Toole, 1980.)

Mini-lysimeters have been designed and field tested. Mini-lysimeters are a scaled-down version of the traditional weighing lysimeters, which often weigh several hundred kilograms. The simplicity of fabrication and maintenance of these assures that they can be fabricated locally and handled easily. The results have demonstrated that the units are sensitive, accurate, and reliable and can be used to measure ET directly under field conditions (Tomar and O'Toole, 1980). Mini-lysimetry is well-suited to turfgrass ET measurement because of the typical uniformity, high plant density and fiberous root system of turf.

Recently, a new method called time domain reflectometry

(TDR) was developed to monitor water content in unfrozen soils (Davis amd Annan, 1977; Topp et al., 1980). TDR is an indirect method of soil moisture determination based on the relationship between the relative complex dielectric constant and the volumetric unfrozen water content of the soil (Stein and Kane, 1983).

A few advantages of using the TDR instrument are as follows (Stein and Kane, 1983):

1. Data can be obtained over very small horizontal or vertical distances
2. The measurement is nondestructive
3. The average moisture content can be determined with depth

TDR could be used to estimate water use rate of turfgrasses based on soil water content differences over a given time period. This method would be nondestructive, suited to laboratory or field use, and could be used <u>in situ</u> or on undisturbed soil samples (Davis, et al., 1977). Water use rates ($T_i - T_f$) could be established for a 24 hour period by subtracting final TDR measurments ($T_f$) from initial TDR measurements ($T_i$). This could be accomplished by measuring the soil water content of a turf and then taking another measure over a time period sufficient to estimate ET. Assuming that the initial water content was measured at field capacity (all gravitational water has drained off) of a soil, the second water content measurement would then reflect the amount of water lost through ET.

The research in this chapter was initiated to:

1. Compare two techniques used to measure water use rates; Microlysimetry and TDR
2. Measure and determine differences for water use rate of 12 Cynodon dactylon genotypes

# MATERIALS AND METHODS

A field study was conducted at the Oklahoma State University Turfgrass Research Center in Stillwater, Oklahoma. Twelve bermudagrass genotypes were selected to measure water use rates. They included 'Tifgreen', 'U-3', 'Midiron', and nine experimental genotypes chosen from the cold tolerant bermudagrass breeding program at Oklahoma State University.

Experimental units 2.4 x 3.0 m were established 6 July, 1987. Plots were arranged in a randomized complete block design with four replications. The soil profile was a Norge loam. The turfgrass received high maintenance with mowing twice weekly at 3.5 cm and fertilized at a rate of 0.5 kg N 93 $m^{-2}$ per month during the growing season. The plots were irrigated to prevent the onset of visual wilt symptoms.

Water use rates were determined over a 24-hour period on seven dates throughout the summer and fall months of 1988. Two methods of measuring water use rate, mini-lysimetry and time domain reflectometry (TDR), were used for each plot.

Mini-lysimeters were constructed on 15 April, 1988. The black plastic containers, 152 mm in diameter by 177 mm deep, were filled with fritted-clay. The turf in the mini-lysimeters was established by vegetative propagation and were initially maintained in a greenhouse. Daytime greenhouse temperature was kept at 29 C while the night temperature was maintained at 21 C. The lysimeters were watered daily during establishment and fertilized at a rate of 0.13 kg N

93 $m^{-2}$ per week. The turf in the mini-lysimeters was clipped as needed at 3.5 cm, corresponding to the mowing height in the field plots. The mini-lysimeters were allowed to form a dense canopy, which took approximately 60 days, prior to movement into the field plots.

A black plastic mini-lysimeter sleeve was placed in each of the field plots. Sleeves were 254 mm in diameter and 254 mm deep. The mini-lysimeters were placed in the sleeves with pea gravel at the bottom to adjust the canopy of the turfgrass in the lysimeter to the surrounding turf. Pea gravel facilitated gravitational water drainage.

Water use rates (WUR) were determined for the genotypes by calculating the weight lost by the mini-lysimeters over a 24-hour period. The procedure began by saturating the containers, then allowing drainage to field capacity. The bottoms of the lysimeters were then sealed with a plastic cap to prevent further drainage. Mini-lysimeters were weighed ($w_i$) and placed in the plastic sleeves within each respective plot following this initial weighing. Water use rate was calculated as the difference between initial weight of a lysimeter at field capacity and its final weight ($w_f$) 24 hours later,

$$WUR = w_i - w_f$$

The weight of water lost was converted to mm 24-$hours^{-1}$ for the sampling volume contained in the mini-lysimeters.

Water use rate for the twelve genotypes was also

estimated by the TDR technique simultaneously with mini-lysimetry so that the both methods were under the same climatic conditions during measurement. TDR transmission lines were placed vertically in each field plot containing lysimeters. The soil volume measured with these lines was 1215 $cm^3$. The TDR instrument (IRAMS Soil Moisture Analyzer) was used to measure volumetric water content, expressed as a percentage of the total volume sampled by the transmission lines.

The field plots were irrigated to saturation prior to making TDR measurements. The plots were allowed to drain to field capacity, which occurred within 36 hours. Upon recording initial weights of the mini-lysimeters, a initial volumetric water content reading ($t_i$) was taken with the TDR instrument. After 24 hours and recording the final weight of the lysimeters, a final TDR reading ($t_f$) was taken. Differences in the volumetric water content over the 24 hour period was considered to be the amount of water lost through evapotranspiration. WUR was calculated by subtracting the final TDR measurement from the initial,

$$WUR = t_i - t_f$$

The water use rate was converted from a percentage to mm $day^{-1}$ for the area sampled by the transmission lines.

# RESULTS AND DISCUSSION

There was a significant genotype by method interaction on all dates sampled in determining water use rate for the twelve genotypes (P=0.01). Therefore, WUR for the genotypes was analyzed separately for the two methods.

No difference in WUR was detected among the twelve genotypes using the TDR technique. However, analysis of WUR by mini-lysimetry indicated significant differences among the genotypes (Table 1). There was no genotype by date interaction for both techniques, thus WUR for the genotypes was averaged over dates. Experimental 42-3 and cultivar 'U-3' had significantly higher water use rates than 47-3, 1-7, 8-7, and Midiron.

Water use rate by the genotypes as measured by mini-lysimetry was always higher than rates measured by TDR (Figure 1). The difference between the two methods was significant on all dates (P=0.05). Due to the contrast in temperature of the August sampling dates versus October dates (Table 2), analysis was conducted to examine the consistency between the methods, comparing the August dates with the October dates. There was a significant difference among the August and October dates (P=0.05). This difference (Table 3) indicated that mean WUR using mini-lysimetry for the August dates was considerably greater than the mean WUR for the October dates using lysimetry. However, this difference was not observed using TDR.

The reason for this inconsistency may be that the mini-

lysimetry method is more precise in measuring WUR than TDR. Another possible reason why the mini-lysimeter method had a higher WUR during the summer than the fall could be due to restricted on root growth within the container. A higher root mass within the volume of the mini-lysimeter than would occur naturally could cause the WUR to be slightly higher than usual. This effect might be reduced during the fall when the plant metabolism is slowed in preparation for winter dormancy.

Using mini-lysimetry allowed identification of genotypes with significantly different water use rates. In contrast, the TDR method was not able to distinguish differences in WUR among the genotypes. In conclusion:

1. Scientist have shown mini-lysimetry to be an accurate technique to measure water use rate.
2. Differences in water use rate among the selected genotypes was detected using mini-lysimetry in this study.
3. Other experiments should be undertaken to determine if the proposed TDR method is an acceptable way to estimate WUR by plants.

# LITERATURE CITED

Beard, J.B. 1973. Turfgrass science and culture. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Danielson, R.E., C.M. Feldhake, and P.M. Haw. 1979. Water requirements for urban lawns. Colorado Completion Report to OWRT Project B-035-WYO. 91p.

Davis, J.L. and A.P Annan. 1977. Electromagnetic detection of soil moisture: progress Report 1. Can. J. Remote Sens. 3:76-86.

Davis, J.L., G.C. Topp, and A.P. Annan. Electromagnetic detection of soil water content: Progress Report II. Proceedings of the Workshop on Remote Sensing of Soil Moisture and Ground-Water. Nov. 8-10, 1976. Canadian Aeronautics and Space Institute. P. 96-109.

Feldhake, C.M., R.E. Danielson, and J.D. Butler. 1983. Turfgrass evapotranspiration. I. Factors influencing rate in urban environments. agron. J. 75:824-830.

Jensen, M.E. 1968. Water consumption by agricultural plants. p. 1-22. In T.T. Kozlowski (ed.) water deficits and plant growth. Vol. 2. Academic Press, Inc., New York.

Linaweaver, F.P. Jr., G.C. Geyer, and J.B. Wolff. 1967. A study of residential water use. Federal Housing Administration Technical Studies Program. U.S. Government Printing Office, Washington, D.C.

Stein, J. and D.L. Kane. 1983. Monitoring the unfrozen water content of soil and snow using time domain reflectometry. Water Resource Research. 19:1573-1584.

Tanner, C.B. 1967. Measurement of evapotranspiration. In R.M. Hagan, H.R. Haise, and T.W. Edminister (ed.) Irrigation of agricultural lands. Agronomy. 11:534-574. Madison, Wisconsin.

Tomar, U.S. and J.C. O'Toole. 1980. Design and testing of a microlysimeter for wetland rice. Agron. J. 72:689-692.

Topp, G.C., J.L. Davis, and A.P. Annan. 1980. Electromagnetic determination of soil moisture: measurements in coaxile transmission lines. Water Resource Research. 16:574-582.

van Bavel, C.H.M. 1961. Lysimetric measurements of evapotranspiration rates in the eastern United States. Soil Sci. Soc. Am. Proc. 25:138-141.

Table 1. Water use rate among genotypes averaged over dates using mini-lysimetry method.

| Genotype | WUR † |
|---|---|
| | mm $day^{-1}$ |
| 42-3 | 6.6a ‡ |
| U-3 | 6.5a |
| 1-8 | 6.4ab |
| Tifgreen | 6.2abc |
| 47-4 | 6.1abcd |
| 41-3 | 6.1abcd |
| 45-3 | 5.6abcd |
| 40-3 | 5.9abcd |
| 47-3 | 5.6bcd |
| 1-7 | 5.6cd |
| Midiron | 5.4d |
| 8-7 | 5.2d |

† WUR values were averaged over four replications and seven sampling dates

‡ Means with same letter not significantly different at P=0.05, using least square mean procedure.

Table 2. Maximum and minimum temperatures of sampling dates in water use study.

| Date | Temperature † min | max |
|---|---|---|
| | ---- C ---- | |
| Aug 9 | 25 | 39 |
| Aug 10 | 22 | 37 |
| Aug 12 | 22 | 34 |
| Aug 25 | 17 | 38 |
| Aug 26 | 19 | 39 |
| Oct 12 | 2 | 20 |
| Oct 13 | 2 | 21 |

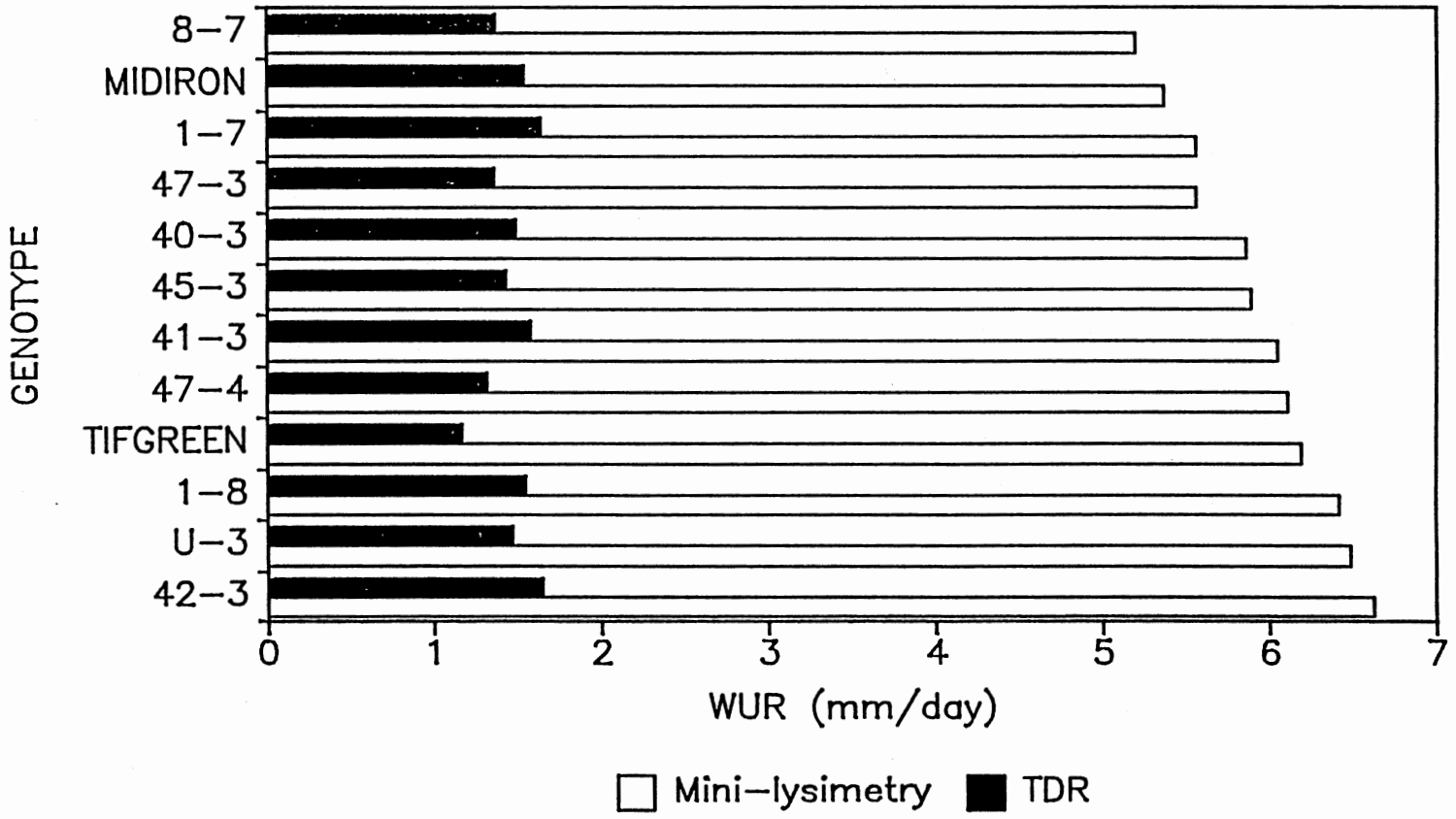
† Temperature recorded at Agronomy Research Station, Stillwater, Oklahoma.

Table 3. Difference in mean water use rate for two methods during August and October sampling dates, averaged over genotype.

| Date | WUR† | | |
|---|---|---|---|
| | Mini-lysimeter | TDR | Difference |
| | ----------mm $day^{-1}$---------- | | |
| August | 7.58 | 1.99 | 5.59 |
| October | 2.69 | 1.18 | 1.51 |

†WUR values were averaged over five dates in August and two dates in October.

Fig. 1. Water use rate of twelve bermudagrass genotypes using TDR and Mini-lysimetry, averaged over seven dates and four replications.



# CHAPTER II

## DROUGHT AVOIDANCE MECHANISMS OF TEN BERMUDAGRASS GENOTYPES

### INTRODUCTION

Selecting turfgrass species or cultivars that are adapted to humid or arid climates is often governed by water usage. The transition zone is an area where both cool-season and warm-season turfgrasses can be grown, but often expose the turf to periods of both humid and arid climate stresses. Thus, it is desirable for turfgrass breeders to develop cultivars which can flourish during periods of adequate rainfall, yet maintain productivity during drought stress. One method of accomplishing this is by selecting turf species with drought avoidance characteristics.

Under non-limited moisture conditions, most turfgrass species concentrate their root systems in the upper 15-20 cm of the soil profile (Bennett and Doss, 1960; Doss et al., 1960; Tovey et al., 1969). Previous research has demonstrated that interspecific differences exists among the plants ability to redistribute their root system downward in the soil profile in response to drying soil. This is true for both warm-season and cool-season turfgrasses (Bennett and

Doss, 1960; Burton et al., 1954; Doss et al., 1960; Evans, 1978; Sheffer et al., 1987). Some grass plants differ intraspecifically in the ability to redistribute roots as a drought avoidance mechanism. Research with spring wheat demonstrated that when moisture was limited, an extensive root system gave one cultivar an advantage in avoiding yield reductions versus six others (Hurd, 1968).

This study was initiated to evaluate the response of ten bermudagrass genotypes to simulated drought stress, and to determine if differences exists in the ability to redistribute roots as a drought avoidance mechanism. A second possible means of drought avoidance measured was the distribution of stored energy within the roots in response to a soil drying cycle.

Several methods of studying roots and their response to various soil water regimes have been proposed. Researchers have used soil cores as a technique to determine root distribution during a drought period (Sheffer et al., 1987; Horst et al., 1985; Peacock and Dudeck, 1985). Water extraction rates were used to determine the depth of absorbing roots in Kentucky bluegrass (Madison and Hagan, 1962). Bennett and Doss (1960) studied soil coring, water extraction rates, and soil monoliths to determine the effect of soil moisture level on root distribution of cool-season forage species. Doss et al.(1960) also conducted experiments on warm season species using a combination of these three methods.

Using polyvinyl chloride (PVC) tubes for growth chambers was demonstrated to be an effective way to study rooting of several plant species. Thomas (1986) used PVC tubes to achieve a realistic balance between transpiration and available soil water, and to permit free root growth and the gradual development of drought responses. Soil columns were used to study patterns of water uptake and root distribution of soybeans in the presence of a water table (Reicosky et al., 1972). The simplicity of the equipment and its ability to permit application of soil compactive forces made it ideal for studies on the effects of soil compaction on root growth (Murdoch et al., 1974).

PVC tubes were selected to grow bermudagrass plants in this drought avoidance study for several reasons. (1) The tubes could be housed in a controlled environment which would allow for plant growth during periods outside of the normal growing season. (2) The experimental set-up allowed for controlled irrigation depths which would simulate drought stress. (3) At the end of the drought stress period, tubes could be severed at selected depths and root distribution measured throughout the soil profile.

Fritted clay was used as the growing medium in the tubes. Fritted clay is a granular material made by firing coarsely-milled, dry clay in a rotary kiln. The material has a relatively low dry-bulk density, is noncohesive, drains very rapidly, retains a large quantity of plant-available water, appears to be chemically inert, and can easily be

washed off the roots (van Bavel et al., 1978). The watering depth could also be lowered in the tubes to simulate drought, with minimal capillary movement upward. This insured that the plants would have to concentrate their roots deeper in the profile to maintain productivity.

Total soluble carbohydrate, or total nonstructural carbohydrate (TNC), may be defined as all carbohydrates which can be used as available energy in the plant body (Smith, 1969; Weinmann, 1947). Carbohydrate reserves are essential for survival and the production of plant tissues when carbohydrate utilization exceeds photosynthetic activity (Smith, 1969). A considerable amount of the work conducted in this area has been with grazing and cutting studies in relation to the total carbohydrates readily available for regrowth. The second phase of this experiment was to measure the total soluble carbohydrate reserves of bermudagrass roots grown during the drought stress period, and study any possible trends which might be related to drought avoidance and the energy reserves of the plant.

Various investigators have used different methods to remove TNC from plant tissue. Many are based on the ability of diastatic enzymes to solubilize native, water insoluble starch. Others are based on acid hydrolysis of starch to simple sugars, followed in either case by measurement of solubilized carbohydrates (Burris et al., 1967).

Davis and Daish (1914) found taka-diastase gave more reproducible results than salivary or malt-diastase

extractions. Weinmann (1946) used saliva as a source of alpha-amylase to extract starch and also outlined the widely used taka-diastase method (Weinmann, 1947) which was later modified by Lindahl et al. (1948).

According to Smith (1969), the most accurate overall method to remove TNC from plant tissues in a single extraction is one that employs a diastatic enzyme solution. The enzyme method to remove TNC which was used in this experiment is a modification of a method first described by Weinmann (1947), changed slightly by Lindahl et al. (1949), and modified once again by Smith (1969). It utilizes a phenol-sulfuric assay, which will be used in this study, and described in greater detail in the materials and methods section of this chapter.

# MATERIALS AND METHODS

Drought avoidance mechanisms of ten bermudagrass genotypes were analyzed for use as potential breeding characteristics. This greenhouse investigation was located at the Oklahoma State University Turfgrass Research Center in Stillwater, Oklahoma. The study was duplicated over two periods of time. The spring study was initiated 28 January, 1988 and ended 5 May, 1988. The fall study was conducted from 13 September, 1988 to 31 January, 1989.

Treatments for this study were seven experimental genotypes selected from the bermudagrass breeding program at Oklahoma State University, and the cultivars 'Midiron', 'Tifgreen', and 'U-3'. A randomized complete block design was used with four replications. Plants were grown in PVC tubing 15 cm in diameter by 150 cm deep. The tubes were severed into five 30 cm segments with the upper 30 cm divided into two 15 cm segments. The tubes were taped together with duct tape prior to filling with a fritted clay growing medium.

A single sprig was planted in each tube and allowed to establish a canopy covering the entire surface of the tube before the drought stress period was initiated. The canopy was formed within 45 days for both the spring and fall experiments. Plants were watered and fertilized daily with a nutrient injection system (Ratio:Feeder by H.E. Anderson co.) to maintain a nitrogen level of 0.5 kg 93 $m^{-2}$ using a Peters 28-8-18 solution of N-P-K. Metal halide lamps were used to

simulate a 14-hour photoperiod. A clipping height of 3.5 cm was maintained throughout the growing season. Clippings were collected, dried, and weighed.

The greenhouse maintained a 29 C day and 21 C night temperature. Beginning approximately the second week of the drought stress period, temperature and relative humidity were monitored daily inside of the greenhouse, (Cole-Parmer Hygrothermograph, model 8368-50). The daily maximums and minimums are presented in Appendixes A and B for the spring and fall studies, respectively.

Drought stress was simulated by systematically lowering the watering depth at ten-day intervals from the soil surface to 15, 30, 60, 90, and 120 cm. Root segments were harvested at depths of 0-15, 15-30, 30-60, 60-90, 90-120, and 120-150 cm.

Root mass and total nonstructurable carbohydrate concentration was determined for each section. Canopy temperature was measured at ten-day intervals, corresponding to the drying cycle, using infrared thermometry (Scheduler Plant Stress Monitor, Standard Oil Engineering Co.). Visual quality observations were made at ten-day intervals for all genotypes. Plants were ranked according to their productivity on a scale from one to ten, with the most productive being ranked ten. Productivity for this study was defined as a plants ability to remain healthy and green while possessing minimal stress symptoms caused by the simulated drought stress.

Roots were harvested by slicing the PVC columns at each

depth, then gently washing all of the fritted clay from root material. The roots from each section were placed in bags and dried at 49 C for 48 hours. After drying, weights were recorded for each section.

The roots were ground to pass through a 40-mesh screen. A sample of the roots from each segment was used for the TNC extraction, which followed the Weinmann method as modified by Smith (1969). Ten ml of ethanol was added to each root sample, which ranged in weight from 40-80 mg. The samples were then placed in a boiling water bath for twenty minutes. They were allowed to cool to room temperature. Once cooled, 2.5 ml of sulfuric acid and 0.5 ml of phenol was added to a 0.5 ml sample of the ethanol/root solution.

After cooling to room temperature, the color which formed by this chemical combination was measured on a spectophotometer (Sequoia-Turner, model 340) at 490 nanometers. This measurement was compared with standards of known carbohydrate concentration to determine the amount of nonstructural carbohydrate in the sample. A conversion was made with this amount to estimate the percentage of TNC in the sample of roots contained in each PVC section.

# RESULTS AND DISCUSSION

Throughout both drought stress studies, visual observations of the bermudagrass genotypes indicated plants with superior drought avoidance capabilities. Visual observations were made assuming that healthy, green plants were avoiding the simulated drought stress better than plants possessing symptoms of wilt and discoloration. Visual rankings from the final day of the drought stress period was used to identify those plants with avoidance characteristics.

Clippings from the plants were collected throughout the drought stress period. Shoot weights for each genotype were averaged over the spring and fall studies due to no season by genotype interaction (P=.05). There were significant differences observed among genotypes for shoot weight (Table 4). The experimental genotype 8-7 had a higher shoot weight than all other genotypes. Also, 45-3 had a higher shoot weight than Midiron and 1-8. Genotype 8-7 was not consistant for both studies. It ranked among the highest for visual quality (Table 5) during the spring stress period, but ranked in a lower group during the fall study. Genotype 45-3 consistantly ranked high in both experiments. Other genotypes which ranked high at day 60 of either study did not necessarily have high shoot weights. The production of shoots was not measured over time, therefore, the time period the production took place is not known. Thus, no trends could be identified which would relate shoot weight to high visual quality.

It was speculated that canopy temperature, which often corresponds directly to plant stress, might identify plants less affected by the drought simulation. Analysis of canopy temperature showed no season by genotype interaction on days 20, 30, 40, and 60 of the drought stress period (P=.05), while there was an interaction on days 10 and 50. However, no significant differences in canopy temperature occured for day 10 or 50 in either the fall or spring study (P=.05). Also, there were no differences among genotypes on days 20, 30, 40, and 60 when averaged over the two studies.

Root mass throughout the soil profile was analyzed to measure root distribution in response to drought stress among the ten genotypes. A significant season by genotype interaction occured at all depths for root weight (Table 6). Significant differences were measured for root weight at all depths during the fall study, while there were differences among the genotypes at only depths 15-30, 30-60, 60-90, and 90-120 cm during the spring season (Table 7).

Using a Pearson correlation procedure, root weight at all depths was compared with day 60 of the visual quality rankings. This was performed for both studies to observe how root weight at the various depths may effect drought avoidance (Table 8). Root weight at depths 30-60, 60-90, 90-120, and 120-150 cm were significantly correlated with a high visual quality ranking on day 60 of the fall study. Genotypes such as 40-3, 45-3, and 47- 4, which had high root weights at the significant depths, were ranked high visually which indicates a relationship to drought avoidance. No

correlation between root weight by depth and visual quality was noted for the spring study.

The natural log of root weight was used to depict linear root distribution throughout the soil profile. Plants capable of uniformly redistributing their roots throughout the soil profile in response to the simulated drought stress may be superior in drought avoidance. There were significant differences in the slopes representing linear distribution among genotypes (Table 9). For the fall study, 40-3 and Midiron had more uniform distribution, while U-3 and 8-7 had the least uniform. In the spring study, 1-8 and 47-3 had the least uniform rooting of the ten genotypes. No consistant trends were observed for either study relating moderate or steep slopes to high visual quality on day 60.

There was a significant season by genotype interaction for percent carbohydrate only at the 60-90 cm depth (Table 6). There were differences among genotypes at depths 0-15, 15-30, and 30-60 cm averaged over both the spring and fall studies (Table 10). There were also differences at the 60-90 cm depth for both the spring and fall studies.

A Pearson correlation procedure was calculated to compare carbohydrate content of the bermudagrass roots at the various depths with visual quality on the final day of the drought stress period. No relationship among drought avoidance and carbohydrate content for either the spring or fall study was observed (table 8).

This study successfully demonstrated that there are

significant differences for the genotypes used in this study with regard to their ability to avoid drought stress symptoms. As demonstrated in the analysis of the fall study, this difference among the genotypes may be due to their ability to redistribute roots downward in the soil profile in response to drought stress.

Results from these selected bermudagrass genotypes indicated that distribution of the plants energy reserves apparently had no relation with their ability to avoid problems caused by drought stress. Other physiological processes are undoubtedly responsible for this characteristic and these render further investigation to ensure future efficient utilization of the natural resource, water.

# LITERATURE CITED

Bennett, O.L. and B.D. Doss. 1960. Effect of soil moisture level on root distribution of cool-season forage species. Agron. J. 52:204-207.

Burris, J.S., R.H. Brown, and R.E. Biaser. 1967. Evaluation of reserve carbohydrates in midland bermudagrass (Cynodon dactylon L.). Crop Sci. 7:22-24.

Burton, G.W., E.H. Devane, and R.L. Carter. 1954. Root penetration, distribution, and activity in southern grasses measured by yields, drought symptoms and $P^{32}$ uptake. Agron. J. 46:229-233.

Davis, W.A. and A.J. Daish. 1914. Methods of estimating carbohydrates. II. Estimation of starch in plant materials. J. Agr. Sci. 6:152-168.

Doss, B.D., D.A. Ashley, and O.L. Bennett. 1960. Effect of soil moisture regime on root distribution of warm season forage species. Agron. J. 52:569-572.

Evans, P.S. 1978. Plant root distribution and water use patterns of some pasture and crop species. New Zealand J. of Ag. Res. 21:261-265.

Horst, G.L., A.A. Baltensperger, and M. D. Finker. 1985. Effects of Nitrogen and growing season on root-rhizome characteristics of turf-type bermudagrasses. Agron. J. 77:237-243.

Hurd, E.A. 1968. Growth of roots of seven varieties of spring wheat at high and low moisture levels. Agron. J. 60:201-205.

Lindahl, Ivan, R.E. Davis, and W.O. Shepherd. 1949. The application of the total available carbohydrate method to the study of carbohydrate reserves in switch cane (rundinaria tecta). Plant Physiol. 24:285-294.

Madison, J.H. and R.M. Hagan. 1962. Extraction of soil moisture by Merion bluegrass (Poa pratensis L. 'Merion') turf, as affected by irrigation frequency, mowing height, and other cultural operations. Agron. J. 54:157-160.

Murdoch, C.L., R.A. Criley, and S.K. Fukuda. 1974. An inexpensive method for the study of root growth in containers of solid media. Hortsci. 9:221.

Peacock, C.H. and A.E. Dudeck. 1985. Effect of irrigation interval on St. Augustinegrass rooting. Agron. J. 77:813-815.

Reicosky, D.C., R.J. Millington, A. Klute, and D.B. Peters. 1972.
Patterns of water uptake and root distribution of soybeans (Glycine max.) in the presence of a water table. Agron. J. 62:292-297.

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

Smith, Dale. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. Wisconsin Agric. Exp. Sta. Res. Report 41.

Thomas, Henry. 1985. Water use characteristics of Dactylis glomerata L., Lolium perenne L. and L. multiflorum Lam. plants Annals of Bot. 57:211-223.

Tovey, R., J.S. Spencer, and D.C. Muckel. 1969. Turfgrass evapotranspiration. Agron. J. 61:863-867.

van Bavel, C.H.M., R. Lascano, and D.R. Wilson. 1978. Water relations of fritted clay. Soil Sci. Soc. Am. J. 42:657-659.

Weinmann, H. 1946. Seasonal chemical changes in the roots of some South African highveld grasses. J. South African Bot. 12:57-73.

Weinmann, H. 1947. Determination of total available carbohydrates in plants. Plant Physiol. 22:279-290.

Table 4. Shoot weights for ten bermudagrass selections averaged over spring and fall seasons.

| Genotype | Shoot weight† |
|---|---|
| | g |
| 8-7 | 13.9a‡ |
| 45-3 | 10.9b |
| 1-7 | 10.8bc |
| 47-3 | 9.9bcd |
| 47-4 | 9.8bcd |
| U-3 | 9.7bcd |
| 40-3 | 9.2bcd |
| Tifgreen | 9.1bcd |
| Midiron | 8.9cd |
| 1-8 | 8.3d |

† Shoot weights were averaged over four blocks and two replications in time.

‡ Means followed by same letter not significantly different at P=0.05, using least square means procedure.

Table 5. Visual quality rankings of root distribution study, for last day of drought stress period.

| Spring | | Fall | |
|---|---|---|---|
| Genotype | Ranking † | Genotype | Ranking |
| 47-4 | 8.50a ‡ | 40-3 | 10.0a |
| 1-7 | 7.3ab | 45-3 | 8.0ab |
| 45-3 | 7.3ab | 47-3 | 7.3bc |
| U-3 | 7.0ab | 47-4 | 7.0bc |
| 8-7 | 6.5abc | 1-8 | 6.3bcd |
| 40-3 | 5.0abcd | 1-7 | 5.8cd |
| 47-3 | 4.8bcd | 8-7 | 4.3de |
| Midironcd | 3.3cd | U-3 | 2.8ef |
| Tifgreen | 3.0cd | Midiron | 2.0f |
| 1-8 | 2.5d | Tifgreen | 1.75f |

† Visual quality is ranked from one to ten (ten being superior in apperance), averaged over four replications.

‡ Means followed by same letter not significantly different at P=.05, using least square means procedure.

Table 6. Expected mean squares for season by genotype interaction during spring and fall studies.

| | Expected mean square | |
|---|---|---|
| Depth | Root weight | Carbohydrate |
| cm | g | % |
| 0-15 | 5.2** | 1.2 |
| 15-30 | 2.3* | 1.6 |
| 30-60 | 2.1* | 1.9 |
| 60-90 | 2.2* | 3.5** |
| 90-120 | 2.6* | 1.1 |
| 120-150 | 3.2** | 1.3 |

* and ** = significant at P=.05, and .01, respectively, using general linear models procedure.

Table 7. Root weights at significant depths for all genotypes during both spring and fall studies.

| | Depth | | | | | |
|---|---|---|---|---|---|---|
| | cm | | | | | |
| Genotype | 0-15 | 15-30 | 30-60 | 60-90 | 90-120 | 120-150 |
| | Root weight (spring) | | | | | |
| | g | | | | | |
| | NS | ** | ** | * | * | NS |
| 1-7 | 1265 | 788ab† | 892a | 240ab | 140ab | 82 |
| 47-4 | 1306 | 849a | 778abc | 207abc | 116abc | 105 |
| 40-3 | 1068 | 760ab | 814a | 258a | 161a | 73 |
| 1-8 | 1084 | 755ab | 791ab | 190abc | 67cd | 28 |
| 45-3 | 1163 | 570bc | 623abcd | 196abc | 106abc | 94 |
| 8-7 | 1369 | 531bc | 481d | 133cd | 94bcd | 79 |
| Midiron | 1036 | 452c | 532bcd | 165bcd | 119abc | 97 |
| U-3 | 872 | 491c | 499cd | 144cd | 97bcd | 72 |
| 47-3 | 992 | 463c | 415d | 92d | 47d | 39 |
| Tifgreen | 771 | 397c | 530bcd | 162bcd | 102bcd | 80 |
| | Root weight (fall) | | | | | |
| | g | | | | | |
| | ** | ** | ** | ** | ** | ** |
| 47-4 | 2017b | 681a | 420a | 292a | 166a | 70bcd |
| 8-7 | 2611a | 545ab | 244b | 125cd | 39cd | 4d |
| 47-3 | 1873bc | 633a | 301ab | 212abc | 115ab | 81bc |
| 1-7 | 1822bc | 526abc | 289b | 193abc | 93bc | 61bcd |
| 40-3 | 1246dc | 448bcd | 291b | 274a | 173a | 178a |
| 45-3 | 1277de | 426cd | 281b | 226ab | 131ab | 109ab |
| 1-8 | 1437cd | 469bcd | 232b | 158bcd | 72bc | 62bcd |
| U-3 | 1079de | 389cd | 221b | 85d | 38c | 12cd |
| Tifgreen | 943ef | 344d | 166bc | 134bcd | 88bc | 52bcd |
| Midiron | 467f | 134e | 94c | 60d | 38c | 42bcd |

*, **, and NS = significant at P=0.05, 0.01, and not significant, respectively, using least square means procedure.

† Means followed by same letter not significantly different at noted significance level.

Table 8. Results of analysis for visual quality on day 60 correlated with root weight and % carbohydrate.

| Depth | R correlation | |
|---|---|---|
| | Carbohydrate | Root weight |
| cm | % | g |
| **Spring** | | |
| 0-15 | 0.07 | 0.58 |
| 15-30 | 0.44 | 0.38 |
| 30-60 | 0.23 | 0.19 |
| 60-90 | 0.37 | 0.20 |
| 90-120 | 0.13 | 0.29 |
| 120-150 | 0.51 | 0.52 |
| **Fall** | | |
| 0-15 | 0.15 | 0.34 |
| 15-30 | 0.33 | 0.56 |
| 30-60 | 0.53 | 0.72* |
| 60-90 | 0.31 | 0.86** |
| 90-120 | 0.04 | 0.80** |
| 120-150 | 0.12 | 0.81** |

* and ** = significant at P=.05 and P=.01, respectively, using least square means procedure.

Table 9. Linear regression slopes for root distribution of ten bermudagrass selections for spring and fall experiment.

| Genotype | Slope | |
|---|---|---|
| | Spring | Fall |
| 40-3 | -0.0203a† | -0.0125a |
| Mifiron | -0.0175a | -0.0172ab |
| Tifgreen | -0.0182a | -0.0195bc |
| 45-3 | -0.0193a | -0.0203bc |
| 47-4 | -0.0203a | -0.0218bc |
| 1-8 | -0.0293c | -0.0229bc |
| 47-3 | -0.0270bc | -0.0243c |
| 1-7 | -0.0212a | -0.0254c |
| U-3 | -0.0196a | -0.0321d |
| 8-7 | -0.0222ab | -0.0386e |

† Slopes followed by same letter not significantly different at P=0.05, using least square means procedure.

Table 10. Mean separation of carbohydrate content for ten bermudagrass genotypes, including both spring and fall studies.

| Genotype | Percent Carbohydrate | | | | |
|---|---|---|---|---|---|
| | Depth† | | | | |
| | cm | | | | |
| | 0-15 | 15-30 | 30-60 | 60-90 (Sp) | 60-90 (Fa) |
| 47-4 | 3.58a‡ | 3.5ab | 4.2a | 6.6a | 2.6a |
| 1-7 | 3.46a | 3.5ab | 3.3bc | 3.2bc | 2.4ab |
| 40-3 | 3.43a | 4.7a | 3.4abc | 3.2bc | 2.7a |
| Midiron | 3.30a | 3.3b | 2.3cd | 2.8bcd | 2.7a |
| 45-3 | 3.23a | 3.8ab | 3.4ab | 3.8b | 2.5ab |
| Tifgreen | 3.15a | 3.9ab | 2.9bc | 3.1bc | 2.5ab |
| 1-8 | 2.83a | 3.5ab | 3.1bc | 2.9bc | 2.6a |
| 47-3 | 2.70a | 2.7bc | 3.2bc | 2.8bc | 3.2a |
| 8-7 | 2.65a | 2.8bc | 2.4cd | 2.1cd | 1.4b |
| U-3 | 1.71b | 1.9c | 1.7d | 1.6d | 2.1ab |

†Means for depths 0-15, 15-30, and 30-60 averaged over four replications and both studies, and means for 60-90 cm averaged only over four replications.

‡Means followed by same letter not significantly different at P=0.05, using least square means procedure.

# APPENDIX A

## TEMPERATURE AND RELATIVE HUMIDITY MEASUREMENTS FOR SPRING, 1988

| | Temperature | | Rel. Humidity | |
|---|---|---|---|---|
| DATE | Max | Min | Max | Min |
| 3-22-88 | 42 C | 22 C | 63% | 22% |
| 3-23 | 42 | 23 | 77 | 26 |
| 3-24 | 41 | 22 | 55 | 14 |
| 3-25 | 40 | 23 | 72 | 22 |
| 3-26 | 41 | 22 | 79 | 22 |
| 3-27 | 43 | 22 | 100 | 21 |
| 3-28 | 35 | 23 | 100 | 36 |
| 3-29 | 42 | 23 | 81 | 44 |
| 3-30 | 35 | 23 | 77 | 25 |
| 3-31 | 30 | 21 | 100 | 61 |
| 4-1 | 38 | 21 | 100 | 46 |
| 4-2 | 37 | 21 | 100 | 46 |
| 4-3 | 41 | 22 | 85 | 32 |
| 4-4 | 47 | 22 | 94 | 21 |
| 4-5 | 41 | 22 | 70 | 21 |
| 4-6 | 44 | 22 | 82 | 23 |
| 4-7 | 42 | 22 | 90 | 21 |
| 4-8 | 44 | 22 | 100 | 71 |
| 4-9 | 30 | 22 | 97 | 30 |
| 4-10 | 41 | 22 | 79 | 21 |
| 4-11 | 42 | 22 | 89 | 30 |
| 4-12 | 43 | 22 | 96 | 25 |
| 4-13 | 41 | 22 | 96 | 38 |
| 4-14 | 43 | 22 | 100 | 27 |
| 4-15 | 41 | 22 | 82 | 36 |
| 4-16 | 41 | 22 | 97 | 71 |
| 4-17 | 32 | 22 | 100 | 25 |
| 4-18 | 42 | 21 | 81 | 21 |
| 4-19 | 41 | 22 | 88 | 31 |
| 4-20 | 41 | 22 | 100 | 40 |
| 4-21 | 36 | 22 | 100 | 24 |
| 4-22 | 39 | 22 | 98 | 33 |
| 4-23 | 36 | 22 | 95 | 36 |
| 4-24 | 36 | 22 | 100 | 56 |
| 4-25 | 33 | 22 | 100 | 34 |
| 4-26 | 35 | 22 | 94 | 25 |
| 4-27 | 36 | 16 | 100 | 30 |
| 4-28 | 36 | 20 | 100 | 90 |
| 4-29 | 29 | 23 | 100 | 31 |
| 4-30 | 38 | 23 | 98 | 40 |
| 5-1 | 34 | 22 | 100 | 53 |
| 5-2 | 33 | 21 | 100 | 44 |
| 5-3 | 34 | 22 | 100 | 38 |

# APPENDIX B

## TEMPERATURE AND RELATIVE HUMIDITY MEASUREMENTS FOR FALL,1988

| | Temperature | | Rel. Humidity | |
|---|---|---|---|---|
| Date | Hi | Low | Hi | Low |
| 1-4-89 | 28 C | 19 C | 86% | 55% |
| 1-5 | 35 | 19 | 80 | 20 |
| 1-6 | 33 | 19 | 75 | 38 |
| 1-7 | 35 | 19 | 68 | 28 |
| 1-8 | 29 | 18 | 49 | 35 |
| 1-9 | 33 | 16 | 88 | 40 |
| 1-10 | 34 | 19 | 62 | 41 |
| 1-11 | 32 | 18 | 65 | 23 |
| 1-12 | 34 | 18 | 56 | 35 |
| 1-13 | 33 | 18 | 60 | 24 |
| 1-14 | 34 | 18 | 57 | 31 |
| 1-15 | 25 | 18 | 88 | 45 |
| 1-16 | 35 | 18 | 77 | 40 |
| 1-17 | 36 | 18 | 90 | 42 |
| 1-18 | 38 | 18 | 75 | 19 |
| 1-19 | 36 | 18 | 73 | 22 |
| 1-20 | 37 | 18 | 73 | 31 |
| 1-21 | 34 | 18 | 60 | 24 |
| 1-22 | 36 | 18 | 55 | 14 |
| 1-23 | 32 | 19 | 78 | 22 |
| 1-24 | 35 | 18 | 78 | 26 |
| 1-25 | 34 | 19 | 73 | 30 |
| 1-26 | 35 | 18 | 63 | 37 |
| 1-27 | 35 | 19 | 87 | 35 |
| 1-28 | 24 | 18 | 82 | 66 |
| 1-29 | 29 | 18 | 87 | 58 |
| 1-30 | 37 | 19 | 84 | 25 |
| 1-31 | 36 | 19 | 77 | 15 |

# APPENDIX C

## VISUAL QUALITY RANKINGS FOR ROOT DISTRIBUTION STUDY, INCLUDING SPRING AND FALL STUDIES

### Fall Season

| Genotype | Days from beginning of drought stress | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 |
| Midiron | 2.50 | 2.00 | 1.50 | 1.50 | 1.25 | 2.00 |
| Tifgreen | 3.25 | 2.75 | 3.00 | 2.75 | 2.75 | 1.75 |
| U-3 | 4.75 | 3.00 | 2.75 | 2.00 | 2.50 | 2.75 |
| 1-7 | 6.75 | 6.75 | 7.50 | 6.25 | 5.50 | 5.75 |
| 1-8 | 6.00 | 3.75 | 4.25 | 6.25 | 5.75 | 6.25 |
| 40-3 | 9.75 | 8.00 | 8.25 | 9.00 | 8.75 | 10.00 |
| 45-3 | 6.00 | 6.50 | 7.75 | 6.75 | 7.50 | 8.00 |
| 47-3 | 4.25 | 6.25 | 6.25 | 5.75 | 7.00 | 7.25 |
| 47-4 | 5.25 | 6.25 | 6.50 | 7.25 | 8.00 | 7.00 |
| 8-7 | 6.50 | 9.75 | 7.25 | 7.50 | 6.00 | 4.25 |

### Spring Season

| Genotype | Days from beginning of drought stress | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 |
| Midiron | 5.25 | 3.00 | 3.75 | 2.50 | 2.25 | 3.25 |
| Tifgreen | 6.00 | 5.25 | 4.25 | 3.25 | 3.50 | 3.00 |
| U-3 | 5.50 | 5.00 | 6.50 | 7.00 | 6.00 | 7.00 |
| 1-7 | 8.00 | 8.00 | 7.25 | 6.75 | 7.25 | 7.25 |
| 1-8 | 2.25 | 2.00 | 1.75 | 2.50 | 2.25 | 2.50 |
| 40-3 | 4.50 | 5.25 | 5.75 | 6.50 | 4.50 | 5.00 |
| 45-3 | 8.25 | 9.25 | 9.00 | 8.25 | 8.50 | 7.25 |
| 47-3 | 2.75 | 3.75 | 3.00 | 3.50 | 4.00 | 4.75 |
| 47-4 | 7.00 | 7.00 | 5.75 | 8.25 | 8.25 | 8.50 |
| 8-7 | 6.00 | 7.00 | 8.00 | 6.50 | 7.50 | 6.50 |

VITA[2]

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