FIFTH YEAR

PROGRESS REPORT

concerning

PHYSIOLOGICAL INVESTIGATIONS

in

DEVELOPING WATER CONSERVING MINIMAL MAINTENANCE TURFGRASSES AND CULTURAL SYSTEMS

Volume V

Submitted by:

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I. INTRODUCTION

The project on Developing Water Conserving, Minimal Maintenance Turfgrasses and Cultural Systems is now past the midpoint in the original 10-year master plan of research objectives and allied study areas. The progress and accomplishments to date have been personally quite rewarding for those of us actually involved in the research.

Now some of the turfgrass breeders are starting to utilize the concepts we developed as well as the specific screening techniques. For example, Dr. Taliaferro is considering shifting his emphasis of bermudagrass breeding from enhanced rooting to improved drought tolerance/hardiness. Dr. Engelke at Dallas is building a deep sand root zone for drought stress studies and will follow experimental techniques pioneered here at College Station, Texas over the past four years. Dr. Baltensperger at New Mexico State entered a set of his most advanced bermudagrass selections in our drought resistance study the past two summers with very positive results and has now submitted a set of selections for assessment of evapotranspiration rates during this fall at College Station, Texas. Similarly, we are working with Dr. Engelke of the Dallas Center on characterizations of four zoysiagrass and three St. Augustinegrass selections in terms of drought avoidance, tolerance, and resistance (see Appendix). Drs. Baltensperger and Riordan are following the canopy resistance-leaf area concept in selection for low water use rates.

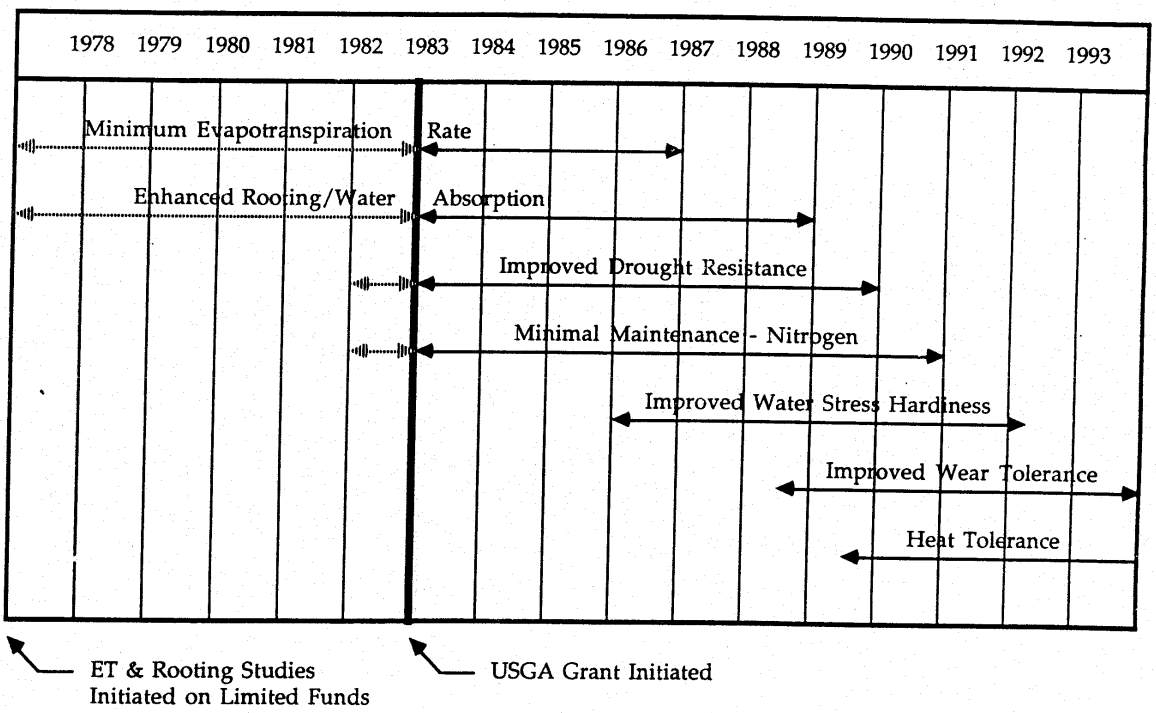
In terms of the major research objectives: (A) We are well along toward completing the first research objective of developing concepts that will assist the breeder in plant selection criteria and cultural systems to Minimize Water Use Rates, (B) In the area of Enhanced Rooting and Water Absorption, we are making very excellent progress and conducting pioneering studies in the area of root hair characterizations; but at a much slower rate than originally planned due to the nature of the studies involved, (C) In the area of Improved Drought Resistance, the progress made to date has been excellent; we are well advanced in completing the research on warm-season turfgrasses and about ready to initiate mechanistic studies on the cool-season turfgrass species, (D) In the fourth area regarding the Mechanistic Basis of Minimal Maintenance Turfgrasses, we have some very excellent leads in the area of carbohydrate partitioning and are now pursuing these in detail utilizing radioisotope studies, (E) Finally, in the area of Improved Water Stress Hardiness, the initial studies are now underway. Thus, it is too early to predict the extent of progress that can be achieved in the next few years.

SUMMARY

This report represents the status report for the fifth year of intensive research activity devoted to developing water conserving, minimal maintenance turfgrasses and cultural systems. The primary objective in this report is to present a status update on progress made during the past 12 months on the individual research objectives. Detailed results and specific data on each research objective and study are presented. The current status of the research objectives and individual studies under each research objective are summarized in the following table.

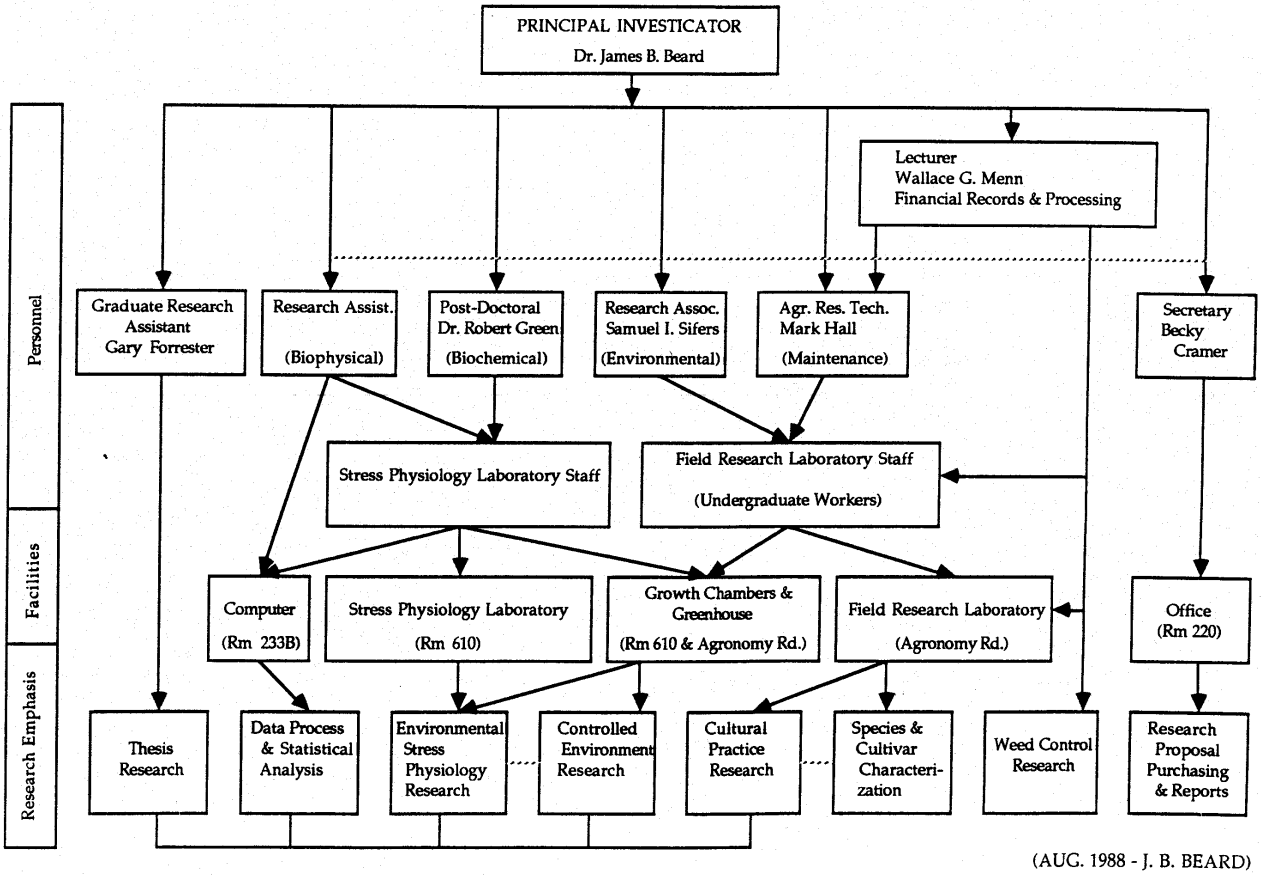
Research Objective	Studies Completed: Scientific Papers Published	Studies Completed: Scientific Papers in Preparation	Studies in Progress	New Studies Just Initiated	Studies On Hold
A. Minimal Water Use Rate	2	8	2	2	1
B. Enhanced Rooting/Water Absorption	--	6	8	1	3
C. Improved Drought Resistance	--	4	2	2	1
D. Basis of Minimal Maintenance Turfgrass	--	1	3	--	1
E. Improved Water Stress Hardiness	--	1	1	--	--

SCHEDULE OF RESEARCH OBJECTIVES: FOR THE DEVELOPMENT OF WATER CONSERVING, MINIMAL MAINTENANCE TURFGRASSES AND CULTURAL PRACTICES



(AUG. 1988 - J. B. BEARD)

Turfgrass Research Project Organizational Structure, Texas A&M University, College Station, Texas



(AUG. 1988 - J. B. BEARD)

II. IMPLEMENTATION

A. Organization

The research staff organizational structure is shown on page 4. Although each individual has assigned areas of research responsibility, there must be and is much interactive cooperation among the group. As project leader I am very proud of the research staff that has been assembled. They are very dedicated to this project of developing water conserving, minimal maintenance turfgrasses. Each has a specific unique technical expertise that allows us to conduct a diverse range of in-depth pioneering type studies. The names of individuals assisting in each study area are listed following the objective statement.

B. Personnel

Mr. William Richie began employment in June of 1988. Bill received his Master of Science degree in Agronomy, May, 1988. His master's work focused on understanding the structural composition of the sorghum stalk in relationship to stalk strength. Additionally, the specific composition of sorghum hemicelluloses was determined using HPLC analysis. Prior to full-time employment in the turfgrass physiology lab, he worked part-time for the USDA in a sorghum breeding program. Responsibilities include developing methodology for soluble carbohydrate extraction from warm-season turfgrasses in relation to the SRD phenomena.

C. Facilities Development

The status of our physical facilities to pursue the key research objectives outlined in this project is good. As originally planned, the relative percentage of our experiments involving greenhouse and laboratory activities has been increasing while the field dimension of our experimental activities has been decreasing. This trend will continue for the first five research thrust areas. However, with the initiation of wear stress studies and at a future date the heat hardiness studies, this will cause an increase in field activities during the initial 2 to 3 years to develop the turf tolerance characterizations needed under typical field conditions.

TEXAS A&M UNIVERSITY
TURFGRASS RESEARCH FACILITIES

A. Turfgrass Stress Physiology Lab:

The 2,100 square feet complex includes a biochemistry volatiles lab, physical stress lab, isotope room, histology room, and dark room which have capabilities in carbohydrate, protein, lipid, and enzyme analyses. Equipment includes gas chromatography, open system for differential analysis of CO_2 exchange, disc gel and SDS electrophoresis, thin layer chromatography, column chromatography, spectrophotometers, refrigerated centrifuge, carbon^{14} isotope facilities, spectral radiometer, potentiometers, hygrometers, thermocouple psychrometers, porometers, etc.

B. Plant Growth and Stress Chambers:

Four high-light controlled environment plant growth chambers.
Programmed low temperature and chill stress chamber.
Heat and drought stress simulation chamber.

C. Greenhouse:

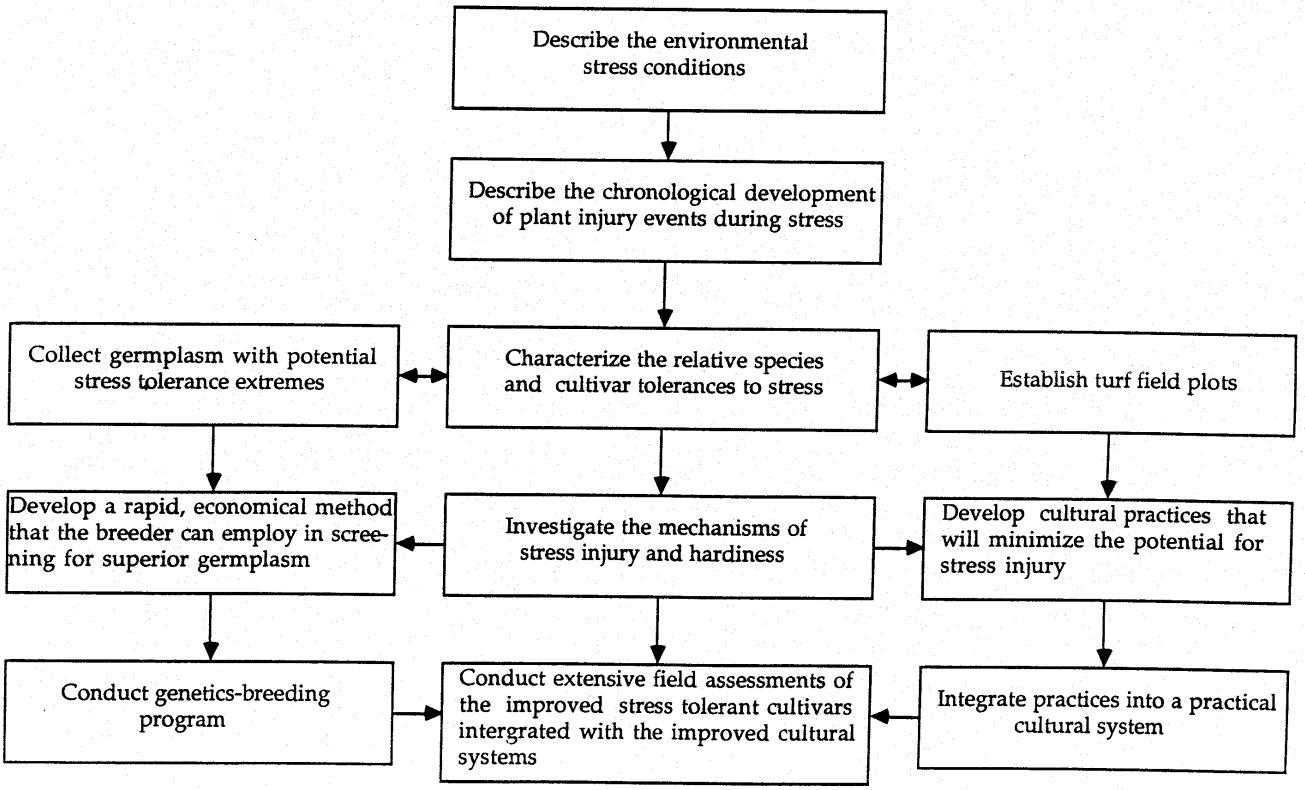
Have 1,600 square feet underglass with evaporative cooling and programmed mist irrigation which is comprised of a warm-season grass house, a cool-season grass house, and an isolation room with mist chamber; plus headhouse support facilities.

D. Turfgrass Field Laboratory:

Consists of 14 acres of turf plots including 4 acres with a sand modified root zone, 55,000 square feet of 'green' type turf plots, 65,000 square feet of tree shaded turf plots, a linear gradient irrigation area, and a microclimate monitoring system. The plots are irrigated with a fully automatic, valve in head pop-up system with master and satellite control units.

A 5,000 square foot Field Lab Building is composed of a diagnostic lab, microclimate-irrigation control center, growth room, equipment service and teaching shop, and a representative selection of turfgrass maintenance equipment.

AN ENVIRONMENTAL STRESS PHYSIOLOGY - GENETICS MODEL TO IMPROVE STRESS TOLERANCE IN TURFGRASSES



III. ANNUAL STATUS REPORT OF ONGOING RESEARCH CONDUCTED DURING THE FOURTH YEAR

This section summarizes ongoing research that has been conducted during the past year and/or is planned for the upcoming year. Research that has been completed and is currently in the report/scientific article preparation stage is summarized in Section V. The summary of ongoing investigations for the five major research thrusts is as follows.

A. Minimal Water Use Rates - Ten studies have been completed, two studies are continuing, two new studies were initiated, and one is on hold.

B. Enhanced Rooting/Water Absorption - Six studies have been completed, eight studies are continuing, two are waiting for available space, ten studies are on hold, and one study is in the planning stage.

C. Improved Drought Resistance - Four studies are completed, two studies are continuing, one study is on hold, and two studies are in the planning stage.

D. Mechanistic Basis of Minimum Maintenance Turfgrasses - One study is completed, three studies are continuing, and one is on hold.

E. Improved Water Stress Hardiness - This is a new research thrust initiated in 1986 that was part of the overall master plan. One study has been completed and one is continuing.

A. OBJECTIVES FOR MINIMAL WATER USE RATE: RESEARCH STATUS AND RESULTS

This major research thrust relates primarily to the development of low evapotranspiration (water use) rates for turfs that are normally irrigated, thereby, contributing to water conservation. Also, the development of turfgrasses and cultural systems possessing reduced evapotranspiration rates will contribute one dimension to a drought avoidance strategy that is a component of drought resistance.

A-10 Determine the comparative evapotranspiration rates for eleven zoysiagrasses that have a diverse array of canopy densities, leaf orientations, and leaf extension rates. Initiated in 1985. S. Sifers, R. Green, and C. Atkins.

Status - Field studies completed, with additional controlled environment simulation studies scheduled for the winter of 1988-89. (Intraspecies Comparison and Breeding Markers)

Results - Comparative evapotranspiration rates of eleven zoysiagrass genotypes as evaluated in both the field and an environmental simulation chamber are presented in Table A-10.1. The overall range in ET rate variation is quite small, typically being less than 20%. This contrasts to many of the other turfgrass

species assessed where a much broader range of evapotranspiration rates were found among the commercially available cultivars and near release selections. Thus, a much wider range in genotypes, as related to evapotranspiration rates, needs to be obtained in comparison to the eleven cultivars selected for this study by Dr. Milton Engelke.

Detailed evapotranspiration assessment studies conducted in a controlled environment simulation chamber along with the associated plant parameters are shown in Tables A-10.2 and A-10.3. Shoot density was positively correlated with the evapotranspiration rate, whereas the correlation with leaf retention rate was not significant. This suggests that a modeled composite assessment of the plant parameters affecting the canopy resistance-leaf area concept in relation to evapotranspiration is required in the case of the zoysiagrass species where the range in ET rates is quite narrow. Also, there was no correlation between the evapotranspiration rate and the stomatal density on either the abaxial or adaxial surfaces, as has been found in other species earlier.

A-11 Investigate more critically the influences of cutting heights and nitrogen/potassium nutritional levels on turfgrass evapotranspiration rates. Initiated in 1985. S. Sifers, W. Menn, and M. Hall.

Status - Cultural treatments were continued on the Tifway bermudagrass turf along with visual ratings begun during late 1985. Cultural treatments included three cutting heights of 0.5, 1.0, and 1.5 inches, three nitrogen nutritional levels of 0.5, 1.0, and 1.5 pounds per 1,000 square feet per growing month, and three potassium levels of 0.5, 1.0, and 1.5 pounds per 1,000 square feet per growing month. These cultural treatments are combined in all possible combinations in three replications. The experimental site is a modified sand root zone with a subsurface drainage system. Specific water use rate measurements using the water balance method with mini-lysimeters were planned for 1988. Upon completion of these studies a drought resistance investigation is scheduled. These studies have been delayed due to decreased funding. (Improved Cultural Systems)

Table A-10.1 Evapotranspiration and vertical leaf extension rates of eleven zoysiagrass genotypes determined under nonlimiting water conditions in both field plots and the environmental simulation chamber.

Genotype/Cultivar	Evapotranspiration Rate (mm d^{-1})						Leaf Extension Rate (mm d^{-1})					
	Field			Chamber	Overall without chamber	Overall with chamber	Field			Chamber	Overall without chamber	Overall with chamber
	1985	1986	1987				1985	1986	1987			
Belair	4.1 b*	4.8 a	2.5 e	8.9 cd	3.8 d	5.1 b	6.8 cd	8.4 ab	10.5 d	4.1 a	8.6 bc	7.5 c
El Toro	4.1 b	4.9 a	2.8 cde	9.4 abcd	3.9 cd	5.3 ab	10.8 a	7.1 ab	12.1 abc	4.1 a	10.0 d	8.5 a
Emerald	4.0 b	4.7 a	2.9 bcde	10.3 a	3.9 cd	5.5 ab	5.4 d	4.9 c	12.3 ab	2.6 f	7.6 d	6.3 d
FC-13521	4.1 b	5.0 a	2.5 e	10.1 a	3.8 d	5.4 ab	6.6 cd	6.6 bc	13.5 a	2.8 ef	8.9 b	7.4 c
KLS-05	4.1 b	4.6 a	3.4 abc	8.7 cd	4.0 bcd	5.2 ab	5.1 d	6.5 bc	11.5 bcd	2.9 ef	7.7 cd	6.5 d
KLS-11	4.9 ab	5.5 a	3.6 ab	8.4 d	4.7 a	5.6 a	8.2 bc	8.7 a	10.9 cd	3.1 de	9.3 ab	7.7 bc
KLS-13	4.2 b	4.6 a	3.3 abcd	9.4 abcd	4.0 bcd	5.4 ab	7.3 c	7.6 ab	12.1 bc	4.0 ab	9.0 ab	7.8 abc
Korean Common	4.2 ab	5.1 a	2.9 cde	8.5 d	4.1 bcd	5.2 ab	10.0 ab	7.6 ab	10.9 cd	3.5 cd	9.5 ab	8.4 ab
Meyer	5.2 a	5.3 a	2.7 de	9.9 ab	4.4 abc	5.4 ab	8.1 bc	7.2 ab	11.5 bcd	2.7 ef	9.0 ab	7.8 abc
PI 231146	4.1 b	4.7 a	3.7 a	9.5 abc	4.2 abcd	5.5 ab	5.2 d	4.7 c	12.6 ab	1.8 g	7.5 d	6.0 d
41-21-5	4.6 ab	5.2 a	3.8 a	9.0 bcd	4.5 ab	5.6 a	7.3 c	8.1 ab	11.8 bcd	3.6 bc	9.1 ab	7.7 bc
$LSD_{0.05}$	1.00	1.07	0.66	1.03	0.53	0.47	1.92	1.99	1.36	0.46	1.02	0.79

Mowing heights for 1985, 1986, and 1987 field evaluations and chamber evaluation were 50.8, 25.4, 25.4, and 32.0 mm, respectively.
* Means within the same column followed by the same letter are not significantly different, T TEST (LSD) procedure, alpha = 0.05.

Table A-10.2 Evapotranspiration (ET) rates of 11 zoysiagrass genotypes determined under non-limiting soil moisture and uniform environmental conditions of the environmental simulation chamber; plus associated leaf extension rates, shoot densities, and leaf blade stomata densities.

Genotype/Cultivar[a]	ET[b]	Leaf Extension Rate (LER)[c]	Shoot Density[d]	Stomata Density	
				Abaxial[e]	Adaxial[f]
	$mm\ d^{-1}$	$mm\ d^{-1}$	$No.dm^{-2}$	$No.\ mm^{-2}$	
KLS-11	8.4 d[g]	3.1 de	307.3 ef	351 a	447 cde
Korean Common	8.5 d	3.5 cd	234.0 f	344 a	467 c
KLS-05	8.7 cd	2.9 ef	760.0 b	295 b	453 cd
Belair	8.9 cd	4.1 a	281.0 f	316 ab	453 cd
41-21-5	9.0 bcd	3.6 bc	429.3 d	301 b	407 e
KLS-13	9.4 abcd	4.0 ab	404.0 de	285 b	422 de
El Toro	9.4 abcd	4.1 a	306.0 ef	345 a	517 ab
PI 231146	9.5 abcd	1.8 g	1552.0 a	344 a	526 a
Meyer	9.9 ab	2.7 ef	592.0 c	279 b	451 cd
FC-13521	10.1 a	2.8 ef	785.3 b	291 b	476 bc
Emerald	10.3 a	2.6 f	842.0 b	299 b	449 cde
$LSD_{0.05}$	1.0	0.5	120.2	38	42

[a] Eleven genotypes (with three replications of each) fully turfed and acclimated were grown in black plastic pots (22.0 cm diameter, 21.5 cm deep, 5.4 L volume, filled with fritted clay) under greenhouse and field conditions for 3.25 years (being used intermittently for ET research). The canopies were cut and maintained via a reel mower at a height of 3.2 cm above the lip of the pot. Turfs were acclimated in the environmental simulation chamber for 5 days prior to ET rate and LER determinations which required 7 days.

[b] Evapotranspiration rate determined by water balance measurements made over 24 hour periods under environmental simulation chamber conditions. Means are the average of three replicate pots of each genotype with three ET determinations per pot determined under uniform temperature, irradiance, dew point, and wind speed conditions. A complete block of genotypes was simultaneously measured for ET and LER which consisted of three independent measurements at different pot locations within the chamber. The average irradiance was 1,230 $\mu Em^{-2}s^{-1}$, the average relative humidity was 36.5%, the average temperature was 30.6°C, and the average wind speed was 0.66 ms^{-1}.

[c] Leaf extension rates determined by taking 20 leaf measurements per pot, waiting 48 hours and taking 20 more. The difference was then divided by two, to convert the measurements to a 24-hour period. Means are the average of three replicate pots of each genotype with three determinations per pot made over its seven day ET determination.

[d] Shoot density determined by randomly placing a cut-out (0.5 cm^2) on the pot's canopy, and counting the individual shoots inside by hand. Numbers were converted to dm^2 basis.

[e] Stomata density (AB) determined by counting the stomates inside the 0.0625 mm^2 grid of a microscope, then converting the number to a mm^2 basis. The counts are means of eleven looks per leaf and three leaves per pot with three replicate pots per genotype.

[f] Stomata density (AD) determined by counting the stomates inside the 0.0625 mm^2 grid of a microscope, then converting the number to a mm^2 basis. The counts are means of eleven looks per leaf and three leaves per pot with three replicate pots per genotype.

[g] Means within the same column followed by the same letter are not significantly different, T Tests (LSD) procedure, alpha = 0.05.

Table A-10.3. Correlation coefficients for evapotranspiration (ET) rate with related plant parameters for 11 *Zoysia* genotypes.

Parameter	Leaf Extension Rate (LER)	Shoot Density	Stomatal Density	
			Abaxial (AB)	Adaxial (AD)
ET Rate	-0.22	0.44*	-0.26	0.00
Leaf Extension Rate		-0.81**	0.03	-0.24
Shoot Density			-0.04	0.38*
AB Stomatal Density				0.57**

*, ** Significant at the P= 0.05 and 0.01 level, respectively.

A-13 Determine the comparative evapotranspiration (ET) rates for six centipedegrass cultivars. Initiated in 1986. S. Sifers and M. Hall.

Status - The third year of field studies have been completed and analyzed. The controlled environment simulation chamber studies remain to be completed. (Intraspecies Comparison and Breeding Markers)

Results - The comparative evapotranspiration rates and allied leaf extension rates for six centipedegrass genotypes are shown in Table A-13.1. The range in ET rates is extremely small being less than 10%. Evidently the germplasm of the commercially available and near release centipedegrass cultivars is very narrow in terms of the characteristics contributing to evapotranspiration rates.

A-14 Determine the comparative evapotranspiration (ET) rates for six bermudagrass cultivars submitted for testing by Dr. Arden Baltensperger, New Mexico State University, in a cognitive effort. The cultivars are Arizona Common, Tifgreen, Texturf 10, NM S-4, MN 30, and Nu Mex Sahara. S. Sifers, M. Hall, and R. Green.

Status - The six cultivars have been received and planted in mini-lysimeters. Field studies and environmental simulator studies are being conducted in the fall, 1988 and winter of 1989 to assess the comparative evapotranspiration rates. (Intraspecies Comparison)

Table A-13.1 The comparative evapotranspiration (ET) and leaf extension rate (LER) of six centipedegrass genotypes under nonlimiting moisture conditions in the field over three years*.

Genotype	Evapotraspiration Rate (mm d^{-1})				Leaf Extension Rate (mm d^{-1})			
	1986	1987	1988	Overall	1986	1987	1988	Overall
GA. Common	3.0 a**	5.5 a	5.6 ab	4.7 a	4.5 ab	4.4 ab	1.7 a	3.5 a
Tenn. Hardy	2.8 a	5.4 ab	5.8 a	4.6 a	7.1 a	4.5 ab	1.9 a	4.8 a
Oklawn	2.8 a	5.5 a	5.3 ab	4.5 a	5.1 a	5.9 a	2.1 a	4.5 a
AU Centenial	2.6 a	5.4 ab	5.5 ab	4.5 a	0.4 b	3.9 b	2.0 a	2.1 b
AC - 44	2.7 a	5.2 ab	4.7 b	4.2 b	6.2 a	4.2 ab	2.3 a	4.2 a
AC - 26	2.5 a	5.0 b	5.0 ab	4.2 b	3.5 ab	4.5 ab	2.6 a	3.5 a
$LSD_{0.05}$	0.54	0.51	0.96	0.30	4.34	1.90	2.77	1.34

* Mowing heights for 1986, 1987, and 1988 are 25.4, 38.1, and 38.1 mm, respectively.

** Means with the same letter within the same column are not significantly different, T TEST (LSD) procedure, alpha = 0.05.

A-15 Determine the effect of dull mower blade on evapotranspiration rate and several leaf and canopy morphological characteristics of St. Augustinegrass and bermudagrass. Initiated in 1988. R. Green, C. Atkins, and M. Hall.

Status - This project currently is being planned and will be initiated within the next month. It will involve two grass species, Raleigh St. Augustinegrass and Tifway bermudagrass, established in minilysimeters and subjected to two treatments: sharp mower blade and dull mower blade. Measurements will be made periodically on ET rate, vertical leaf extension rate, and leaf and canopy characteristics. ET rate measurements will be made in the environmental simulation chamber. (Mechanistic Study)

B. OBJECTIVES FOR ENHANCED ROOTING/WATER ABSORPTION: RESEARCH STATUS AND RESULTS

Development of an enhanced rooting capability will allow the turfgrass plant to absorb moisture from a greater portion of the soil profile. The relationship of rooting to the rate of moisture withdrawal must be quantified. Delineation of the rooting dimensions will contribute to both a reduced water use rate and to the avoidance dimension of drought resistance. Thus, these rooting investigations interface closely with two of the other concurrent research objectives, A and C.

B-3 Investigate the relationships of rooting to evapotranspiration rate under water stress conditions. S. Sifers.

Status - This investigation is "on hold" due to a lack of a functional rhizotron facility. Specific funds have not been identified for the construction of a rhizotron/lysimeter/rainout shelter facility. The actual site development work has been completed. (Mechanistic Study)

B-4 Conduct exploratory studies of turfgrass root enhancing agents. Initiated in 1984. S. Sifers.

Status - The first study for 1988 was not completed due to death of the Penncross bentgrass turf plugs at 65°F (18°C) during chamber acclimation. A repeat study is underway and was very successful through the heat stress phase. This study is using 30 cm long mini-root columns with a clear plastic viewing strip to allow detailed observation of the root system. Use of these columns will allow us to conduct non-destructive testing. Turfs were subjected to temperatures of 65°F (18°C), 75°F (24°C), 85°F (30°C), and 95°F (35°C) during the heat stress phase. The chamber temperature has been lowered to 65°F (18°C) to determine what shoot/root regrowth will occur. (Mechanistic and Cultural Studies)

Results - There was complete shoot die back on all turf at the highest temperature with shoot color similar to Royal Horticulture Society group 163-D.

Root system responses varied with treatment. Those turfs treated with iron, or a seaweed extract have no roots remaining on the viewing strip, and no shoot regrowth has occurred after five weeks of the recovery phase. Roots in the untreated turfs are tan and have died back to within 90 mm of the crowns. No shoot or root regrowth has occurred to date. Roots of turfs treated with B_1, sucrose, a mixture of these, or oxamide remained white or tan throughout the heat stress. Shoot regrowth was noted during the first week of 65°F for B_1 treatments, during week two for sucrose and oxamide treatments, and during week three for the mixture. No noticeable root die back has occurred in these treatments to date. New white roots from the crown area were observed during week two of the recovery phase for the mixture, week three for B_1, week five for sucrose and the untreated turfs.

This experiment is continuing. Preliminary data would indicate that the iron and the seaweed extract did not enhance bentgrass root survival at high sustained temperatures, but that B_1, sucrose, a mixture of these, and oxamide did

show promise as root enhancing agents.

Shoot die back at the high temperatures without accompanying root die back may be attributed to the high light intensity and lower humidity conditions of the chamber, but this phenomena needs further investigation before a conclusion can be made.

B-5 Determine the cause of spring root decline (SRD) of warm-season turfgrasses as well as methods to minimize its potentially negative effects (see B-16 for carbohydrate analysis and B-18 for the use of PGR's in preventing SRD). Initiated in 1984, with the biochemical studies initiated in 1986. S. Sifers, R. Green, B. Richie, F. Gonzalez, and G. Forrester.

Status - Initial experimentation was involved in the development of a technique for incorporating radioactive $^{14}CO_2$ into warm-season turfgrasses grown in PVC root columns, harvesting plants by leaf, verdure, and root sections, and assaying for radioactivity by the scintillation method.

Following a successful first phase, the second phase of experiments involved two independent, replicated studies for determining the fate of radioactive carbon, assumed to be incorporated into carbohydrate, in St. Augustinegrass turfs labeled prior to shoot dormancy and then induced into greenup under either SRD or non-SRD conditions. Plants were harvested in four sections (leaf, crown, upper 10 cm roots and lower roots) at dormancy, maximum root decline, early root regeneration and late root regeneration. If movement of carbohydrate is involved with SRD, then movement of the radioactive labeled carbohydrate in SRD and non-SRD treatments should differ. See results section for data concerning the second phase of experimentation.

The third phase of experiments involves two studies for determining the fate of radioactive carbon in St. Augustinegrass and bermudagrass labeled prior to shoot dormancy and then induced into greenup under either SRD or non SRD conditions; plants were harvested during dormancy, early root decline, maximum root decline, early root regeneration and late root regeneration. In these experiments the amount of radioactive carbon will be determined in three carbohydrate components (sugars, starch, and structural carbohydrate) in five tissue structures (leaf, bud, stem, upper 10 cm roots, and lower 10 cm roots). Both experiments are completed and the tissue prepared for carbohydrate analysis. We have had to spend time refining the methodology for carbohydrate analysis (see B-16) which is now complete. Tissue analysis will begin shortly. We also have initiated experiments to investigate the effect of N levels during SRD (see B-17) and if PGR's or hormones can alter C-partitioning and prevent SRD (see B-18). (Mechanistic Study)

Results - Results of the second phase of experimentation are as follows (Tables B-5.1 and B-5.2).

1. Predormancy - Late Root Regeneration
   a. Total label in crown tissue was highest at dormancy with a significant decline at MRD and a significant rise at LRR. There was also a significant decline in label concentration and total crown weight during MRD with a significant rise of the latter at ERR.
   b. Decline in total label of crown at MRD is associated with a non-significant rise of total label of leaf, though there was a significant decline in label concentration of leaf at MRD. A rise in total label in crown tissue at LRR was associated with a non-significant decline in total label in leaf. The decline in total label of leaf at LRR was associated with a significant decline in total weight.
   c. At MRD, there was a significant decline of total label and concentration of lower root sections which continued through LRR.
   d. There was a non-significant decline in total label of upper root sections from dormancy through ERR.
   e. Plants were not fully established at dormancy initiation; data are included as a reference point. Four, preferably five replications are needed for this type of work.

2. SRD vs non-SRD
   a. At MRD, SRD plants had significantly less crown weight, and less total label ($PR > F = 0.1018$) than non-SRD plants. SRD plants also had significantly less label concentration in the lower root sections and also less total label ($PR > F = 0.0539$) than non-SRD plants.
   b. At LRR, SRD and non-SRD plants are similar in terms of label and weight of plant section. Exception was that leaf weight of SRD plants was greater than non-SRD plants ($PR > F = 0.0547$).

Conclusions

1. The ^{14}C labeling procedure was successful for monitoring the translocation of carbohydrate.

2. Translocation of carbohydrate is associated with root decline during spring greenup.

3. Cultural practices that impact negatively on leaf area during SRD could result in death of plant, as most carbohydrate is located in leaf area during greenup.

4. Further studies are currently being conducted to determine the amounts of sugar, starch, and structural carbohydrate along with the fate of label in leaf, stem, bud, and root sections in St. Augustinegrass and bermudagrass. Further studies also are being conducted to determine the effect of N fertilization on SRD (B-17) and if PGR's can be used to alter C-partitioning and prevent SRD (B-18).

Table B-5.1. Summary of label movement and plant section weight.

PLANT SECTION	DPM/MG X 1000		TOTAL DPM X 1000		WEIGHT G		DPM/MG X 1000	TOTAL DPM X 1000	WEIGHT G
				DORMANCY INITIATION					
LEAF	14.040 a*		9,431 a		0.671 c				
CROWN	2.880 b		1,787 c		0.622 c				
U. ROOT	0.989 ab		912 a		0.939 a				
L. ROOT	0.522 b		428 ab		0.827 ab				
				DORMANCY					
LEAF	16.583 a		12,981 a		0.781 c				
CROWN	4.693 a		28,473 a		6.080 a				
U. ROOT	0.989 ab		1,381 a		1.442 a				
L. ROOT	1.356 a		599 a		0.445 b				
				MAXIMUM ROOT DECLINE (MRD)					
				SRD				NON-SRD	
LEAF	2.731 b	I**	24,784 a	I	8.453 ab	I	3.461 I	28,034 I	8.275 I
CROWN	0.726 c	I	865 c	I	1.225 bc	II	0.796 I	2,584 I	3.433 I
U. ROOT	0.287 b	I	1,058 a	I	3.360 a	I	0.790 I	1,024 I	1.539 I
L. ROOT	0.266 b	II	171 c	I	0.600 ab	I	0.546 I	373 I	0.692 I
				EARLY ROOT REGENERATION (ERR)					
				SRD					
LEAF	2.915 b		30,819 a		10.750 a				
CROWN	0.398 c		972 c		2.600 b				
U. ROOT	1.520 a		507 a		0.349 a				
L. ROOT	0.273 b		127 c		0.470 b				
				LATE ROOT REGENERATION (LRR)					
				SRD				NON-SRD	
LEAF	2.007 b	I	12,036 a	I	6.006 b	I	5.148 II	16,390 I	3.276 I
CROWN	1.724 bc	I	8,143 b	I	4.750 a	I	1.746 I	9,170 I	5.197 I
U. ROOT	0.380 b	I	715 a	I	1.880 a	I	0.491 I	1,258 I	2.827 I
L. ROOT	0.182 b	I	247 bc	I	1.441 a	I	0.187 I	210 I	1.367 I

* Means in the same column in the same plant section followed by the same letter are not significantly different, Duncan's multiple range test, $\alpha = 0.05$.

**Means in the same row in the same measurement followed by the same roman numeral are not significantly different, Duncan's multiple range test, $\alpha = 0.05$.

Table B-5.2. Summary of plant response under two different greenup temperatures.

Nov. 14	Turfs labeled	
Nov. 25	Initiation of shoot dormancy at 5°C	
Jan. 5 (Figure)	Shoot dormancy	
Jan. 22 (Day 1)	Shoot greenup initiated at either 35°C (SRD) or 24°C (non SRD)	
Days following initiation of greenup	SRD (greenup at 35°C)	non SRD (greenup at 24°C)
Day 11 Initial Root Decline	Approximately 34% greenup Approximately 11% root decline Roots mostly tan, no white roots	Approximately 30% greenup No root declined Roots not as tan as SRD, some white roots
Day 15 Maximum Root Decline	Approximately 40% greenup Approximately 65% root decline Roots mostly tan, no white roots, No new adventitious roots, or just initiated	No root decline Roots not as tan as SRD, some white roots and new adventitious roots
Day 23 Early Root Regeneration	Approximately 63% greenup Approximately 96% root decline New roots initiated only from crown	Approximately 61% greenup No root decline Root regrowth from crown and root tips
Day 36 Late Root Regeneration	Approximately 95% greenup Almost complete root decline New roots initiated from crown, very few from root tips	Approximately 85% greenup No root decline Root regrowth from crown and root tips

B-6 Assess the interspecific rooting potentials of twelve major cool-season turfgrasses under non-limiting moisture conditions. Initiated in 1985. S. Sifers.

Status - The repeat study during the winter of 1987-88 scheduled for the root-column/facility failed prior to harvest. It may not be possible to successfully complete this study with available facilities. However, one more attempt will be made in winter of 1988-89. (Interspecies Comparisons)

B-7 Assess the interspecific rooting potentials of twelve major cool-season turfgrass species under heat stress and non-limiting moisture conditions. Initiated in 1984. S. Sifers.

Status - See B-6.

B-10 Assess the intraspecific rooting potentials of 24 bermudagrass cultivars under non-limiting moisture conditions. Initiated in 1986. S. Sifers.

Status - One harvest has been completed and is being analyzed. The second set of this study has been growing for 90 days. Progress is satisfactory and this study should be completed this year. (Intraspecies Comparison)

B-11 Assess the intraspecific rooting potentials of 11 zoysiagrass cultivars under non-limiting moisture conditions. To be initiated in 1987. S. Sifers.

Status - A root-column facility has been constructed. The 11 zoysiagrass cultivars will be planted as space becomes available in the root-column facility. (Intraspecies Comparisons)

B-12 Assess the intraspecific rooting potentials of 10 St. Augustinegrass cultivars under non-limiting moisture conditions. To be initiated in 1987. S. Sifers.

Status - A root-column facility has been constructed. The St. Augustinegrasses will be planted as space becomes available in the root-column facility. (Intraspecies Comparisons)

B-13 Assess root hair location, density, size, and viability among 13 cool-season turfgrasses under non-limiting moisture conditions. Initiated in 1987. R. Green.

Status - Root Hair Study I was initiated February, 1987 and harvested in June, 1987. The intact root systems have been fixed and are being stored in jars containing ethanol under refrigeration. Analysis will be initiated when labor and time are available. (Mechanistic Study)

B-15 Determine the root hair viability among the major warm-season and cool-season turfgrasses. Initiated in 1987. R. Green and M. Oprisko.

Status - Our first objective, to find a stain for determining root hair viability, has been confirmed with a second independent study. Other confirmation studies continue. (Mechanistic Study)

Results - Evan's blue was confirmed as the best stain for warm-season turfgrasses (Tables B-15.1 - B-15.3). Remaining work concerning the use of Evan's blue includes: 1) confirming its vital staining ability against viability determined by a 20 M sucrose drench and nuclear stains, 2) in terms of vital staining, verification of storage of roots in phosphate buffer vs fresh root tissue, and 3) confirmation of root hair viability of the major warm-season and cool-season turfgrasses (pp. 24 and 28, USGA progress report, Oct. 31, 1987). A new series of experiments are being developed to investigate the effects of drought on root hair populations and viability (see B-19).

Conclusion - A successful technique for determining root hair viability via Evan's blue has been confirmed.

Table B-15.1. Characteristic staining patterns of 12 warm-season perennial grass genotypes, in which viability is recorded as a value from 1 to 4, where 1 is no difference and 4 is an extreme difference in color.

Species/Cultivar	Stains				
	Evan's blue	Phenosafranin	Neutral red	Congo red	Methylene blue
Bahiagrass:					
Argentine	3.36 a[a]	1.00 c	2.21 b	2.63 a,b	1.00 c
Pensacola	1.87 a	1.32 a	0.36 a	1.03 a	1.60 a
Bermudagrass:					
FB119	2.50 a	1.66 b,c	1.10 c	1.76 b	1.82 b
Texturf 10	3.50 a	2.66 b	1.46 c	2.22 b	2.34 b
Tifdwarf	3.14 a	1.10 b	1.76 a,b	2.24 a,b	0.72 b
Tifgreen	4.00 a	-2.66[b]c	1.31 b	1.31 b	-2.45 c
Tifway	3.57 a	1.27 b	1.16 b	0.13 b	-2.64 c
Centipedegrass:					
Ga. Common	3.74 a	2.21 b	1.33 c	2.50 b	2.14 b
St. Augustinegrass:					
Tx. Common	3.88 a	2.02 c	1.00 d	2.70 b	2.74 b
Seashore Paspalum:					
Adalayd	3.21 a	2.83 a	3.07 a	2.71 a	-3.48 b
Zoysiagrass:					
Emerald	3.46 a	1.19 b	1.37 b	1.09 b	1.16 b
Meyer	3.70 a	1.00 b	1.13 b	1.14 b	1.11 b

[a] Means followed by the same letter, within the same row are not significantly different, Duncan's Multiple Range Test ($\alpha = 0.05$).

[b] Negative sign indicates a reversal of staining color between live and dead root sections.

Table B-15.2. Determination of minimal sample size for characterizing root hair viability of 12 warm-season perennial grasses using five different vital stains.

Species/Cultivar	Stains														
	Evan's blue			Phenosafranin			Neutral red			Congo red			Methylene blue		
	ℓ	r	p[a]	ℓ	r	p	ℓ	r	p	ℓ	r	p	ℓ	r	p
Bahiagrass:															
Argentine	4.1[b]	0.9	5.0	0[c]	0	0	5.9	8.0	10.7	6.5	8.5	2.2	0	0	0
Pensacola	7.2	7.1	7.0	3.2	1.2	2.7	2.2	1.4	32.4	0.5	0.06	0.04	0.2	0.9	22.1
Bermudagrass:															
FB 119	6.3	15.4	3.9	6.9	3.2	2.2	1.3	1.0	0.3	7.2	2.3	4.0	9.0	6.1	1.7
Texturf 10	3.3	3.7	2.5	9.3	5.1	3.9	3.3	2.1	2.8	6.0	8.3	1.5	6.2	5.4	7.9
Tifdwarf	7.0	0.9	11.7	2.2	1.6	0.6	6.3	1.9	11.5	8.0	8.6	5.7	5.2	0.7	65.9
Tifgreen	0	0	0	7.5	5.1	3.7	3.2	6.7	1.2	3.4	2.0	0.9	9.2	13.1	11.4
Tifway	2.3	1.4	2.7	2.6	1.6	1.9	2.0	0.7	0.4	6.3	2.8	45.6	6.5	3.4	15.0
Centipedegrass:															
Ga. Common	2.7	3.6	0.4	7.7	5.5	2.3	4.0	3.0	2.8	8.3	7.7	2.6	8.6	5.6	6.9
St. Augustinegrass:															
Tx. Common	1.5	0.5	0.4	10.1	3.6	5.2	0	0	0	8.4	4.9	1.5	3.6	7.2	4.1
Seashore Paspalum:															
Adalayd	7.2	1.2	0.1	8.6	3.8	6.3	6.8	1.5	1.6	6.5	2.7	7.3	6.7	1.3	0.4
Zoysiagrass:															
Emerald	4.0	3.1	0.04	2.6	1.0	2.2	4.2	1.5	1.2	1.5	0.8	0.4	1.9	1.6	1.6
Meyer	3.5	2.0	0.2	0	0	0	1.6	1.1	0.5	0.4	3.7	1.2	2.4	0.4	0.7
Overall Mean	4.1	3.3	2.8	5.1	2.6	2.6	3.4	2.4	5.5	5.3	4.4	6.1	5.0	3.8	11.5

[a] ℓ = looks; r = roots; p = plants.

[b] Minimum sample sizes were determined from the equation, $n = (z_{\alpha/2})^2\sigma^2 / E^2$, where n = minimum sample size, $z_{\alpha/2} = 1.96$ at the $\alpha = .05$ level, σ^2 = the variance of real data, and E = one half the acceptable confidence interval. In this case all differential staining data were recorded as one of the following integer values, 1, 2, 3, or 4. Since the data must be recorded as one integer or another, the confidence interval is 1 and E = 0.5.

[c] Zero sample sizes occur when all the differential staining data for all the roots of all the plants for that genotype-stain combination were the same.

Table B-15.3. Indicator colors and mode of action of five vital stains assessed in this study.

Stain Name	Indicator Colors		Mode of Action
	live	dead	
Evan's Blue	colorless or golden	blue	The molecule is too large to pass through pores of a living cell's wall, so it stains by accumulation in dead cells; areas with large pores or slime can also trap it.
Neutral Red	red	pink	It stains living cell walls and interiors by electroadsorption.
Phenosafranin	red[a]	pink	It stains live cell walls (and possibly cell interiors) by electroadsorption.
Congo Red	red	brown	Stain molecules are directly deposited inside the submicroscopic pore system of the cell walls.
Methylene Blue	blue	colorless	It stains living cell walls (and 12 possibly cell interiors) by electroadsorption.

[a]Indicator colors for phenosafranin are the reverse of those previously reported by Widholm.

B-16 Carbohydrate analysis of warm-season turfgrasses from the actively growing phase through shoot dormancy to shoot greenup phase. Initiated 1987. R. Green, B. Richie, F. Gonzalez, and G. Forrester.

Status - The initial objective was to develop methodology for determination of three carbohydrate components: sugars (glucose + fructose + sucrose), starch, and structural carbohydrate. This objective is now completed; we are ready to initiate the carbohydrate analysis required for the experimentation of B-5, B-17, and possibly B-18.

Results - Three extraction procedures and several assays have been tested. Extraction procedures included amyloglucosidase/amylase enzyme extraction for total nonstructural carbohydrate (TNC), water extraction for sugars followed by enzyme extraction for starch, and ethanol extraction for sugars followed by enzyme extraction for starch. Following rather extensive testing we have chosen the latter extraction.

We have tested five assays for sugar analysis; they included HPLC (high performance liquid chromatography), Boehringer Mannheim enzymatic assay, phenol-sulfuric acid colorimetric assay, chromatropic acid colorimetric assay, and anthrone colorimetric assay. The first two assays were considered standards since neither are feasible for our project. Phenol-sulfuric acid assay proved to be a consistent assay with values closest to the standard assays. It's values are approximately 15-20% higher than those from the HPLC or Boehringer Mannheim enzymatic assay when sugars are determined following extraction in ethanol. Apparently, phenol-sulfuric is reading some other compounds as hexose, such as phenols or pectins. The problem is during the extraction, not the assay itself because with glucose standards the assay is very accurate and consistent. Since we are more concerned with relative differences between treatments and tissues than absolute sugar values we will not pursue more improvements in methodology.

We are ready to initiate the second phase of this project which is analysis of tissues from experimentation of B-5, B-17 and possibly B-18.

Conclusions - A reliable, consistent method for the determination of sugars (glucose + fructose + sucrose), starch, and structural carbohydrate (residual) has been developed and successfully tested on warm-season perennial grasses.

B-17 Determine the effect of N and temperature on seasonal carbohydrate levels in St. Augustinegrass. Initiated in 1988. G. Forrester.

Status - The initial objective of this study was to determine the partitioning of total nonstructural carbohydrates during a complete season of growth, from actively growing state through dormancy and back to an actively growing state, under three different levels of N fertilization and two differing temperature regimes.

Planting of St. Augustinegrass was accomplished in March of 1988. The growth assembly was the same as used in experimentation in B-5. During the time needed for turfgrasses to mature in columns, extraction and assay procedures were perfected (see B-16).

Presently, N treatments, applied as a modified Hoagland solution, have been initiated with the turfgrasses becoming adjusted to the treatment. The next phase includes labeling and movement of plant material into growth chambers for temperature treatment followed by harvests at various times from predormancy through greenup and resumption of optimal growth.

Along with controlled environmental growth studies, plugs have been harvested monthly from the Texas A&M University turfgrass Field Lab and are being analyzed for sugars and starches in 5 separate plant parts (root, stem, bud, leaf and remaining tissue). At this time there has been eight harvests from March through October with two harvests already analyzed.

B-18 Determine if the carbon movement associated with spring root decline (SRD) can be altered by applications of plant growth regulators and hormones. Initiated in 1988. R. Green, G. Forrester, F. Gonzalez, and B. Richie.

Status - Recently obtained data from study B-5 indicate that during maximum spring root decline more radioactive labeled C (carbohydrate) has left the verdure and root sections in SRD St. Augustinegrass plants than non-SRD St. Augustinegrass plants. If drastic movements of carbohydrate out of root and verdure sections during fast greenup can be slowed, then it may be possible to prevent SRD. Some plant growth regulators have been shown to alter radioactive labeled C movement, with subsequent higher levels in the root system. The first phase of this experiment involves surveying several PGR's and hormones for their ability to redirect radioactive C movement with subsequent higher levels in root and verdure sections. The second phase of this project involves the testing of the selected PGR for its ability to prevent SRD, confirmed visually and by radioactive C movement. The turfgrass species chosen for this project is St. Augustinegrass. (Mechanistic Study)

B-19 Determine the effect of moisture stress on root hair density and viability in warm-season turfgrasses. To be initiated in 1989. R. Green and M. Oprisko.

Status - This study is in the planning phase. It will involve growing warm-season turfgrasses in Dee pots containing sand under greenhouse conditions. Progressive drought will be induced with a subsequent return to nonlimiting moisture conditions. Periodically, plants will be harvested and characterized for root hair population and viability (Mechanistic Study)

C. OBJECTIVES FOR IMPROVED DROUGHT RESISTANCE: RESEARCH STATUS AND RESULTS

Following the onset of soil drought, a grass plant exhibits leaf rolling, firing of the outer lower leaves, eventually a cessation of growth, and finally total browning of the aboveground shoot tissues. At this point, it is defined as being in a state of dormancy. Once rainfall occurs, most perennial turfgrasses have varying degrees of ability to reinitiate new shoot growth, depending on the particular species and duration of drought stress. **Drought resistance** is broadly defined as the ability of a plant to survive an extended soil drought. Note that a turfgrass that has a low water use rate is not necessarily drought resistant. These are two entirely different physiological parameters.

An important component of drought resistance is termed **drought avoidance**. It encompasses such characteristics as a reduced evapotranspiration rate and deeper rooting which, respectively, slows the rate of water loss from the shoots and increases the ability to absorb moisture from a greater portion of the soil profile. As a result, the point at which a plant enters dormancy is delayed and, therefore, the potential period of time when a plant is subjected to severe moisture stress during dormancy is shortened. Thus, it can be seen that Objective A, concerning Minimal Water Use Rates, and Objective B, concerning Enhanced Rooting/Water Absorption, will provide information concerning two key dimensions of drought avoidance.

C-2 Characterize the morphological, anatomical, and physiological plant parameters associated with drought avoidance among 11 major warm-season turfgrass species. Initiated in 1984. K. Kim and S. Sifers.

Status - A two-year field study of the comparative drought avoidance among 11 warm-season grasses was completed on a newly constructed modified sand root zone. In 1985, a greenhouse study was completed to determine the contribution of rooting to drought avoidance. Subsequently a controlled environmental growth chamber study and a field study were conducted to determine if there were any stomatal associations with the drought avoidance mechanism of each grass. A polyethylene glycol (PEG) study was conducted in the greenhouse to insure a uniform root medium water potential, by eliminating the rooting contribution. This approach could indicate the relative importance of the rooting and the stomatal contributions of each grass. The data were analyzed and summarized in a Doctoral Thesis which was mailed to each USGA Research Committee member and to the USGA Library in Far Hills, New Jersey.

Another PEG study will be conducted in the greenhouse to assess the performance of each grass under 100% RH and a controlled PEG solution, starting in the winter of 1988-89. (Species Comparison and Mechanistic Study)

C-4 Assess the relationship between rooting characteristics and drought resistance of twelve major warm-season perennial turfgrasses. Initiated in 1984. S. Sifers and K. Kim.

Status - The initial study under non-limiting soil moisture conditions was completed during the winter of 1985 in the greenhouse and the data were

analyzed in relation to drought avoidance. A Doctoral Thesis covering this data was mailed to each USGA Research Committee member.

The rooting potential of the same grasses when under water stress will be investigated in PVC root columns which are being established in the greenhouse. Water stress will be imposed during the winter of 1987 and again in 1988-89 winter. The study is being repeated due to problems encountered during the first experiment. (Mechanistic Study)

C-7 Assess the relationship between rooting characteristics and drought resistance of 12 major cool-season turfgrasses. S. Sifers and K. Kim.

Status - Study on hold. (Mechanistic Study)

C-8 Assessment of drought tolerance studies using PEG techniques on bermudagrass and St. Augustinegrass. R. Green and M. Oprisko.

Status - In the planning stages. (Mechanistic Study)

C-9 Drought avoidance studies involving assessments of the rate of stomatal closure and wax formation using scanning electron microscope techniques on bermudagrass and St. Augustinegrass. R. Green and M. Oprisko.

Status - In the planning stages. (Mechanistic Study)

D. OBJECTIVES FOR MECHANISTIC BASIS OF MINIMAL MAINTENANCE TURFGRASS: RESEARCH STATUS AND RESULTS

A basic premise of this overall research project thrust is that those turfgrasses which have greater water conservation characteristics also will possess characteristics contributing to turfgrasses that, from an overall standpoint, can be described as minimal maintenance types. Minimal maintenance implies the least possible resource requirements in terms of water and nutrients, plus low maintenance inputs such as labor, energy, and pesticides. One of the first priorities in investigations concerning minimal maintenance turfgrasses is to determine the morphological, anatomical, and physiological factors associated with a species possessing minimal maintenance traits. These traits can then be utilized by turfgrass breeders to provide a more sound basis for selecting minimal maintenance turfgrasses.

D-2 Assess the morphological, anatomical, and physiological plant characteristics associated with adaptation to low nitrogen requirements and their relationship to the drought resistance and recuperative potential of bermudagrasses. Initiated in the spring of 1986. S. Sifers.

Status - A preliminary field study has been completed in conjunction with objective C-5. Leaf extension rate, internode length, root mass relative to shoot mass, and visual quality were the parameters being measured and observed. The preliminary study was combined with objective C-5 which was beneficial. However, a separate study will now be required to allow plant nitrogen depletion and stress to occur before the drought and recuperation events.

A more detailed study is planned for 1989 as greenhouse space becomes available. Turfs of Tifway, Santa Ana, Texturf 10, A-22, Midway, and Centennial bermudagrass have been planted in 30 cm plastic pots and will be moved to the greenhouse before cold weather. This selection of genotypes was based on field drought data accumulated over the last four years. Two cultivars were selected from each of the relative classifications of high, medium, and low for leaf firing and shoot recovery listed in our last Progress Report. (Mechanistic Study)

D-3 Investigate the morphological, anatomical, and physiological plant parameters associated with minimal maintenance characteristics of zoysiagrass cultivars. Initiated in 1986. S. Sifers.

Status - A greenhouse study is underway.

Root observation columns have been planted with Meyer, Emerald, and El Toro zoysiagrasses in the greenhouse. These cultivars were selected because they possess leaf width differentials from narrow to broad plus a variety of rooting characteristics. A field study was initiated in 1988 to verify the observations. This study is a duplication of objective D-1, except the target species is zoysiagrass rather than bermudagrass. (Intraspecies Comparison and Mechanistic Study)

D-4 Investigate mechanisms associated with the adaptation of bermudagrass and zoysiagrass cultivars to regimes of low nitrogen availability that permit cultivars to adapt to a minimum maintenance environment. Initiated in 1986. P. Vermeulen and S. Sifers.

Status - This study has been placed on hold due to higher priority studies and lack of available manpower. (Mechanistic Study)

D-5 Investigate the nitrogen economy of 10 warm-season turfgrasses by ^{15}N-isotope and N-balance methodology. Initiated in 1986. R. Green.

Status - The first phase of experimentation is completed. A greenhouse study was initiated in September of 1986 by planting 7.6-cm plugs of each turfgrass in plastic pots containing fritted clay. Plants were fertilized with a complete nutrient solution at a rate of 0.25 lb N (1% ^{15}N) per 1000 sq ft per month. Following detailed anatomical measurements of leaf, stem, and root growth, the study was harvested in June of 1987. All plant, soil, and fertilizer nitrogen quantitative inputs and final amounts were determined. All fertilizer nitrogen in the various plant parts and in the soil were determined to calculate the fertilizer uptake efficiency and loss. The quantities of organic and extractable soil N were determined. (Mechanistic Study)

Results (Tables D-5.1 - D-5.9)

1. Soil N was basically unchanged for the duration of the study, 0.0056 percent Total N, and less than 0.18 percent of Total N was extractable NO_3-N.

2. There were differences among the warm-season turfgrasses for partitioning of plant N in leaf, crown, and root tissue, particularly in the first two tissues.

3. There was almost three times as much plant weight per mg N for crown and root tissue than for leaf tissue.

4. Recovery of fertilizer N did not vary among the warm-season turfgrasses and was about 70 percent. However, partitioning of fertilizer N did vary among the grasses and basically followed the same partitioning pattern as plant N.

5. Partitioning of N in leaf, crown, and root tissue is associated with dramatic differences in leaf, crown and root morphological characteristics.

6. The plant-soil systems of the warm-season turfgrasses recovered about 80 percent of all N input.

Conclusion - How a warm-season turfgrass partitions absorbed N is strongly related to plant characteristics that develop acceptable turfgrass quality. In turf, the above may be of more critical interest than the ability to absorb N from fertilizer, soil, or biological N fixation. Work will continue to determine the effects of multiple levels of N fertilization on N economy, total tissue carbon content, leaf and shoot morphology and root length and morphology.

Table D-5.1 Plant and soil nitrogen (N) distribution for each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	Plant N	Leaf N	Crown N	Root N	Soil[1] N
	----------mg----------				
Emerald Zoysiagrass	398 a*	149 c	176 a	71 a	222 a
Meyer Zoysiagrass	371 ab	191 b	138 b	44 c	193 b
Pensacola Bahiagrass	358 abc	216 a	80 de	58 abc	228 a
Tx. Common St. Augustine-grass	355 bc	186 b	104 cd	65 ab	222 a
Argentine Bahiagrass	337 bcd	218 a	74 e	45 c	199 b
Adalayd Seashore paspalum	316 cd	143 c	109 c	56 abc	202 b
Ga. Common Centipede-grass	309 d	159 c	97 cde	53 bc	210 ab

[1] Starting soil N was 217 mg. Also, for all soils, extractable NO_3-N was less than 0.18 percent of total N.

* Means followed by the same letter within the same column are not sign. different, Duncan's Mult. Range Test, $\alpha = 0.05$.

Table D-5.2. Partitioning of plant nitrogen (N) by plant section for each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	Leaf N / Plant N	Crown N / Plant N	Root N / Plant N
Argentine Bahiagrass	0.65 a*	0.22 e	0.13 bc
Pensacola Bahiagrass	0.61 a	0.24 e	0.16 abc
Tx. Common St. Augustinegrass	0.52 b	0.29 d	0.18 a
Ga. Common Centipedegrass	0.51 b	0.31 cd	0.17 ab
Meyer Zoysiagrass	0.50 b	0.37 b	0.12 c
Adalayd Seashore Paspalum	0.46 b	0.36 bc	0.19 a
Emerald Zoysiagrass	0.34 c	0.44 a	0.19 a

* Means followed by the same letter within the same column are not sign. different, Duncan's Mult. Range Test, $\alpha = 0.05$.

Table D-5.3. Plant weight and N relationships within each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	Plant N	Plant Weight	Leaf Wt[1] Leaf N	Crown Wt Crown N	Root Wt Root N
	--------mg--------				
Emerald Zoysiagrass	398 a*	58962 a	70 a	195 bc	212 a
Meyer Zoysiagrass	371 ab	43790 b	59 bc	177 c	188 abc
Pensacola Bahiagrass	358 abc	41500 bc	56 c	223 a	206 ab
Tx. Com. St. Augustinegrass	355 bc	39967 bc	72 a	175 c	128 d
Argentine Bahiagrass	337 bcd	36241 c	59 bc	190 bc	207 ab
Adalayd Seashore paspalum	316 cd	38285 bc	56 c	176 c	171 c
Ga. Com. Centipedegrass	309 d	39715 bc	65 ab	205 ab	180 bc

[1] (mg/mg).
* Means followed by the same letter within the same column are not sign. different, Duncan's Mult. Range Test, $\alpha = 0.05$.

Table D-5.4. Selected leaf characteristics for each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	Leaf N	Leaf Weight	Leaf Length	Leaf Width
		--mg--	---------mm--------	
Pensacola Bahiagrass	High Leaf	12006 abc*	112 a	3.0 bcd
Argentine Bahiagrass	N	12783 ab	102 a	3.7 b
Meyer Zoysiagrass	Med. Leaf	11237 bc	42 b	2.6 cd
Tx. Com. St. Augustinegrass	N	13327 a	28 c	6.0 a
Emerald Zoysiagrass	Low Leaf	10442 c	35 bc	1.7 e
Adalayd Seashore paspalum	N	7961 d	36 bc	2.2 de
Ga. Com. Centipedegrass		10335 c	36 bc	3.5 bc

* Means followed by the same letter within the same column are not sign. different, Duncan's Mult. Range Test, $\alpha = 0.05$.

Table D-5.5. Several crown characteristics for each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	Crown N	Crown Weight	Total Coverage[1]	Shoot Density[2]	Total Length of Stem[3]	Third Internode Length
		--mg--	--cm^2--		--cm--	--mm--
Emerald Zoysiagrass	High Crown N	33780 a*	361 a	79 a	34 a	1.8 cd
Meyer Zoysiagrass	M. High Crown N	24414 b	344 a	75 a	22 b	1.7 cd
Adalayd Seashore Paspalum	Med. Crown N	19062 c	309 b	43 b	16 bc	3.3 c
Tx. Com. St. Augustinegrass		18242 cd	342 a	11 c	14 bc	11.5 a
Ga. Com. Centipedegrass		19773 c	337 ab	21 c	9 c	5.7 b
Pensacola Bahiagrass	Low Crown N	17768 cd	258 c	11 c	16 bc	0.6 d
Argentine Bahiagrass		14109 d	262 c	8 c	14 bc	0.5 d

[1] Complete coverage of pot was 366 cm^2.
[2] Number of live shoots in a 5.25 cm diam. plug.
[3] Total length of rhizomes and/or stolons in a 5.25 cm diam. plug.
* Means followed by the same letter within the same columns are not sign. different, Duncan's Mult. Range Test, $\alpha = 0.05$.

Table D-5.6. Several root characteristics for each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	Root N	Root Weight	Number of Adventitious Roots in a 5.25 cm Diam. Plug
		--mg--	
Emerald Zoysiagrass	High Root N	14740 a*	109 ab
Tx. Com. St. Augustinegrass		8399 c	32 e
Pensacola Bahiagrass	Med. Root N	11726 b	105 ab
Adalayd Seashore Paspalum		9674 bc	86 bc
Ga. Com. Centipedegrass		9607 bc	53 de
Meyer Zoysiagrass	Low Root N	7947 c	130 a
Argentine Bahiagrass		9350 c	66 cd

* Means followed by the same letter within the same column are not sign. Different, Duncan's Mult.

Table D-5.7. Summary of dramatic N partitioning events and plant morphological characterizations of each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	N Partitioning	Plant Morphological Characteristic
Argentine Bahiagrass	H Leaf N L Crown N L Root N H Fert N In Leaf L Fert N In Crown	Long leaves Low total coverage Low shoot density Short internode length
Pensacola Bahiagrass	H Leaf N L Crown N H Fert N in Leaf	Long leaves Low total coverage Low shoot density Short internode length High no. advent. roots
Ga. Com. Centipede	None	Low-med shoot density
Adalayd Seashore paspalum	H Root N M-L Fert N in Leaf H-M Fert N in Crown	Low leaf weight Med shoot density
Emerald Zoysiagrass	L Leaf N H Crown N H Root N L Fert N in Leaf H Fert N in Crown	Narrow leaves High shoot density High total length of stem
Meyer Zoysiagrass	L Root N H-M Fert N in Crown L Fert N in Root	High shoot density
Tx. Com. St. Augustinegrass	H Root N	Short leaves Wide leaves Low shoot density Long internode length Low no. advent. roots

H = high; M = medium; L = low.

Table D-5.8. Fertilizer excess 15N recovery and partitioning within each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	Plt 15N Ex[1] Fert 15N Ex	Plt & Soil 15N Ex Fert 15N Ex	Leaf 15N Ex Plt 15N Ex	Crown 15N Ex Plt 15N Ex	Root 15N Ex Plt 15N Ex
Emerald Zoysiagrass	0.74 A*	0.82 A	0.39 D	0.45 A	0.16 A
Argentine Bahiagrass	0.71 A	0.76 AB	0.66 A	0.19 C	0.15 AB
Pensacola Bahiagrass	0.70 A	0.77 AB	0.62 AB	0.23 BC	0.15 AB
Tx. Com. St. Augustinegrass	0.66 A	0.74 AB	0.60 AB	0.24 BC	0.16 A
Meyer Zoysiagrass	0.65 A	0.68 B	0.56 BC	0.34 B	0.10 B
Ga. Com. Centipedegrass	0.63 A	0.70 AB	0.59 AB	0.26 BC	0.15 AB
Adalayd Seashore Paspalum	0.63 A	0.67 B	0.50 C	0.32 B	0.18 A
$\bar{X}$	0.67	$\bar{X}$ 0.73			

[1] A total of 2.413 mg 15N excess in 377.419 mg N was applied to each plant.
* Means followed by the same letter within the same column are not sign. different, Duncan's Mult. Range Test, $\alpha = 0.05$.

Table D-5.9. N balance for each of seven warm-season turfgrasses grown under low N conditions.

Species/ Cultivar	N Balance =	(Final Plt N + Final Soil N) -	(Starting Soil N + Fert N + Starting Plug N)	
	----------mgN----------			
Emerald Zoysiagrass	-113 a*	629 a	739 ab	
Pensacola Bahiagrass	-124 a	588 ab	712 abc	
Tx. Com. St. Augustinegrass	-145 ab	580 ab	725 abc	
Argentine Bahiagrass	-148 ab	536 bc	682 c	
Ga. Com. Centipedegrass	-166 ab	520 c	686 c	
Adalayd Seashore paspalum	-185 ab	515 c	700 bc	
Meyer Zoysiagrass	-204 b	565 bc	747 a	
$\bar{X}$	-155	$\bar{X}$ 562	$\bar{X}$ 713	562/713 = .79

* Means followed by the same letter within the same column are not sign. different, Duncan's Mult. Range Test, $\alpha = 0.05$.

E. OBJECTIVES FOR IMPROVED WATER STRESS HARDINESS: RESEARCH STATUS AND RESULTS

Objective C is devoted to improve drought resistance from the aspect of drought avoidance and those external plant characteristics contributing to a low water use rate, enhanced rooting,and survival through dormant structures during extended periods of water stress. In contrast, Objective E addresses the dimension of **drought tolerance**. This involves those internal plant characteristics that enable certain plant tissues to survive the water stress once the drought avoidance phase is terminated and the plant enters severe internal tissue moisture stress. Such dimensions as osmotic regulation, inherent internal tissue hardiness and plasticity, cellular structure, and certain physiological dimensions, such as proline/ABA synthesis need to be investigated in relation to drought tolerance.

E-2 Investigate the cellular structure of warm-season turfgrass species and associated changes that occur during water stress, and characterize the possible relationship to the drought tolerance mechanism. To be initiated in 1989.

Status - This study was designed to investigate the inter- and/or intracellular structure of warm-season turfgrass species before and after water stress. The initial study was supposed to be conducted during the summer of 1986 in a controlled environmental growth chamber. However, due to the busy schedule at the Electron Microscopy Center located at the Texas A&M University, this could not be conducted. This study is on hold because Dr. Kim's poistion was not filled due to financial limitations. (Mechanistic Study)

IV. ANNUAL STATUS REPORT OF COMPLETED RESEARCH BEING PREPARED FOR PUBLICATION

The major research objectives and associated individual studies that are currently being written and submitted for publication in scientific journals are summarized in this section. A research project is really not fully completed until it has been written and published in both a scientific and a trade journal. The process includes (a) drafting and multiple revisions of a manuscript; (b) internal departmental review by three colleagues; (c) submission to the Texas Agricultural Experiment Station for a final review and assignment of a TAES manuscript number; (d) submission to the USGA Research Committee for review and approval; and (e) submission to the appropriate scientific journal where it is then reviewed by three peers in the field. Then following any revisions suggested by the reviewers, it is published in the scientific journal. Normally, this process requires from 8 to 18 months, depending on the extent of revisions suggested by the reviewers.

Major emphasis will be placed on manuscript preparation during the upcoming winter months. Currently, this research project has in the publication phase the following.

A. Minimal Water Use Rate - 7 publications

B. Enhanced Rooting/Water Absorption - 5 publications

C. Improved Drought Resistance - 4 publications

D. Basis of Minimal Maintenance Turfgrass - 2 publications

E. Improved Water Stress Hardiness - 1 publication

A. MINIMAL WATER USE RATE: RESEARCH COMPLETED AND PUBLICATION STATUS

A-1 Determine the comparative potential evapotranspiration rates of eleven major warm-season turfgrass species under non-limiting moisture conditions. Initiated in 1983. K. Kim.

Status - Research was completed in 1985, entailing two full years of field studies, plus two laboratory studies in the controlled environmental simulation chamber. The evapotranspiration rates of eleven major warm- season turfgrasses were assessed by means of the water balance method using a mini-lysimeter technique. The scientific paper was written, approved by the USGA Green Section, and was published in the 1988 March-April issue of Crop Science: 28(2):328-331. It is entitled "Comparative Turfgrass Evapotranspiration Rates and Associated Plant Morphological Characteristics". (Species Comparisons)

A-2 Assess the relationships of shoot morphology to the potential evapotranspiration rates of eleven major warm-season turfgrasses. Initiated in 1983. K. Kim and S. Sifers.

Status - Research was completed in 1985, entailing two full years of field studies and one extensive controlled environmental simulation chamber study. A scientific paper was written, approved by the USGA Research Committee, and published in Crop Science. It has been combined with the results from Objective A-1 into one paper. (Mechanistic Aspects and Development of Breeding Markers)

A-3 Compare the stomatal characteristics, densities, and distribution among ten major warm-season and twelve major cool-season turfgrasses under controlled environment growth chamber conditions. Initiated in 1983. D. Casnoff and R. Green.

Status - The warm-season turfgrass interspecies study was completed in 1985, and the scientific paper has been written. A final draft will be submitted to HortScience for review and publication. (Species Comparisons and Mechanistic Study)

A-4 Establish the accuracy with which the water-heat stress simulation module reproduces representative evapotranspiration rates typically observed in the field. Initiated in 1983. S. Griggs and K. Kim.

Status - Research was completed in late 1985. The findings were positive with a high correlation. It has been decided that we will not proceed with publication, but rather incorporate these data into another scientific paper. (Research Techniques)

A-5 Determine the comparative potential evapotranspiration rates of twelve major cool-season turfgrasses. Initiated in 1983. S. Griggs and R. Green.

Status - A detailed series of experiments was completed in the water/heat stress environmental simulator in 1986. The draft of a scientific paper has been submitted to the Journal of the American Society for Horticulture Science. (Species Comparisons)

A-6 Determine the potential for using turfgrass leaf growth inhibitors in water conservation. Initiated in 1983. K. Kim and R. Green.

Status - The greenhouse research involving two studies was completed in 1987. The scientific paper has been submitted to HortScience. (Improved Cultural Systems)

A-7 Compare the influences of cutting height and nitrogen rate on the evapotranspiration rates of eleven major warm-season turfgrasses. Initiated in 1983. K. Kim and S. Sifers.

Status - Field studies over two years were completed in 1986. A scientific paper has been written and submitted to the Texas Agricultural Experiment Station for review. (Improved Cultural Systems)

A-8 Determine the comparative genetic variability in potential evapotranspiration rates of 24 bermudagrass cultivars under non-limiting moisture conditions. Initiated in 1984. S. Sifers and K. Kim.

Status - A three-year study was completed in 1987, and the results were processed and analyzed. A scientific paper has been drafted and submitted for departmental review. (Intraspecies Comparisons)

A-9 Assess the validity and relative accuracy of visual estimates of evapotranspiration rates using the canopy resistance - leaf extension concepts on mowed bermudagrass and zoysiagrass cultivars. Initiated in 1984. S. Sifers, G. Horst, and M. Engelke.

Status - A two-year study has been completed for mowed bermudagrass and zoysiagrass cultivars. Visual rankings for 24 bermudagrasses and 11 zoysiagrasses have been statistically compared to actual evapotranspiration rates. All data are now processed, and detailed statistical analyses were conducted by G. Horst. The scientific paper is being prepared with the research from objectives A-9 and A-12 being combined into one paper. (Breeding Markers)

A-12 Assess the validity and relative accuracy of visual estimates of evapotranspiration on unmowed bermudagrass turfs using the high canopy resistance - low leaf area concept as it would be applied in a turfgrass breeding program. Initiated in 1985. S. Sifers, M. Engelke, and G. Horst.

Status - Greenhouse and field studies were completed assessing 24 unmowed bermudagrass cultivars grown in mini-lysimeters in 1987. Three evaluators, Dr.'s Beard, Engelke, and Horst, visually estimated the evapotranspiration rates across three replications of each turf cultivar. These assessments were compared statistically to the actual evapotranspiration rates by G. Horst. A scientific paper is being prepared by the collaborators. (Breeding Markers)

B. ENHANCED ROOTING/WATER ABSORPTION: RESEARCH COMPLETED AND PUBLICATION STATUS

B-1 Characterize the root systems of 11 major warm-season turfgrass species under non-limiting and water stressed conditions. Initiated in 1984. D.Casnoff and S. Griggs.

Status - The research techniques for detailed characterization of grass roots have been developed as described in the 1985 Progress Report. Thus, more specific objectives are being pursued as outlined in Objectives B-8 and B-9. The techniques developed will be described in the paper published under B-2. (Techniques Study)

B-2 Assess the interspecific rooting potentials of 11 major warm-season turfgrasses under non-limiting moisture conditions. Initiated in 1984. D. Casnoff and S. Sifers.

Status - Research was completed in 1985, which included two greenhouse studies using the root-column facility. The scientific paper has been written, approved by the USGA Research Committee, and submitted to Agronomy Journal for publication. It is entitled "Assessment of the Interspecific Rooting Potentials of Eleven Warm-Season Perennial Turfgrasses under Non-limiting Moisture Conditions". (Species Comparison)

B-5 Determine the cause of spring root decline (SRD) of warm-season turfgrasses as well as methods to minimize its potentially negative effects. Initiated in 1984 with the biochemical studies initiated in 1986. S. Sifers and R. Green.

Status - Carbohydrate movement was found to be associated with SRD in St. Augustinegrass. This finding involved two replicated studies to determine the fate of radioactive carbon in St. Augustinegrass leaf, crown, and root tissue labeled prior to shoot dormancy and then induced into greenup under either SRD or non-SRD conditions. A manuscript of this work is in advanced preparation. (Mechanistic Study)

B-8 Assess root hair location, density, size, and viability among 13 warm-season turfgrasses under non-limiting moisture conditions. Initiated in 1985. R. Green and M. Oprisko.

Status - Root hair studies I, II, III, and IV are completed and the data analyzed. A manuscript covering this work will be submitted for Departmental review shortly. (Species Comparison and Mechanistic Study)

B-14 Assess the extent of mycorrhiza development on the roots of four major warm-season turfgrasses and their relationship to evapotranspiration rates. Initiated in 1987. D. Knox.

Status - Assessments made on turfs from the TAMU Turfgrass Field Research Laboratory and from representative turf collected in the College Station, Bryan, Houston, and Dallas areas revealed very extensive mycorrhizal development on all the major warm-season turfgrasses. Inoculation experiments were conducted during the summer of 1987 in the greenhouse investigating the effect of mycorrhizal infection on evapotranspiration rates of the major warm-season turfgrasses. The water balance method, previously described, was used in this experiment which was completed in July. The data showed the presence of mycorrhiza increased the evapotranspiration rate significantly. Dr. Knox has returned to his faculty position in South Africa and we now await the draft of a paper to be published as a TAES Report. (Mechanistic Study)

B-15 Determine the root hair viability among the major warm-season and cool-season turfgrasses. Initiated in 1987. R. Green and M. Oprisko.

Status - A draft of a scientific paper covering the first phase of this project has been written and is in Departmental review.

C. IMPROVED DROUGHT RESISTANCE: RESEARCH COMPLETED AND PUBLICATION STATUS

C-1 Characterize the comparative drought avoidances, drought tolerances, and drought resistances of eleven warm-season turfgrass species. Initiated in 1984. K. Kim.

Status - Two years of field study on a newly constructed modified sand root zone, as well as in the greenhouse and in a controlled environment growth chamber utilizing mini-lysimeters have been completed. The data were analyzed and a Doctoral Thesis has been published. Copies were mailed to each USGA Research Committee member and to the USGA Library at Far Hills, New Jersey. Scientific papers have been prepared and submitted for Departmental review. (Species Comparison)

C-3 Characterize the morphological, anatomical, and physiological plant parameters associated with the drought resistance (i.e., recuperative ability) of eleven major warm-season turfgrass species following subjection to severe drought stress. Initiated in 1984. K. Kim.

Status - Three sets of preliminary studies were completed in both the field and greenhouse in 1984, followed by an extensive field study in 1985 and 1986. Shoot recovery was the primary response used in assessing the attributes related to drought resistance. Since drought resistance is the combination of drought avoidance and drought tolerance, the relative importance of factors contributing to drought resistance was investigated and assessed in relation to the results from drought avoidance study C-2. A more detailed physiological and anatomical investigation was conducted during the fall and winter of 1987. A paper has been drafted and is being submitted for Departmental review. (Mechanistic Study)

C-5 Characterize the comparative drought resistances of the major warm-season turfgrass cultivars including 24 bermudagrasses, 6 zoysiagrasses, 6 centipedegrasses, and 5 St. Augustinegrasses. Initiated in 1985. S. Sifers and K. Kim, and J. Walker.

Status - Three years of field studies on a newly constructed modified sand root zone were completed, and the data were analyzed and summarized. In the third year of the study, new experimental selections were added to the field plot. They included 3 bermudagrasses from New Mexico State University; 3 cool-season turfgrasses (Kentucky 31 tall fescue, Adelphi Kentucky bluegrass, Pennfine perennial ryegrass) from the University of Nebraska; and 3 St. Augustinegrasses, 2 buffalograsses, and 4 zoysiagrasses from the Texas Agricultural Experiment Station at Dallas. A paper is in advanced editing for Departmental review. (Intraspecies Comparisons)

C-6 Characterize the ultrastructure and wax accumulation on the leaf surfaces and over the stomata, when under water stress, that are associated with drought resistance of warm-season turfgrass species. Initiated in 1985. K. Kim.

Status - The initial study with three species was conducted in a controlled environmental growth chamber during the winter of 1985, followed by an extensive study with eleven turfgrasses during the summer of 1986 conducted in the field. Leaf samples were freeze-dried and photographed with a scanning electron microscope to observe the stomatal characteristics and wax accumulation on both sides of the leaf blade. The results were analyzed and interpreted in relation to drought avoidance mechanisms of each turfgrass in a Doctoral Thesis which was mailed to each USGA Research Committee member. The draft of a scientific paper is in advanced editing for Departmental review. (Mechanistic Study)

D. MECHANISTIC BASIS OF MINIMAL MAINTENANCE TURFGRASS: RESEARCH COMPLETED AND PUBLICATION STATUS

D-1 Investigate the morphological, anatomical, and physiological plant parameters associated with minimal maintenance-low nitrogen stress tolerance characteristics of bermudagrass cultivars. Initiated in 1984. S. Sifers.

Status - Both field and greenhouse studies were completed in 1986, including analyses of tissue fractions for nitrogen content. The data analyses are also completed. A Masters Thesis has been published and a copy mailed to each USGA Research Committee member. A draft of a scientific paper is in advanced preparation. (Intraspecies Comparisons and Mechanistic Study)

D-5 Investigate the nitrogen economy of 10 warm-season turfgrasses by ^{15}N-isotope and N-balance methodology. Initiated in 1987. R. Green.

Status - Analysis is completed and a manuscript will be written shortly. (Mechanistic Study)

E. OBJECTIVES FOR IMPROVED WATER STRESS HARDINESS: RESEARCH COMPLETED AND PUBLICATION STATUS

E-1 Characterize the physiological changes occurring in the turfgrass leaf during water stress to determine possible drought tolerance (hardiness) mechanisms of the major warm-season turfgrasses. Initiated in 1985. K. Kim.

Status - An initial study was conducted during the winter of 1985 in a controlled environmental growth chamber with three species, followed by a greenhouse study with eleven turfgrasses. Leaf firing, shoot recovery and tissue proline content were examined. Data were collected, analyzed and interpreted in relation to the drought tolerance level of each grass. A proline investigation also was conducted in the field in the summer of 1986 to confirm the results from the previous studies. A research paper is now in advanced preparation. (Mechanistic Study)

V. BUDGET STATUS

Cost containment has continued to be a high priority during the past 12 months in order to adjust to the reduced budget level. This has been particularly critical since supplemental grants, such as the $10,000 from Chemlawn Service Corporation of the past year, were not available during this budget year. Adjustments have been made in the form of one technical research position not being refilled. Even then, my research staf has shouldered an excessively heavy work load during the past year in order to sustain key ongoing studies. This stressful stiuation cannot be continued. Adjustments will be accomplished by not initiating new studies combined with the completion of some existing studies. A supplemental grant as requested to the Committee in July of 1988 would avoid this reduction in research progress that otherwise will put the project behind schedule.

VI. PUBLICATIONS

The scientific publication activity has been summarized in Section IV. In addition to the technical research papers being drafted, oral reports and published abstracts of research supported by the USGA were presented at the American Society of Agronomy Meetings in December of 1987, in Atlanta, Georgia. They are as follows:

1. "Characterization of Nitrogen Economy Among the Major Warm-Season Turfgrasses Using Nitrogen Balance and ^{15}N Assay Methodology" by R. L. Greeen and J. B. Beard. 1987 Agronomy Abstracts. p. 135.

2. "Drought Resistance of Eleven Major Warm-Season Turfgrasses Under Water Stress Induced by Polyethylene Glycol (PEG)" by K. S. Kim and J. B. Beard. 1987 Agronomy Abstracts. p. 136.

3. "Investigations into Carbohydrate Partitioning of Warm-Season Turfgrasses during Spring Root Decline Using ^{14}C Radioisotope Tracer Methods" by S. I. Sifers, R. L. Green, and J. B. Beard. 1987 Agronomy Abstracts. p. 139.

Two reports of research supported by the USGA are published in the 1988 Agronomy Abstracts, and are scheduled to be presented at the American Society of Agronomy Annual Meetings in December of 1988 in Anaheim, California. They are as follows:

1. The effects of flurprimidol and mefluidide on ET, leaf growth and quality of St. Augustinegrass grown at two soil moisture levels, R. L. Green, K. S. Kim, and J. B. Beard, 1988 Agronomy Abstracts, p. 151.

2. An assessment of vital and mortal stains for research of root hair viability of 12 warm-season perennial grasses, M. J. Oprisko, J. B. Beard, and R. L. Green, 1988 Agronomy Abstracts, p. 154.

B. TAES PROGRESS REPORTS PUBLISHED:

Progress reports of research supported by the United States Golf Association were released to the public via Texas Turfgrass Research which is published annually by the Texas Agricultural Experiment Station. They are as follows:

1. "Comparative Evapotranspiration Rates of Thirteen Turfgrasses Grown Under Both Non-Limiting Soil Moisture and Progressive Water Stress Conditions" by K. S. Kim, J. B. Beard, L. L. Smith, and M. Ganz. Texas Turfgrass Research - 1983. p. 39.

2. "Spring Root Decline Induction Studies" by S. I. Sifers and J. B. Beard. Texas Turfgrass Research - 1984. pp. 8-14.

3. "The Effects of Nitrogen Fertility Level and Mowing Height on the Evapotranspiration Rates of Nine Turfgrasses" by K. S. Kim and J. B. Beard. Texas Turfgrass Research - 1984. pp. 77-81.

4. "Assessment of the Genetic Potentials for Root Growth of Eleven Warm Season Perennial Turfgrasses under Non-limiting Moisture Conditions" by D. M. Casnoff and J. B. Beard. Texas Turfgrass Research - 1985. pp. 10-14.

5. "Leaf Blade Stomatal Characterizations of Ten Warm Season C-4 Perennial Grasses and Their Association to the Water Use Rate" by D. M. Casnoff, J. B. Beard, D. G. Verwers, and S. D. Griggs. Texas Turfgrass Research - 1985. pp. 15-18.

6. "Spring Root Decline (SRD): A Research Summary" by S. I. Sifers, J. B. Beard, and K. S. Kim. Texas Turfgrass Research - 1985. pp. 19-30.

7. "Comparative Assessment of Wilting Tendency of Warm Season Turfgrasses" by K. S. Kim and J. B. Beard. Texas Turfgrass Research - 1985. pp. 143-148.

8. "Criteria for Visual Prediction of Low Water Use Rates of Bermudagrass Cultivars" by S. I. Sifers, J. B. Beard, and K. S. Kim. Texas Turfgrass Research - 1986. pp. 22-23.

9. "Morphological and Physiological Plant Parameters of Bermudagrass Cultivars with Low Nitrogen Requirements" by S. I. Sifers and J. B. Beard. Texas Turfgrass Research - 1986. p. 22.

10. "Comparative Drought Resistance Among the Major Warm-Season Turfgrass Species and Cultivars" by K. S. Kim, S. I. Sifers, and J. B. Beard. Texas Turfgrass Research - 1986. pp. 28-30.

11. "Leaf Blade Stomatal Characterization and Potential Evapotranspiration Rates of 12 Cool-Season, C-3 Turfgrasses" by R. L. Green, J. B. Beard, and D. M. Casnoff. Texas Turfgrass Research - 1986. pp. 8-9.

12. "Investigations of Root Hair Size, Number, and Distribution of Seven Species of Warm-Season Turfgrasses" by R. L. Green and J. B. Beard. Texas Turfgrass Research - 1987. pp. 4-11.

13. "Turfgrass Morphological Characteristics Associated with the Evapotranspiration Rate" by K. S. Kim and J. B. Beard. Texas Turfgrass Research - 1987. pp. 49-51.

C. SCIENTIFIC PAPERS PUBLISHED:

1. Johns, D., J. B. Beard, and C. H. M. van Bavel. 1983. Resistance to evapotranspiration from a St. Augustinegrass turf canopy. Agronomy Journal 75(3):419-422.

2. Beard, J. B. and M. C. Engelke. 1985. An environmental genetics model for turfgrass improvement: physiological aspects. Proceedings International Turfgrass Research Conference 5:107-118.

3. Engelke, M. C., J. B. Beard, and P. F. Colbaugh. 1985. An environmental genetics model for turfgrass improvement: developmental aspects. Proceedings International Turfgrass Research Conference 5:127-136.

4. Sifers, S. I., J. B. Beard, and J. M. DiPaola. 1985. Spring root decline (SRD): discovery, description, and causes. Proceedings International Turfgrass Research Conference 5:777-788.

5. Kim, K. S. and J. B. Beard. 1988. Comparative turfgrass evapotranspiration rates and associated plant morphological characteristics. Crop Science 28(2):328-331.

VII. DISSEMINATION OF RESEARCH FINDINGS

Visibility for the USGA's support of our turfgrass water conservation research program has been achieved through speaking at key national and regional turfgrass conferences during the past year. The general topic is usually in the area of water conservation strategies and research updates related to rooting, water use rates, and drought stress. Addresses for 1988 have been or will be given before the following.

1. Canadian National Turfgrass Conference, Toronto, Canada. March, 1988, by J. B. Beard.
2. Australian National Turfgrass Conference, Perth, Australia. June, 1988, by J. B. Beard.
3. Northwest Turfgrass Conference, Spokane, Washington. September, 1988, by J. B. Beard.
4. Symposium on Turfgrass Water Conservation in the Arid Southwest, Las Vegas, Nevada. November, 1988, by J. B. Beard.
5. Texas Turfgrass Conference, Fort Worth, Texas. December, 1988, by S. I. Sifers.
6. Texas Turfgrass Conference, Fort Worth, Texas. December, 1988, by R. L. Green.

VIII. APPENDIX

1988 Agronomy Abstracts:

a. The effects of flurprimidol and mefluidide on ET, leaf growth, and quality of St. Augustinegrass grown at two soil moisture levels.
b. An assessment of vital and mortal stains for research of root hair viability of 12 warm-season perennial grasses.

1988 Scientific Papers Published:

a. Comparative turfgrass evapotranspiration rates and associated plant morphological characteristics.

1988 Scientific Papers Submitted:

a. Leaf blade stomatal characteristics and evapotranspiration rates of 12 cool-season perennial grasses.
b. The effects of flurprimidol and mefluidide on the evapotranspiration rates, shoot growth, and quality of St. Augustinegrass maintained at optimal and suboptimal soil moisture levels.
c. Assessment of vital and mortal stains for determining root hair viability of warm-season perennial grasses.

1988 TAES Turfgrass Research Progress Reports:

a. Investigations of root hair size, number, and distribution of seven species of warm-season turfgrasses.
b. Turfgrass morphological characteristics associated with the evapotranspiration rate.

Correspondence

The effects of flurprimidol and mefluidide on ET, leaf growth, and quality of St. Augustinegrass grown at two soil moisture levels.
R. L. GREEN*, J. B. BEARD, and K. S. KIM, Texas A&M Univ.
The objective of this study was to determine the effects of two plant growth regulators (PGR) and two soil moisture levels (SML) on evapotranspiration (ET), leaf extension rate (LER), and visual turf quality of Texas Common St. Augustinegrass grown under glasshouse conditions in plastic minilysimeters, measuring 22 cm diam and 21.5 cm deep containing fritted clay. Turf coverage and full, uniform and rooting well established prior to treatment application. The three PGR treatments were flurprimidol (0.84 kg ha^{-1}), mefluidide (0.42 kg ha^{-1}), and no PGR; grown at optimal SML (-0.01 MPa) and suboptimal SML (-0.8 MPa). Application of either PGR at either SML reduced ET by an average of 18%, but the duration of significant activity changed due to selection of PGR and SML. Duration of significant ET reduction was 3 and 5 weeks for mefluidide and 5 and 15 weeks for flurprimidol, at optimal and suboptimal SML respectively. Application of either PGR at either SML caused a reduction in LER by an average of 83%, but the duration of significant activity changed due to selection of PGR and SML. Duration of significant LER reduction was 4 and 5 weeks for mefluidide and 8 and 17 weeks for flurprimidol, at optimal and suboptimal SML, respectively. Flurprimidol was a more effective PGR, but its longer duration of reduced turfgrass quality was a drawback. Both PGR's were more effective at the suboptimal SML.

An assessment of vital and mortal stains for research of root hair viability of 12 warm-season perennial grasses.
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This research documents the search and discovery of a simple-to-use, reliable and easily detectable vital stain for root hairs of 12 warm-season perennial turfgrasses. Of the 5 vital stains used in this study, methylene blue, Evan's blue, congo red, neutral red and phenosafranin, only Evan's blue consistently gave the same color contrast for live and dead root hairs on the 12 genotypes (6 species) characterized in this survey. In all cases a dead root hair control (boiled) was compared against fresh roots. All the genotypes were established from single sprigs and grown under greenhouse conditions in plastic conetainers containing sand. While color contrast was confirmed as the indication of live and dead root hairs by the collapse of live root hairs in 20 M sucrose, intensity of color was not. Several of the stains showed inconsistency in the color and intensity of stain uptake by live and dead root hairs. Due to the inconsistency in stain uptake and intensity by root hairs, great emphasis was placed on obtaining an adequate sample size with statistical confirmation. The relative reliability of these stains in descending order was: Evan's blue, methylene blue, phenosafranin, congo red and neutral red with root hairs of 12 C-4 perennial grasses.

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Comparative Turfgrass Evapotranspiration Rates and Associated Plant Morphological Characteristics

K. S. Kim and J. B. Beard*

ABSTRACT

Since water costs are projected to increase substantially, and water availability for turfgrass culture will become more limiting, there is a need for a detailed characterization of water use rates among turfgrass species. The evapotranspiration (ET) rates of 11 C-4 warm-season turfgrasses and one C-3 cool-season turfgrass were evaluated in minilysimeters with fritted clay as the rooting medium utilizing the water balance method. Turf plots of 1.5 × 1.5 m were constructed to ensure a natural environment surrounding each lysimeter. Evapotranspiration rates plus six morphological characteristics of each species were measured under nonlimiting soil moisture. Significant differences in ET rates were observed both among and within genera. 'Texas Common' buffalograss [*Buchloe dactyloides* (Nutt.) Engelm], 'Georgia Common' centipedegrass [*Eremochloa ophiuroides* (Munro.) Hack], 'Arizona Common' bermudagrass [*Cynodon dactylon* (L.) Pers.], 'Tifgreen' and 'Tifway' bermudagrasses [*C. dactylon* (L.) Pers. × *C. transvaalensis* Davy], and 'Adalayd' seashore paspalum (*Paspalum vaginatum* Sw.) had low ET rates; while 'Emerald' zoysiagrass (*Zoysia japonica* Steud. × *Z. tenuifolia* Willd. ex Trin.) was characterized as having a medium ET rate. 'Texas Common' St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] and 'Meyer' zoysiagrass (*Z. japonica* Steud.) possessed medium low ET rates. However, a 1-yr study showed that 'Kentucky 31' tall fescue (*Festuca arundinacea* Schreb.) and 'Argentine' bahiagrass (*Paspalum notatum* Flugg.) had medium ET rates, and 'Common' blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] possessed a medium low ET rate. Those grasses with comparatively lower ET rates were generally characterized by (i) a high canopy resistance, including a high shoot density and relatively horizontal leaf orientation; and (ii) a low leaf area, including a slow vertical leaf extension rate and a narrow leaf texture.

Additional Index Words: Bouteloua, Buchloe, Cynodon, Eremochloa, Festuca, Leaf orientation, Leaf texture, *Paspalum,* Shoot density, *Stenotaphrum,* Vertical leaf extension rate, *Zoysia.*

MORE THAN 50% of water used in Texas in 1980 was for irrigation. In 1980, 3.3 billion m^3 of water were used by municipalities and rural communities of Texas (1). This consumption is expected to double by the year 2000. Since water costs are projected to increase substantially, and water availability for turfgrass culture will become more limited, research is needed to delineate the comparative water use rates of turfgrass species.

Interspecies evapotranspiration (ET) differences have been reported among tall fescue, St. Augustinegrass (both the common species and a dwarf cultivar), bermudagrass ('Santa Ana' and 'Suwannee') Emerald zoysiagrass, matrella zoysiagrass [*Zoysia matrella* (L.) Merr.], kikuyugrass (*Pennisetum clandestinum* Hochst. ex. Chiov.), seashore paspalum, centipedegrass, perennial ryegrass (*Lolium perenne* L. 'Pennfine'), and Kentucky bluegrass (*Poa pratensis* L.) (4, 13). The cutting height, N level, or both were varied among species in all three field studies. This confounds the genetic and cultural influences on ET. Biran et al. (4) concluded that cool-season grasses used 45% more water than warm-season grasses, and observed that among warm-season species, the sparse, tall-growing grasses tended to have high ET rates, whereas the dense, low-growing grasses had low ET rates. The ET rates in their study exceeded pan evaporation. Intraspecies differences in ET rates have been reported among St. Augustinegrass, bermudagrass, and zoysiagrass cultivars (4) and among Kentucky bluegrass cultivars (3, 9). There is a need to assess the comparative ET rates of turfgrass species and cultivars under a uniform cultural regime and to determine the relationships of ET rates to specific plant morphological parameters.

Evapotranspiration is a function of plant, soil, and meteorological factors. Literature demonstrates the relationships between ET rates and net radiation, soil moisture content, air temperature, soil temperature, pan evaporation, wind velocity, relative humidity, and the temperature gradient between air and leaf surface (4, 5, 6, 10, 11).

The objectives of this study were (i) to determine the comparative ET rates of 12 turfgrasses under nonlimiting soil moisture conditions, (ii) to assess the relationships between ET rates and specific plant morphological characteristics, and (iii) to determine the relationships between environmental parameters and the ET rates for each species.

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MATERIALS AND METHODS

The 12 turfgrass species or cultivars included in this study were: Arizona Common bermudagrass, Tifway and Tifgreen bermudagrasses, Meyer zoysiagrass, Emerald zoysiagrass, Georgia Common centipedegrass, Texas Common buffalograss, Common blue grama, Kentucky 31 tall fescue, Adalayd seashore paspalum, Argentine bahiagrass, and Texas Common St. Augustinegrass. Blue grama and bahiagrass were dropped from the May 1984 study, and tall fescue was dropped from the September 1984 study due to weedy plot and/or poor growth in the pots. Turf establishment for both plot and pots was achieved during the latter half of the 1981 growing season prior to the year when the studies were initiated and during the summer of 1984. While the other nine grasses were vegetatively propagated, blue grama, tall fescue, and bahiagrass were seeded at rates of 310, 400, and 480 kg ha^{-1}, respectively, on a pure, live-seed basis. One- and three-year-old plants in pots were used for the 1982 and May 1984 studies, respectively, while 3-wk-old plants in pots were used for the September 1984 study. A nonlimiting soil moisture regime was sustained throughout the establishment phase.

The potential evapotranspiration rates of 12 turfgrasses were assessed under comparable cultural practices and environmental conditions. The grasses were mowed at a 3.8-cm cutting height and fertilized at the rate of 12.5 kg N ha^{-1} biweekly. Mowing was accomplished with a properly sharpened rotary mower and hand clippers for plot area and pots, respectively; the clippings were removed. The P and K soil levels were tested by the Soil Testing Laboratory at Texas A&M University, which suggested adding K. The soil moisture level was maintained in the nonlimiting range. No pesticides were applied during the course of the studies.

Experiments were conducted on a site that had been specially constructed as a contiguous plot area. The experimental design was a randomized block design with three replications. Each 1.5- × 1.5-m plot was surrounded by metal barriers to a 10-cm depth to impair the encroachment of adjacent grass species. The root zone was a well-drained sand (USGA specifications) 1.5 m in depth. Subsurface drainage was provided via 10-cm-diam plastic drain lines spaced 3 m apart. Irrigation, via a rotary pop-up sprinkler system, was applied for 30 min daily, which was equivalent to 10 mm water d^{-1}, during the period when all lysimeters were removed to conduct the ET measurements. Fertilization and mowing practices for the general experimental area were the same as those described for the turfs growing in minilysimeters.

Evapotranspiration rates were determined by the water balance method. Black plastic minilysimeters were 21.6 cm in diameter by 20 cm in depth. Each lysimeter was filled with a fritted clay described by Van Bavel et al. (12). This was chosen as the growing medium because of its low bulk density, rapid drainage, and ability to retain a large quantity of plant available water. The sleeves surrounding each minilysimeter were constructed of 0.7-mm (24 gauge) sheet metal as open-end cylinders with dimensions of 22-cm diam by 20-cm depth. One metal sleeve was placed in the center of each 1.5- × 1.5-m turfed plot. Minilysimeters were positioned in these metal sleeves over a well-drained gravel subbase.

Each day at approximately 0900 h, the turfed lysimeters were removed from their metal sleeves, mowed, and watered at a rate of 1 L per minilysimeter. After 90 min, when the pot stopped leaking, the soil-water content reached about 0.47 kg kg^{-1}, which was equivalent to −0.001 MPa (12). Each lysimeter was then weighed on a Mettler PION balance, (Mettler Instrument Corp., Heightstown, NJ), which had an accuracy of ±0.5 g. Each minilysimeter was weighed again the next morning at 0900 h in the same order, and the leaf extension rate was measured. The ET rate was then calculated on a daily basis. The coefficient of variation for this evaporation assessment technique during the 1982 study was 7.3. The study was conducted over a 3-wk period with a total of 12 daily ET rate measurements taken per replicate of each species or cultivar. In 1984 four and 10 daily ET rate measurements were taken per replicate of each species or cultivars in May and September, respectively.

Shoot density, the number of leaves per square meter, leaf orientation, vertical leaf extension rate, and leaf width were measured upon termination of the study, the first three being indicators of canopy resistance aspect and the last two being indicators of leaf area. Leaf width measurements were taken from the midpoint of the third fully expanded leaf from the top. Leaf extension rates were obtained from the daily shoot height differences measured from the top of the pot to the tip of the representative shoots. Leaf orientation was estimated visually based on a 0 to 9 scale, with 9 being entirely vertical and 0 being entirely horizontal. Presence and degree of pubescence on the leaf blade were visually observed.

The 1983 study was initiated; however, due to poor plant growth, it was aborted. In 1982, the study was conducted in August. To avoid duplication with a drought study, the 1984 study was conducted in May and September.

Average daily maximum and minimum air temperatures 1.5 m above the soil surface, average maximum and minimum soil temperatures 0.3 m below the soil surface, and pan evaporation were measured at the TAES class A National Weather Service Station located 20 m from the ET experimental area. Net radiation was measured at the ET experimental area on an hourly basis with a Miniature Net Radiometer installed 1 m above the turfgrass canopy. A CR5 Digital Recorder (Campbell Scientific, Inc., Logan, UT) was used to collect the data.

Comparisons within the ET rates and the plant morphological characteristics for each species or cultivar were made by Duncan's multiple range test at the $P = 0.05$ level. Simple correlations of ET rates to five environmental parameters were determined.

RESULTS AND DISCUSSION

Comparative ET rates from both the 1982 and the 1984 studies are shown in Table 1. The mean ET rate over a 2-yr period ranged from 4.8 to 6.0 mm d^{-1} for nine species. Significant differences in ET rates were

Table 1. Comparative ET rates of 12 turfgrasses grown under nonlimiting soil moisture and uniform cultural conditions.

Turfgrass species and cultivar	ET rates		
	Aug. 1982	May 1984	Sept. 1984
	mm d^{-1}		
Buffalograss, Texas Common	5.3a*	4.6ab	4.4a
Centipedegrass, Georgia Common	5.5abc	4.7ab	4.9bc
Bermudagrass, Arizona Common	5.8bcd	4.2a	4.9bc
Bermudagrass, Tifgreen	5.4ab	4.6ab	5.2c
Bermudagrass, Tifway	5.9de	4.1a	4.9bc
Seashore paspalum, Adalayd	6.2ef	5.1b	4.7ab
Zoysiagrass, Meyer	5.8cde	4.7ab	5.6d
St. Augustinegrass, Texas Common	6.3f	4.8ab	5.6d
Zoysiagrass, Emerald	6.5f	4.9b	6.0e
Bluegrama, Common	5.7bcd	–	–
Bahiagrass, Argentine	6.3f	–	–
Tall fescue, Kentucky 31	7.1g	5.1b	–
CV	7.3	11.8	12.8

* Means with the same letter in a column are not significantly different at the $P = 0.05$ level in Duncan's multiple range test.

Table 2. Shoot densities, number of leaves per unit area, leaf orientation, leaf extension rates, and leaf widths of 12 turfgrasses.

Turf species and cultivar	Canopy resistance components			Leaf area components	
	Shoot density ($\times 10^3$)	No. leaves per area ($\times 10^3$)	Leaf orientation†	Vertical leaf extension rate	Leaf width
	no. m^{-2}			mm d^{-1}	mm
Buffalograss, Texas Common	332e*	1730d	8.7a	2.8abcde	1.7fg
Centipedegrass, Georgia Common	732de	2170d	2.7i	1.3e	3.4c
Bermudagrass, Arizona Common	1800c	2510d	4.7fg	3.2abcd	1.9ef
Bermudagrass, Tifgreen	2612ab	5120b	4.3h	1.5de	0.9hi
Bermudagrass, Tifway	2308b	4560b	5.0gh	1.8cde	0.8hi
Seashore paspalum, Adalyd	1920c	3730c	4.3h	3.9ab	2.6de
Zoysiagrass, Meyer	788d	2360d	7.7bc	2.7abcde	2.9cd
St. Augustinegrass, Texas Common	372de	1650d	6.0ef	2.2bcde	8.0a
Zoysiagrass, Emerald	2932a	7550a	7.7bc	2.2bcde	1.9efg
Blue grama, Common	412de	1770d	8.3ab	4.4a	1.2fgh
Bahiagrass, Argentine	388de	1610d	6.7de	3.5abc	5.0b
Tall fescue, Kentucky 31	612de	1990d	7.3cd	2.7abcde	3.6c
CV	13.8	10.9	8.5	74.2	21.3

* Means with the same letter in a column are not significantly different at the $P = 0.05$ level in Duncan's multiple range test.
† Based on a 0 to 9 scale: 0 = horizontal and 9 = vertical.

observed among different genera and within the same genus such as *Zoysia*. Classification of ET rates followed the table by Beard (2). They are low (<5.5 mm d^{-1}), medium low (5.5–6.0 mm d^{-1}), medium (6.0–7.0 mm d^{-1}), medium high (7.0–7.5 mm d^{-1}), and high (>7.5 mm d^{-1}).

Associated Plant Morphological Characteristics

The ET rate differences among species/cultivars were associated, to varying degrees, with their respective shoot density, the number of leaves per unit area, leaf orientation, leaf width, and vertical leaf extension rate (Table 2). The first three plant parameters contributed to a high canopy resistance to ET, while the latter two parameters affected the total leaf area and resultant amount of evaporative surface. The external canopy resistance to ET has been shown to be much greater than the internal plant resistance (7). A turf canopy with high leaf and shoot densities, a substantial horizontal leaf orientation, or both would cause greater resistance to the normal upward movement of water vapor through the canopy and, at the same time, would decrease turbulent eddy movements with a resultant increase in vapor density within the canopy.

St. Augustinegrass exhibited a medium low ET rate of 5.8 mm d^{-1}. This response was associated with a low canopy resistance in terms of a very low shoot density and an intermediate leaf orientation, plus a high leaf area due to a very wide leaf and a medium vertical leaf extension rate.

Bahiagrass showed a medium ET rate of 6.3 mm d^{-1} when grown under nonlimiting soil moisture. This response was associated with a rapid vertical leaf extension rate and a wide leaf that resulted in a high leaf area, plus a very low shoot density and intermediate leaf orientation, which contributed to a low canopy resistance. However, this value is from the 1982 study, which showed higher values than the May 1984 and the September 1984 studies mainly due to the August measurement. Thus, special consideration should be taken in terms of ranking this species.

Adalayd seashore paspalum showed a low ET rate of 5.4 mm d^{-1}. This rate was associated with a very rapid vertical leaf extension rate but a medium leaf width, horizontal leaf orientation, high shoot density, and the number of leaves per unit area.

Significant differences were found within the zoysiagrasses. Emerald showed a medium ET rate of 6.0 mm d^{-1}, which was the highest ET among the C-4 grasses, while Meyer showed a medium low ET rate of 5.5 mm d^{-1}. The medium ET rate of Emerald may be associated with its vertical leaf orientation and medium vertical leaf extension rate, in spite of a high shoot density and a large number of leaves. Meyer was intermediate in the morphological components that influence the ET rate.

The ET rates of the three bermudagrasses were in the low range. Arizona Common, Tifgreen, and Tifway ranked low in ET rates at 5.1, 5.2, and 5.2 mm d^{-1}, respectively. A slow vertical leaf extension rate and a narrow leaf that resulted in a low leaf area, plus a high shoot density and a rather horizontal leaf orientation, may have contributed to the low ET rates of bermudagrasses.

Centipedegrass showed a low ET rate, which is contradictory to the results of Biran et al. (4). The canopy characteristics of the centipedegrass used in the latter study were not described. The low ET rate of 5.1 mm d^{-1} for centipedegrass found in this study was attributed to very slow vertical leaf extension rate, plus a near-horizontal leaf orientation and prostrate growth habit that contributed to a high canopy resistance to ET.

The native grass, buffalograss, showed low ET rate of 4.8 mm d^{-1}. Pubescence on the leaf blade surface and the low leaf area may have contributed to the very low ET rate of buffalograss. Buffalograss had a very sparse shoot density and very narrow leaf blades, which contributed to the lower exposed leaf surface to the air. There is the possibility that physiological adjustments within the plant may have contributed to the lowest ET rate of buffalograss.

Another native grass, blue grama, had a medium low ET rate of 5.7 mm d^{-1} in the 1982 study. This medium low ET rate was associated with a low leaf area due to a sparse shoot density and narrow leaf width.

Tall fescue, a C-3 cool-season turfgrass, had a higher ET rate than any of the 11 C-4 grasses in both the

1982 and the May 1984 studies. This is consistent with the results of Biran et al. (4). The medium ET rate of 6.1 mm d^{-1} for tall fescue was associated with its fairly erect leaf orientation and low shoot density, which contributed to a low canopy resistance, plus an intermediate vertical leaf extension rate and a medium wide leaf as well as its C-3 photosynthetic pathway.

Influence of Environmental Factors on ET Rates

Highly significant correlations were found between ET rates under nonlimiting soil moisture conditions and the nearby net radiation, pan evaporation, air temperature, and relative humidity measurements for all grasses except buffalograss. Net radiation was the most highly correlated with ET rates for the 12 grasses. The dense pubescence of the buffalograss leaves increased the thickness of the boundary layer on the leaf surfaces and, therefore, might diminish the correlations with both pan evaporation and relative humidity. It should be noted that, except for net radiation, these environmental parameters were monitored at a site approximately 20 m from the ET experimental area. Thus, these correlations should be assessed in terms of predictive parameters. It is evident that the relative prediction effectiveness differs among species, with buffalograss, bahiagrass, and centipedegrass ranking the poorest.

Soil temperature was not correlated with the ET rate for all grasses under nonlimiting soil moisture conditions. While air temperature directly influences the ET rates of plants by affecting the water vapor pressure deficit, the temperature of the soil is known to influence water uptake by plants in terms of the capability of roots to absorb water. In addition, the resistance to water movement through the soil is temperature dependent. In a study by Tew et al. (10), the soil temperatures ranged from 10 to 40°C, which was wide enough to significantly influence ET. Since the soil temperature range, 27.8 to 31°C during this study, was very narrow and favorable for root activity, soil temperature did not affect the ET rate significantly. This concept can be supported by the significant correlation of ET rates to soil temperature when under progressive water stress conditions, as documented in a subsequent study (8). The soil temperature range in this latter case was from 19 to 28°C.

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LEAF BLADE STOMATAL CHARACTERIZATIONS AND EVAPOTRANSPIRATION RATES OF 12 COOL-SEASON PERENNIAL GRASSES

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Additional index words. *Agrostis*, *Festuca*, *Lolium*, *Poa*, stomata, water use rate

Abstract. The objective of this investigation was to determine the association between stomata frequency of 12 perennial cool-season turfgrasses, encompassing 9 species, and their evapotranspiration (ET) rates under non-limiting soil moisture and controlled environmental conditions. These findings will contribute to a strategy for the development of cool-season turfgrasses with improved water conservation and/or drought resistance. Three replicates of each turfgrass were seeded onto a fritted clay root zone and established for 5 months under greenhouse conditions. The turfs were then acclimated in a controlled environment growth chamber with conditions similar to those described for the simulation test chamber. Abaxial and adaxial leaf surface stomatal density counts were made from polyvinyl leaf impressions at 200 magnification. Following leaf excision for stomatal characterizations, the turfs were immediately transferred to a controlled environmental simulation chamber for ET rate assessments based on lysimeter measurements made over a 24-hour period. The simulation chamber imposed a photoperiod of 14 hours, photon flux density of 1,080 μmol $m^{-2}s^{-1}$, and average air velocity of 0.5 m s^{-1}, plus an air temperature and dew point maintained at 22° and 12°C, respectively.

Significant differences in stomatal density were found among the 12 cool-season turfgrasses on both the abaxial and adaxial leaf surfaces. The densities were generally greater on the adaxial than on the abaxial surface; and were considerably lower than those reported for 10 major warm-season turfgrasses. Significant differences in ET rates were also found among the 12 cool-season turfgrasses. The Kentucky bluegrass

(*Poa pratensis* L.) cultivars exhibited the highest ET rates, while the fine-leafed fescues (*Festuca rubra* and *longifolia* L.) exhibited the lowest rates, except for 'Big Horn' sheep fescue (*Festuca ovina* L.) which exhibited an intermediate ET rate. As a group, the cool-season turfgrasses were characterized by higher ET rates than the major warm-season turfgrasses. A significant negative correlation was found between the ET rate and the adaxial stomatal density. This lack of a positive relationship between ET rate and stomatal density supports the concept that turfgrass breeding programs designed to develop water conserving turfgrasses should emphasize plant characteristics that increase the canopy resistance and decrease the leaf area.

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A major concern in the development of minimal maintenance turfs is the breeding of grasses with increased total drought resistance and/or increased ability to conserve water while maintaining acceptable turf quality under irrigated conditions. One component of increased total drought resistance or increased water conservation is a reduction in water loss via evapotranspiration (7, 16). Mechanisms that contribute to less water loss include reductions in epidermal conductance, absorbed radiation, and/or evaporative surface area. Another mechanism for restricting water loss involves the development of a wax layer on the leaf surface (4). Although stomata comprise only about one percent of the total leaf blade surface area, they serve as key sites for transpiration and thus are of interest in reducing water loss.

Some research has been reported concerning stomatal characteristics and evapotranspiration (ET) of turfgrasses. Johns et al. (6) studying resistances to evapotranspiration from St. Augustinegrass, (*Stenotaphrum secundatum* [Walt.] Kuntze), showed that under adequately watered conditions, 20 to 30 percent of actual ET was controlled by resistance of the leaf epidermis and stomata disposition; and that ET was influenced to a much greater extent by aerodynamic and canopy resistances. Casnoff *et al.* (3), studying leaf blade stomatal arrangement and density of 10 warm-season perennial turfgrasses and their association to ET rates, found significant differences among the turfgrasses for ET rate and stomatal density. They also noted a significant negative correlation between ET rate and abaxial stomatal density. Kopec *et al.* (11) found significant differences in ET among a collection of forage-type and turf-type tall fescue (*Festuca arundinacaea* Schneb.) cultivars with the latter type having lower ET. Shearman (13), working with a collection of 20, well-watered Kentucky bluegrass (*Poa pratensis* L.) cultivars found significant differences among the cultivars for ET rate, shoot density, verdure, and adaxial stomatal density. However, only verdure was correlated significantly to cultivar ET rates. In an earlier study, Shearman and Beard (14) working with creeping bentgrass (*Agrostis stolonifera* L. var. *palustris* [Huds.]

Farw. 'Penncross') observed that as light intensity was increased during a preconditioning period, ET rate and stomatal density significantly increased. However, when increasing nitrogen rates were applied during a preconditioning period under a uniform light intensity, the ET rates were negatively correlated to stomatal density.

The objectives of this study were 1) to characterize the stomatal densities of 12 perennial cool-season turfgrasses, encompassing nine species and 2) to assess their associated ET rates under non-limiting soil moisture conditions and uniform cultural practices in a controlled environmental simulation chamber.

MATERIALS AND METHODS

The 12 cool-season turfgrasses characterized in this study included creeping annual bluegrass [*Poa annua* var. *reptans* (Hausskn.) Timm], chewings fescue (*Festuca rubra* L. ssp. *commutata* Gaud. 'Jamestown'), creeping bentgrass [*Agrostis stolonifera* L. var. *palustris* (Huds.) Farw. 'Penncross'), hard fescue (*F. longifolia* Thuill. 'Waldina'), Kentucky bluegrass (*Poa pratensis* L. 'Bensun', 'Majestic', and 'Merion'), perennial ryegrass (*Lolium perenne* L. 'Manhattan II'), rough bluegrass (*P. trivialis* L. 'Sabre'), sheep fescue (*F. ovina* ssp. *vulgaris* 'Big Horn'), and tall fescue (*F. arundinacea* Schreb. 'Kentucky 31', and 'Rebel'). Three replicates of each turfgrass were seeded at their respected recommended rates (1) and grown in a greenhouse in black plastic containers, 21 cm in diameter and 21 cm deep, filled with fritted clay. Fritted clay was chosen as the growth medium based on the work of Van Bavel *et al.* (17). The greenhouse temperature was controlled so the minimum and maximum did not exceed 21° and 32°C, respectively. Turfs were mowed weekly at a 5-cm cutting height via a reel mower with clippings removed, watered daily to prevent visual wilt, and fertilized biweekly with a nutrient solution (23.0-8.4-14.1, NPK, respectively, plus micronutrients) at a rate equivalent to 0.25 kg N are^{-1} $growing\ month^{-1}$, except for hard fescue which received no fertilizer. The grasses were grown for a 5-month establishment period, when turf coverage was complete and rooting stabilized.

One week before stomatal and ET rate characterizations, the turfs were transferred from the greenhouse to a controlled environment growth chamber and preconditioned in conditions similar to the environmental simulation chamber: day and night temperatures of 22°C, photoperiod of 14 hours, and photon flux density of 500 $\mu mol\ m^{-2}s^{-1}$. No disease or insect injury was visually evident on the turfs during the acclimation and test phases.

Following acclimation, the turfs were mowed, immediately sampled for stomatal characterizations, and then placed in the environmental simulation chamber for ET rate

determinations. Four of the youngest, fully expanded leaf blades were randomly selected and excised from each turfgrass canopy. Two abaxial and two adaxial leaf blade impressions were made by first painting a thin layer of polyvinyl solution over one surface of each leaf blade and then gently removing the dried plastic impression and mounting it on a microscope slide for analysis (12). Two stomatal density counts were made from the midportion of each leaf blade impression at 200 magnification. The actual area observed was 0.25 mm^2, with the counts being converted to a mm^2 basis.

Immediately following excision of leaf blades for stomatal characterization, the turfs were placed in a controlled environmental simulation chamber as described by Johns *et al.* (6) to assess ET rates under uniform temperature, dew point, light intensity, photoperiod, and wind velocity conditions. The chamber was modified to simultaneously accommodate four minilysimeters. Day and night temperatures were 22°C, dewpoint was 12°C (approximately 53% relative humidity), photoperiod was 14 hours, photon flux density was 1,080 μmol $m^{-2}s^{-1}$, and average air velocity was 0.5 m s^{-1}. The evapotranspiration rate for a 24-hr period was determined 3 times for each minilysimeter by the water balance method as described by Johns *et al.* (6) and by Kim and Beard (10).

An analysis of variance was conducted on the stomatal and ET rate data and means separated by the use of Duncan's Multiple Range Test procedure.

RESULTS AND DISCUSSION

Significant differences in stomatal density were found among the 12 cool-season turfgrasses for both the abaxial and adaxial leaf surfaces (Table 1). Densities of the stomata were greater on the adaxial than on the abaxial surface for most of the turfgrasses. Previous work with Penncross creeping bentgrass (15) showed the same relationship in stomatal density between the two leaf blade surfaces. Conversely, half or possibly the majority of 10 warm-season perennial turfgrasses have similar stomatal densities on both leaf blade surfaces (3, 8).

Turfgrasses with the highest adaxial stomatal density included Waldina hard fescue and Penncross creeping bentgrass, 203 and 176 stomata mm^{-2}, respectively; while those ranking lowest included Merion Kentucky bluegrass and Kentucky 31 tall fescue, 73 and 68 stomata mm^{-2}, respectively. The adaxial stomatal densities observed for 3 Kentucky bluegrass cultivars were lower than those reported by Shearman (13). This may be due to different growing conditions. Light intensity and temperature have been reported to affect stomatal densities of creeping bentgrass (14).

Turfgrasses ranking highest in abaxial stomatal density included Penncross creeping bentgrass and creeping annual bluegrass, 100 and 71 stomata mm^{-2}, respectively; while Sabre rough bluegrass, Jamestown chewings fescue, Big Horn sheep fescue, and Waldina hard fescue had no stomata in their abaxial leaf surfaces. Perennial ryegrass had stomata only adjacent to and on both sides of the midrib; while all other species had stomata over the entire abaxial surface; except for the fine-leafed fescues and rough bluegrass which had no stomata.

The abaxial and adaxial stomatal densities of the cool-season turfgrasses observed were considerably lower than those reported for a collection of the major warm-season turfgrasses (3, 8). There was no correlation between the abaxial and adaxial stomatal densities at the interspecies level for the 9 cool-season turfgrasses; unlike the significant positive correlation reported by Casnoff *et al.* (3) at the interspecies level

for 10 major warm-season turfgrasses. Stomata density is affected by both the environmental and cultural conditions during leaf development. Thus, the most important aspect of the densities reported herein involves the relative differences and not the absolute values.

Significant interspecies differences for ET rate were found among the 12 cool-season turfgrasses, ranging from 7.4 mm day^{-1} for Waldina hard fescue to 12.4 mm day^{-1} for Merion Kentucky bluegrass. The highest ET rates were exhibited by the Kentucky bluegrasses and the lowest by the fine-leafed fescues, except for Big Horn sheep fescue. Significant interspecies variations in ET rates also have been reported among 10 major warm-season turfgrasses (3, 8) and at the intraspecies level among a collection of 20 Kentucky bluegrass cultivars (13) and among a collection of 6 tall fescue cultivars (11).

As a group, the cool-season turfgrasses were characterized by higher ET rates than the warm-season turfgrasses when both groups are assessed under their respective optimal growing conditions (1). It should be indicated that the cutting height and nitrogen nutritional level can significantly influence ET rates (5, 9, 14). The ET rates of 10 major warm-season turfgrasses ranged from 5.7 mm day^{-1} for common buffalograss (*Buchloe dactyloides* [Nutt.] Englem.) to 9.4 mm day^{-1} for 'Emerald' zoysiagrass (*Zoysia japonica* Steud x *Z. tenuifolia* Willd ex trin) when characterized in the same environmental simulation chamber as the cool-season turfgrasses; except for a 30°C air temperature and 10°C dewpoint (3). For comparison, Waldina hard fescue, a cool-season turfgrass with the lowest ET rate, would rank intermediate among the 12 warm-season turfgrasses. Biran *et al.* (2) reported that both tall fescue and perennial ryegrass consumed more water than any of 9 warm-season turfgrasses when grown under hot, semi-arid conditions.

In this study there was a significant negative correlation ($r = -0.456$; $P = .005$) between ET rate and the adaxial stomatal density and a minimally significant positive

correlation ($r = 0.327$; $P = 0.05$) between ET rate and the abaxial stomatal density at the interspecies level among the 9 cool-season turfgrasses. Casnoff *et al.* (3) reported a significant negative correlation between ET rate and the abaxial stomata density and no correlation between ET rate and the adaxial stomata density at the interspecies level among 10 warm-season turfgrasses. Shearman (13) reported that ET rate was not correlated to adaxial stomatal density at the intraspecies level, but was correlated to verdure among a collection of 20 Kentucky bluegrass cultivars. This lack of a positive relationship between ET rate and stomatal density may reflect (a) stomatal aperture is more important than stomatal density and/or (b) ET rate is more associated with plant parameters that affect aerodynamic and canopy resistances, such as leaf area (leaf width, length, and extension rate), shoot density, and leaf orientation than plant parameters affecting resistance of the leaf epidermis and stomata disposition (5, 6, 9). In support of the first possibility, Casnoff *et al.* (3) working with carpetgrass (*Axonopus compressus* [Swarty] Beauv.), common bermudagrass, and Texas Common St. Augustinegrass found that common bermudagrass (medium ET rate) had a high stomatal density with stomata significantly shorter and narrower than Texas Common St. Augustinegrass (high-medium ET rate) with medium-low stomatal density. This research and the work of others (3, 6, 9, 13, 14) indicates that considerable inter- and intraspecies variation in ET rates exist and that breeding programs designed to develop water conserving turfgrasses, especially for irrigated conditions, should place priority on plant parameters which increase the canopy resistance and decrease the leaf area.

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Comparative stomata densities and evapotranspiration rates for 12 cool-season turfgrasses

Turfgrass	Cultivar	Stomata No. mm^{-1}[x] Adaxial	Abaxial	ET Rate[y] (mm day^{-1})
Hard fescue	Waldina	203 a[z]	0 d	7.4 e
Creeping bentgrass	Penncross	176 ab	100 a	10.1 abcd
Sheep fescue	Big Horn	147 abc	0 d	9.3 cde
Chewings fescue	Jamestown	142 abcd	0 d	7.7 de
Creeping annual bluegrass		135 bcde	71 ab	9.8 bcde
Kentucky bluegrass	Bensun	125 bcdef	41 bcd	12.4 a
Perennial ryegrass	Manhattan II	125 bcdef	17 cd	9.1 cde
Tall fescue	Rebel	88 cdef	46 bcd	11.4 abc
Rough bluegrass	Sabre	87 cdef	0 d	8.4 de
Kentucky bluegrass	Majestic	79 def	37 bcd	11.9 ab
Kentucky bluegrass	Merion	73 ef	24 bcd	12.4 a
Tall fescue	K-31	68 f	55 bc	9.9 abcde

[x]Stomata density counts based on number per 0.25 mm^2 at 200 x.

[y]ET rate based on lysimeter measurements made in a 24-hour period under non-limiting soil moisture conditions in a controlled environmental simulation chamber having a photoperiod of 14 hours, photon flux density of 1,080 μmol $m^{-2}s^{-1}$, wind speed of 0.5 m s^{-1} measured 20.3 cm above turf canopy, and air temperature and dew point maintained at 22° and 12° C, respectively.

[z]The mean of three replications. Means within a column followed by the same letter are not significantly different, Duncan's Multiple Range Test, alpha = 0.05.

The effects of flurprimidol and mefluidide on the evapotranspiration rate, shoot growth, and quality of St. Augustinegrass maintained at optimal and suboptimal soil moisture levels

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Additional index words: leaf extension, PGR, plant growth regulator, *Stenotaphrum secundatum*, water use rate

Abstract. The objective of this study was to determine the effects of 2 plant growth regulators (PGR) and 2 soil moisture levels (SML) on the evapotranspiration (ET) rate, leaf extension rate (LER), and visual turfgrass quality of 'Texas Common' St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] grown under glasshouse conditions in black plastic minilysimeters, measuring 22 cm diam and 21.5 cm deep which contained fritted clay. Turfs were established plugs which were fully rooted prior to treatment applications. Subsequently data were collected on a weekly basis for 21 weeks. The treatments included N-[2,4-dimethyl-5-[[(trifluoromethyl) sulfonyl] amino] phenyl] acetamide (mefluidide) applied at 0.42 kg ha^{-1}, α-(1-methylethyl)-α-[4-(trifluoromethoxy) phenyl]-5-pyrimidinemethanol (flurprimidol) applied at 0.84 kg ha^{-1} and no PGR under optimal (-0.01 MPa) or suboptimal (-0.8 MPa) SML. Assessments of ET rate were based on the water balance method using lysimeter measurements made over a 24-hr period and LER was determined over a 7-day period. Plant growth regulators were effective in reducing ET rate and LER; and at both soil moisture levels flurprimidol significantly reduced ET rate, LER, and turf quality for a longer duration

than mefluidide. Application of either PGR at either SML reduced ET rate by an average of 18%, but the duration of significant activity varied with the PGR and SML. Duration of a significant ET rate reduction was 3 and 5 weeks for mefluidide and 5 and 15 weeks for flurprimidol at optimal and suboptimal SML, respectively. Application of either PGR at either SML caused a reduction in LER by an average of 83%, but the duration of significant activity varied with the PGR and SML. Duration of significant LER reduction was 4 and 5 weeks for mefluidide and 8 and 17 weeks for flurprimidol, optimal and suboptimal SML, respectively. Flurprimidol significantly reduced turfgrass quality by an average 18% for 9 weeks at the optimal SML (average turfgrass quality was 6.9 on a 1 to 9 scale) and by an average 27% for 15 weeks at the suboptimal SML (average turfgrass quality was 6.3). Mefluidide significantly reduced turfgrass quality for a much shorter duration; 20% for 1 week at the optimal SML (average turfgrass quality was 7.0) and an average 15% reduction for 2 weeks at the suboptimal SML (average turfgrass quality was 7.0). It was concluded that flurprimidol was a more effective PGR than mefluidide for St. Augustinegrass but the longer duration of reduced turfgrass quality is the former's drawback. Secondly, the use of either PGR is more effective at the lower soil moisture level. Thus, current PGR's probably have their greatest potential on low-maintenance turfs which typically are characterized by a low soil moisture.

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Plant growth regulators have been reported as being effective for causing suppression of both shoot growth and seedhead development in cool-season turfgrasses (2, 4, 5, 6, 13) and warm-season turfgrasses (1, 10, 15, 18). Since water costs are projected to increase substantially and water availability for turfgrass culture will become more limited, research is needed to describe ways of reducing turfgrass water use. Shoot growth rate and evapotranspiration (ET) rate of Texas Common St. Augustinegrass and 'Tifway' bermudagrass [*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Davy] were reduced by applications of plant growth regulators (PGR's) (9). Similar results also have been reported on cool-season perennial grasses (7, 14). Subsequent research confirmed that shoot growth rate was a prime determinant for assessment of ET rate of turfgrasses (12, 16). The objective of this study was to determine the effects of mefluidide and flurprimidol on ET rate, leaf extension rate (LER), and turfgrass quality of Texas Common St. Augustinegrass maintained at optimal and suboptimal soil moisture levels (SML).

During 26 June 1986, mature turf plugs of Texas Common St. Augustinegrass, measuring 20 cm in diam, were cut from a field plot located at the Texas A&M University Turfgrass Field Research Laboratory. The root system was severed adjacent to the crown and the plugs were thoroughly washed to eliminate adhering soil. The turfed plugs were then transplanted onto a predetermined weight of fritted clay ('Absorb-N-Dry', Balcones Mineral Corp., Flatonia, TX) contained in black plastic minilysimeters, measuring 22 cm diam and 21.5 cm in deep. The turfs were fertilized at a rate of 50, 100, and 50 kg N, P, K ha^{-1} mo^{-1}, respectively, with biweekly nutrient solution applications for the duration of the study. Turfs were mowed weekly at a 7.6 cm cutting height via a reel mower and clippings removed. Maximum and minimum temperatures in the glasshouse did not exceed 35° and 24°C, respectively. Three weeks prior to spray application of the PGR treatments, 2 SML treatments, approximately

-0.01 MPa (optimal moisture) and -0.8 MPa (suboptimal moisture) were imposed over the minilysimeters by gradually adjusting weight over a 2-week period to a calculated weight. The calculated weight was based on the curve of volumetric water content (M^3/M^3) to soil pressure potential that was previously generated for fritted clay (17) and total weight was adjusted for fresh plant weight. The minilysimeters were maintained at their appropriate SML for the remainder of the study by adding distilled water every 2 days to compensate for evapotranspirational water loss. On 14 July 1987, the minilysimeters were treated with mefluidide and flurprimidol at a rate of 0.42 and 0.84 kg ha^{-1}, respectively, in a laboratory spray chamber (3) calibrated for a finished spray volume of 467.6 L ha^{-1}. There were 3 replicates for each SML-PGR treatment combination. Evapotranspiration rate for a 24-hr period was measured on a weekly schedule for 21 wk following PGR application by using the minilysimetry technique combined with the water balance method as described by Johns (8) and Kim and Beard (12). These determinations were made between day 6 and day 7 of the 7-day mowing schedule while LER was determined for the entire 7 days. Leaf extension rates were determined by calculating the difference between shoot height of 10 leaf blades randomly selected and measured from the top edge of the minilysimeter, immediately following mowing and then 7 days later prior to mowing. During the study, visual turfgrass quality was rated on a scale of 1 to 9; 9 was best, 1 was poorest, and 5 was the minimal acceptable turfgrass quality for a lawngrass. Percent reduction or enhancement caused by treatments was calculated as [(observation-control)/control] x 100.

Flurprimidol and mefluidide significantly affected ET rate, LER, and turfgrass quality of St. Augustinegrass whereas duration of both PGR treatments was affected by the SML (Tables 1-3). At both SML, flurprimidol significantly reduced ET rate, LER, and turfgrass quality for a longer duration than mefluidide. Previous work with the

cool-season species, Kentucky bluegrass (*Poa pratensis* L.), also showed that flurprimidol suppressed shoot growth and reduced turfgrass quality for a longer duration than mefluidide (4, 6). Flurprimidol caused an increased tiller number which was related to a greater root weight. Doyle and Shearman (7) reported that flurprimidol and mefluidide reduced ET rates for 14 days beginning 21 days after treatment for Kentucky bluegrass. They also reported that both PGR's reduced plant height for the period of 21 to 35 days after treatment and that mefluidide plant heights were greater than the control at 35 to 42 days after treatment. Flurprimidol only suppresses growth while mefluidide suppresses growth and development (10).

At optimal SML, flurprimidol significantly reduced the ET rate for 5 weeks (week 3 to week 8, though to week 10 is noteworthy) and at suboptimal SML for 15 weeks (week 2 to week 17). Evapotranspiration was reduced by an average 15% at optimal SML and 18% at suboptimal SML. At optimal SML, mefluidide significantly reduced the ET rate for 3 weeks (week 2 to week 5) by an average reduction of 20% but also caused a consistent, noteworthy enhancement of the ET rate for 9 weeks (week 7 to week 16). Enhanced ET rate via increased growth rates following growth suppression was also reported for Kentucky bluegrass treated with mefluidide (7). At suboptimal SML, mefluidide significantly reduced the ET rate for 5 weeks (week 2 to week 7) by an average reduction of 18%.

At optimal SML, flurprimidol significantly reduced LER for 8 weeks (week 2 to week 10, though to week 15 is noteworthy) and at suboptimal SML for 17 weeks (week 2 to week 19). Leaf extension rate was reduced by an average 85% at optimal SML and by an average 79% at suboptimal SML. At optimal SML, mefluidide significantly reduced LER for 4 weeks (week 2 to week 6) by an average reduction of 85%, but also caused a significant enhancement for 5 weeks (week 7 to week 12, though to week 14 is noteworthy) by an average enhancement of 51%. At suboptimal SML, mefluidide

significantly reduced LER for 5 weeks (week 2 to week 7) by an average reduction of 82%, but caused a significant enhancement for 3 weeks (week 10 to week 13, though to week 21 is noteworthy) by an average enhancement of 52%. At either SML reduction in LER was sooner following PGR treatment application and a shorter duration for mefluidide than for flurprimidol.

At optimal SML, flurprimidol caused a significant reduction in turfgrass quality for 9 weeks (week 5 to week 14, though to week 15 is noteworthy) and at suboptimal SML for 15 weeks (week 3 to week 18, though to week 19 is noteworthy). Average reduction in turfgrass quality was 18% at optimal SML and 27% at suboptimal SML; turfgrass quality at either SML remained above 5 (minimum acceptable turfgrass quality for a lawngrass). At optimal SML, mefluidide caused a significant reduction in turfgrass quality for 1 week (week 5, though to week 9 is noteworthy followed by a nonsignificant enhancement) and at suboptimal SML for 2 weeks (week 7 to week 9). Average reduction in turfgrass quality was 20% at optimal SML and 15% at suboptimal SML. Turfgrass quality was closely related to suppression and enhancement of LER caused by either PGR; that is, turfgrass quality increased as shoot growth resumed from treatment with PGR. This point is most dramatically shown by the suppression and enhancement of LER following treatment with mefluidide.

Plant growth regulators were very effective in reducing the ET rate and LER in St. Augustinegrass. Application of either PGR at either SML caused a reduction in ET rate by an average 18%, but the duration of significant activity varied with the PGR and SML. Duration of significant ET rate reduction was 3 and 5 weeks for mefluidide and 5 and 15 weeks for flurprimidol at optimal and suboptimal SML, respectively. Both PGR's had a longer duration of activity at suboptimal SML and the duration of activity for flurprimidol was increased more by the suboptimal SML than for mefluidide.

Application of either PGR at either SML reduced LER by an average 83%, but the

duration of significant activity varied with PGR and SML. Duration of significant LER reduction was 4 and 5 weeks for mefluidide and 8 and 17 weeks for flurprimidol at optimal and suboptimal SML, respectively. Rogers *et al.* (15) reported a significant irrigation effect on bermudagrass field plots treated with metsulfuron methyl + sulfometuron methyl combinations. Conversely, Wu *et al.* (18) working with potted plants of bermudagrass grown under greenhouse conditions and treated with either maleic hydazide, chlorflurenol, ethephon, fluoridamid, mefluidide, or various combinations reported plants grown under a wet regime (watered daily) showed no significant difference in chemical retardant effects on shoot growth and internode length from those grown under a dry regime (watered every 3 days). Application of mefluidide caused a significant LER enhancement (average 52% enhancement) of similar duration as its preceding LER reduction. The duration of significant LER enhancement was 5 and 3 weeks at the optimal and suboptimal SML, respectively.

Flurprimidol reduced turfgrass quality for a much longer duration than mefluidide. The quality of turfs treated with flurprimidol was reduced by an average 18% for 9 weeks at optimal SML (average turfgrass quality was 6.9 on a 1 to 9 scale) and reduced by an average 27% for 15 weeks at suboptimal SML (average turfgrass quality was 6.3). Mefluidide reduced turfgrass quality for a much shorter duration; 20% for 1 week at optimal SML (average turfgrass quality was 7.0) and an average 15% reduction for 2 weeks at suboptimal SML (average turfgrass quality was 7.0).

In conclusion, flurprimidol was more effective PGR than mefluidide for St. Augustinegrass in terms of duration of ET rate and LER reduction. However, the considerably longer duration of reduced turfgrass quality is the former's drawback. Lower rates of application for flurprimidol may be considered. Use of either PGR is more effective at the lower soil moisture level. Thus, tuffgrass cultural programs that include the use of PGR's should reduce the amount of irrigation to gain maximum

benefit from the PGR. Also, either PGR probably has the greatest potential on turfs that are not intensively managed.

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Table 1. Effects of 2 plant growth regulators on ET rates of St. Augustinegrass maintained under 2 soil moisture levels and glasshouse conditions.

Weeks following Treatments	Evapotranspiration Rate (mm d^{-1})					
	Optimal Soil Moisture			Suboptimal Soil Moisture		
	Untreated	Flurprimidol	Mefluidide	Untreated	Flurprimidol	Mefluidide
0	8.0 a*	7.9 a	8.0 a	5.8 a	5.8 a	5.8 a
2	8.7 a	8.0 ab	7.1 b	7.0 a	6.1 b	6.2 b
3	11.8 a	10.2 b	8.6 c	9.0 a	7.4 b	7.6 b
4	10.5 a	9.1 b	8.5 b	8.8 a	7.3 b	7.5 b
5	9.1 a	7.6 b	7.7 b	7.9 a	6.3 b	6.1 b
6	8.4 a	6.8 b	7.8 a	7.2 a	5.8 ab	5.0 b
7	8.7 ab	7.6 b	9.2 a	7.7 a	6.3 c	6.7 b
8	10.1 a	8.7 b	10.6 a	8.4 a	6.8 b	7.6 ab
9	3.1 ab	2.7 b	3.5 a	2.7 a	2.0 b	2.7 a
10	7.7 ab	6.9 b	8.3 a	6.8 a	5.5 b	6.9 a
12	6.8 a	6.6 a	7.3 a	6.1 a	5.2 b	6.3 a
13	5.6 a	5.5 a	6.0 a	5.2 a	4.5 b	5.4 a
14	3.3 a	3.2 a	3.4 a	3.1 a	2.6 a	3.2 a
15	7.8 a	7.8 a	8.7 a	7.4 b	6.1 c	8.3 a
16	7.0 a	6.9 a	8.2 a	6.5 a	5.1 b	7.2 a
17	3.4 a	3.5 a	3.5 a	3.6 a	3.1 b	3.7 a
18	5.2 a	5.0 a	5.2 a	5.6 a	4.8 a	5.7 a
19	2.2 a	2.2 a	2.3 a	2.3 a	2.1 a	2.3 a
20	5.1 a	5.0 a	4.8 a	6.0 a	5.8 a	5.9 a
21	4.0 a	3.9 a	3.9 a	4.1 a	4.2 a	4.2 a

*Means followed by the same letter in the same row and same soil moisture level are not significantly different, Duncan's Multiple Range Test, $\alpha = 0.05$.

Table 2. Effects of 2 plant growth regulators on the leaf extension rates of St. Augustinegrass maintained under 2 soil moisture levels and glasshouse conditions.

Weeks following Treatment	Leaf extension rate (mm d^{-1})					
	Optimal Soil Moisture			Suboptimal Soil Moisture		
	Untreated	Flurprimidol	Mefluidide	Untreated	Flurprimidol	Mefluidide
2	9.8 a*	4.0 b	1.4 b	5.8 a	2.3 b	1.5 b
3	7.8 a	0.4 b	0.1 b	4.6 a	0.7 b	0.5 b
4	6.1 a	0.1 b	0.2 b	4.0 a	0.3 b	0.1 b
5	4.4 a	0.0 b	0.5 b	3.6 a	0.1 b	0.0 b
6	3.9 a	0.0 c	1.8 b	2.8 a	0.1 b	0.1 b
7	6.1 b	0.1 c	8.6 a	5.8 a	0.1 c	3.7 b
8	6.5 b	0.6 c	10.2 a	6.2 a	0.1 b	6.5 a
9	7.0 b	2.2 c	10.5 a	7.1 a	0.4 b	7.3 a
10	6.8 b	2.8 c	10.3 a	7.0 b	0.7 c	9.1 a
12	4.3 b	3.4 b	6.7 a	3.0 b	0.6 c	5.8 a
13	5.1 ab	3.7 b	6.5 a	4.1 b	1.0 c	5.5 a
14	4.7 ab	3.3 b	6.0 a	4.6 a	0.8 b	5.8 a
15	4.2 a	2.9 b	4.4 a	3.6 a	0.9 b	4.4 a
16	8.5 b	8.4 b	10.2 a	9.1 a	3.0 b	11.2 a
17	8.4 a	7.5 a	8.8 a	9.4 a	3.6 b	10.3 a
18	8.2 ab	7.6 b	9.0 a	9.8 a	4.3 b	10.9 a
19	9.0 a	8.7 a	8.7 a	9.3 a	6.1 b	10.0 a
20	4.7 a	4.5 ab	4.1 b	4.7 b	4.4 b	5.9 a
21	6.6 a	6.5 a	6.0 a	5.6 a	5.7 a	6.9 a

*Means followed by the same letter in the same row and same soil moisture level are not significantly different, Duncan's Multiple Range Test, $\alpha = 0.05$.

Table 3. Effects of 2 plant growth regulators on the turfgrass quality of St. Augustinegrass maintained under 2 soil moisture levels and glasshouse conditions.

Weeks following Treatment	Turfgrass quality (1-9; 9=best)					
	Optimal Soil Moisture			Suboptimal Soil Moisture		
	Untreated	Flurprimidol	Mefluidide	Untreated	Flurprimidol	Mefluidide
3	8.7 a*	8.0 a	8.7 a	9.0 a	5.3 b	8.3 a
5	8.7 a	7.3 b	7.0 b	8.7 a	7.0 b	7.3 ab
7	8.7 a	6.7 b	7.7 ab	8.3 a	6.0 b	7.0 b
9	7.7 a	6.3 b	7.0 ab	8.0 a	5.3 c	7.0 b
14	8.7 a	7.3 b	9.0 a	8.7 a	6.0 b	8.7 a
15	8.3 ab	7.3 b	9.0 a	8.0 a	6.3 b	8.7 a
16	8.7 a	8.3 a	9.0 a	9.0 a	6.7 b	9.0 a
17	8.7 a	8.3 a	9.0 a	9.0 a	6.7 b	9.0 a
18	8.7 a	8.7 a	9.0 a	9.0 a	7.7 b	9.0 a
19	8.7 a	9.0 a	9.0 a	9.0 a	8.0 a	9.0 a
21	9.0 a	9.0 a	9.0 a	9.0 a	8.7 a	9.0 a

*Means followed by the same letter in the same row and same soil moisture level are not significantly different, Duncan's Multiple Range Test, $\alpha = 0.05$.

An assessment of vital and mortal stains for determining root hair viability of warm-season perennial grasses

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ABSTRACT

Since root hairs have been shown to actively absorb water and nutrients, characterizing the amount and viability of root hairs is important, such as in the study of the components of drought resistance. The objective of this study was to find an effective, simple-to-use vital stain for root hairs of warm-season perennial grasses. This entailed the growth of individual sprigs of 12 genotypes encompassing six species under greenhouse conditions in plastic conetainers containing sand. The five vital stains assessed were 0.5% Evan's blue, 0.1% methylene blue, 1% congo red, 0.1% phenosafranin and 0.1% neutral red, all in 0.05 N phosphate buffer (pH 7.0). Vital stain effectiveness was determined by the percentage of genotypes in which vitality could be determined using the live/dead color difference, as measured on a scale of 1 to 4, from worst to best. The best stain was Evan's blue which was able to determine vitality in 100% of the genotypes tested, with an average color difference value of 3.3. The effectiveness of the other five stains were as follows: 66% for methylene blue, 58% for congo red, 50% for phenosafranin and 25% for neutral red, which had color difference values between 2.3 and 2.4.

The recent resurgence of interest in the mechanisms of drought resistance in plants has stimulated studies in root morphology and root-environment interactions. Traditional methods of describing roots in research have included mass, length, and number with little attention to root hairs. Yet, root hairs are one of the major water absorptive cells of the plant (1). Thus understanding their location, enumeration, and physiological condition under non-limiting and limiting soil moisture levels is essential:

The objective of this study was to find a vital stain which could distinguish between functioning (live) and nonfunctioning (dead) root hairs over a collection of the most common species of warm-season perennial turfgrasses. The specifications desired in a root hair viability stain for perennial grasses are confining. The stain needs to work quickly, be definitive, not require extensive and expensive equipment, and should not require exotic chemicals or procedures. Such a simple-to-use stain could be used in the field by non-technically trained personnel with minimal cost for equipment and supplies. No fluorescent stains were considered in this study since they require a very expensive fluorescent microscope, expensive chemicals, and highly trained personnel.

Root hairs or trichoblasts are differentiated root epidermal cells with usually one 'papillae' like projection into the rhizosphere. Although all of their functions and physiological responses have not yet been delineated, a few have been well documented. Caillox (1) showed that root hairs, besides passively absorbing water, do actively absorb and excrete water in a non-osmotic way that is linked to metabolism. While the presence of root hairs adds surface area and root length to a plant, the ability to actively absorb water by live root hairs could increase effective absorptive surface by a larger factor than that indicated by the added surface area and length. Foehse and Jungk (4) showed that the formation of root hairs is strongly influenced by the supplies of phosphate and nitrate ions in the

plant. Itoh and Barber (6) concluded that actual phosphate ion uptake by the plant correlated well with root surface area only when the root surface area of root hairs was included in the calculation of total root surface area. These studies suggest that root hairs are involved in ion uptake and that measurements of root length and surface area alone, may provide insufficient data.

Previous vital stain studies have shown a variability in stain uptake between species as well as between root hairs. Popesco (10) observed variability in stain uptake by root hairs, when studying water absorption of root hairs. Ward et al. (13), while using congo red to enhance the visibility of wheat roots, determined that stain uptake varied between roots and species of such annual grasses as wheat (*Triticum aestivum* L. 'Moro' and 'McDermid'), barley (*Hordeum vulgare* L. 'Steptoe'), triticale (*X Triticosecale* 'Witmack 204'), oats (*Avena sativa* L.) and sorghum (*Sorghum bicolor* L. Moench). These monocots stained more intensely than the dicots, rape (*Brassica napus* L.), alfalfa (*Medicago sativa* L.), peas (*Pisum sativum* L.), soybeans (*Glycine max* L. Merr.), safflower (*Carthamus tinctorius* L.) and sugarbeet (*Beta vulgaris* L.). Zhirmunskaya and Markina (16) also noted variability in the uptake of the stains, methylene blue and bromothymol blue, by pea (*P. sativum* 'Moskovskii 766'), 'Moskovskii 121' barley, corn (*Zea mays* L. 'Odesskaya') and wheat (*T. aestivum* 'Karsnozernaya') due to herbicide exposures. Widholm (14) in his search for a vital stain to use in determining the viability of cultured plant cells of tobacco (*Nicotiana tabacum* L.) pith, tomato (*Lycopersicon esculentum* Mill.) stem, garden carrot (*Daucus carota* L.) root, germinating rice (*Oryza sativa* L.) seed and soybean (*G. max)* stem also observed variability in stain uptake between cells and species.

These observations suggest that one must survey several stains to find the best vital stain for a species. This also implies that attention must be paid to sample size as well as the characteristic colors of live and dead root hairs. The

appearance of a dramatic color difference between live and dead root hairs in a species for a particular stain may be insignificant if there is no consistency among root hairs, roots and plants.

MATERIALS AND METHODS

Plants. Six species of warm-season, C-4, perennial turfgrasses encompassing 12 genotypes were characterized in this study. The turfgrass species and genotypes used were: bahiagrass (*Paspalum notatum* Flugg. 'Argentine' and 'Pensacola'); seashore paspalum (*P. vaginatum* Sw. 'Adalayd'); St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze 'Texas Common'); centipedegrass (*Eremochloa ophiuroides* [Munro.] 'Georgia Common'); zoysiagrass (*Zoysia japonica* Steud. 'Meyer') and the F_1 zoysiagrass hybrid (*Z. japonica* x *Z. tenuifolia* Willd. ex Trin. 'Emerald'); and bermudagrass (*Cynodon dactylon* [L.] Pers. 'FB119' and 'Texturf 10') and the F_1 bermudagrass hybrids (*C. dactylon* x *C. transvaalensis* Davy 'Tifdwarf', 'Tifway' and 'Tifgreen').

Each genotype was vegetatively propagated from uniform, individual sprigs with 1 to 3 cm of root length. Individual sprigs were planted (15 per genotype) in plastic conetainers (4 cm diameter, 21 cm length) containing a medium-textured sand. Plants were watered daily, fertilized biweekly from a granular fertilizer (19-3.5-8.3 N, P, K, respectively) at a rate equivalent to 1.19×10^{-4} gN m^{-2}, mowed weekly at a 2.5 cm cutting height via hand clippers with clippings removed, and grown under greenhouse conditions maintained between 37° and 26°C, high and low temperatures, respectively. After a minimum of 42 d growth, four healthy plants from each genotype were harvested by removing the conetainer from the soil core and washing the sand away from the roots by soaking and gently shaking in water. Only one genotype was harvested and surveyed for vital stains at a time. This required approximately seven days per genotype. Six adventitious roots, 10 cm long, containing intact primary and secondary branches were excised from each plant, stored in vials containing 0.05 N phosphate buffer with a pH of 7.0, and maintained at 4°C. One vial, designated as a dead control, was placed in a boiling water bath for 10 min, cooled and

stored at 4°C (3).

Stains. Five stains, 6,6'-[(3,3'-dimethyl-4,4'biphenylylene)bis(azo)]bis[4-amino-5-hydroxy-1,3-naphthalenedisulfanic acid tetrasodium salt] [Evan's blue (EB)]; 3,7-diamino-5-phenylphenazinium chloride [phenosafranin (PS)]; 3-amino-7-dimethylamino-2-methylphenazine hydrochloride [neutral red (NR)]; 3,3'-[4,4'-biphenylylene-bis(azo)]bis[4-amino-1-naphthalene sulfonic acid] disodium salt [congo red (CR)]; and 3,7-bis[dimethylamino]-phenazothianium chloride [methylene blue (MB)]; were used at a concentration of 0.1% (w/v) in 0.05 N phosphate buffer, pH 7.0, except for EB at 0.5% and CR at 1.0% (5, 13, 14). The characteristics of each stain are listed in Table 1. Following a maximum of 18 h storage, each of the six roots were cut into 2-cm long sections in preparation for differential staining. One section from each of the six adventitious roots (five live, one dead) was placed in individual petri dishes containing one of five different stain solutions that were prepared weekly from 5x concentrated solutions (stains in distilled water stored at 4°C in brown bottles) (12). Thus, six root sections, each section originating from a different adventitious root, were placed in each of five petri dishes containing a different stain; one section was from the dead control root. The root sections remained in the staining solution for at least 4 h and not longer than 24 h. Afterwards, excess dye was washed away by soaking in multiple baths of first water then 0.05 N phosphate buffer, pH 7.0. The total washing time varied between stains and genotypes, ranging from 45 min for the EB stain of Tx. Common St. Augustinegrass to 72 h for the MB stain of Argentine bahiagrass. A wash was changed or considered complete if the stain darkened the solution opaque or if the solution remained clear or unchanged for 5 minutes, respectively.

All five live root sections were compared directly to the dead control root section from the same plant on the same slide, so there were a total of 20 slides

made for each genotype (five stains x 4 plants). Color differences between live and dead root sections were scored as a numerical value for each of 10 different microscopic fields or 'looks' on each of five live root sections per stain per plant. These numerical values depended on the color difference between live root hairs on live roots and root hairs of the dead control root: 1 was no difference, 2 was a slight difference in tint, 3 was a large difference in tint or shade and 4 was a complete color change. Differences in color intensity were not considered reliable since they were effected by destaining times. If a plant of a species had a dead control root that did not have a consistent shade for the dead root hairs, the control root was designated variable for that stain and all of the looks on the root sections from that plant for that stain were given the value of 1 (Table 2). A negative sign was placed before the numerical value when the observed colors for live and dead root hairs were reverse from what was expected (Table 1). Typical colors of live and dead root hairs were recorded photographically in triplicate for each stain-genotype combination.

Minimum simple sizes were calculated for looks, roots and plants per species per stain from the total data. This determination was necessary because of the high variability in staining between and within plants and genotypes. Minimum sample sizes were determined from the equation, $n = (z_{\alpha/2})^2\sigma^2 / E^2$, where n = minimum sample size, $z_{\alpha/2} = 1.96$ at the $\alpha = .05$ level, σ^2 = the variance of real data and E = one half the acceptable confidence interval (9). In this case, since all differential staining data were recorded as a whole integer (-4, -3, -2, -1, 1, 2, 3, or 4), the confidence interval width (2E) was 1 and E = 0.5. Variances were from: σ_l^2 was the variance of the 10 looks on each root section for each stain, σ_r^2 was the variance of the means of the looks from the five live root sections for each plant and each stain, and σ_p^2 was the variance of the means from each of the 4 plants for each stain and genotype.

RESULTS AND DISCUSSION

Stain effectiveness. The ability of the five stains to differentiate live from dead root hairs varied widely among the 12 genotypes of warm-season perennial grasses (Table 3). The percentage of genotypes in which each stain was successful (absolute color difference ≥ 2) was as follows: 100% for EB; 66% for MB; 58% for CR; 50% for PS; and 25% for NR. The average absolute color difference across all genotypes for each stain was from best to worst, 3.33 for EB, 2.4 for MB, 2.39 for CR, 2.35 for NR and 2.34 for PS. Therefore EB performed significantly better than all of the other stains tested in terms of its ability to determine viability across six species of warm-season perennial grasses and in terms of its large color difference between live and dead root hairs. Two preliminary studies using the eight stains, EB, MB, CR, NR, PS, bromthymol blue, bromophenol blue and 2,3,5-tripehnoltetrazolium chloride, also concluded that Evan's blue was the best stain to determine root hair viability across a collection of 13 warm-season perennial grass genotypes (unpublished data). Evan's blue is apparently as excellent a vital stain for root hairs as it was for onion (*Allium cepa* L.) scale epidermal cells (3), live bean (*Vicia faba* L. 'Minor') root sections (5) and cultures of tobacco pith, tomato (*Lycopersicon esculentum* Mill.) stem, garden carrot root, germinating rice seed, and soybean stem (14).

Neutral red, however, performed very poorly. This may be due to the lower (7.0) pH of the phosphate buffer used in this study which caused a competition between cell wall staining and stain accumulation in vacuoles as reported by Stadelmann and Kinsel (12). A previous study of neutral red's effect on *Tradescantia blossfeldiana* staminal hairs on excised epidermal tissue, epidermal cells exposed to the environment like root hairs, gave a 98.2% successful viability determination in buffer at pH 7.2 (3). When cultured plant cells were tested with several vital stains, especially tobacco (*N. tabacum*) pith, phenosafranin produced

the most consistent test of viability at pH 5.8 (14). Widholm (14) stated that a pH of 5.8, could be optimum for phenosafranin but not for the other stains tested. This appears to be confirmed since methylene blue, a very poor stain in Widholm's study, worked quite a bit better than phenosafranin in this study. Congo red, although an excellent stain to make roots darker (13), was not an excellent stain for root hair viability under the pH and staining conditions of this study. It is encouraging that Evan's blue retained its vital staining ability at pH's of 5.8 (14), 7.0, and 7.2 (3); while the other stains varied in their abilities.

Variation and minimum sample size. Variations in staining occurred among roots of the same plant and among plants of the same genotype for individual stains. Sporadic staining of the dead root control sections was a large source of this variation (Table 2). However, most of this type of variation was experienced with only two species, bahiagrass and zoysiagrass.

To increase the confidence of the sampling procedure, minimum sample sizes were calculated for the number of looks per root section, the number of roots per plant, and the number of plants per species (replicates) based on the variance of the data collected (Table 4). Evan's blue and phenosafranin, each had a minimum sample size for plants below those used in this study. The other three stains, NR, CR and MB, had minimum sample sizes for plants that varied greatly. This variation was due to individual plants in which there were variable control (dead) roots and reversals in live/dead color. This variation could not be explained by the presence or absence of any infectious organism such as mycorrhyzoids, algae or nematodes. The stain showing the smallest of these variations was EB. This stain acts by exclusion from the living cells, so there is no interaction between the stain, EB, and any living cell contents (5). While the variability in a few dead sections of roots could possibly be explained in some cases by false diffuse staining (12) none of the other mechanisms reported by Stadelmann and Kinsel

could explain both the variability and the reversals.

Ramifications of live/dead color differences and variability. The two observations, variability and the reversals, could be direct cellular observations of the long acknowledged phenotypic plasticity of plants (7). Each plant in this study was grown from individual sprigs taken from one plug and planted in its own individual conetainer. Each conetainer could have acted as its own microenvironment, and the plants responded to that environment. Just as *Escherichia coli* can switch from a glucose to a lactose metabolism depending on the carbohydrate source available, perhaps this kind of response is what was observed with root hairs. Minute differences within roots or their rhizosphere such as absence of enzymes and/or changes in pH may have caused differences in stain reaction, even on the same root (12). Or these responses are typical for each genotype. This study proves neither, just that these responses can occur.

If these live/dead color differences are real and not an observation of phenotypic plasticity, then it may be possible to distinguish different genotypes of the same species by their characteristic stains differences. Table 3 suggests this is possible with the bermudagrasses, Tifway and Tifgreen, since the PS stain of one is the reverse of the other. This observation must be confirmed by the use of unknowns under different growing conditions, before it can be called a genotype characteristic.

CONCLUSIONS

Evan's blue met all of the criteria demanded of a vital stain for warm-season turfgrasses. It was simple, easy to use under varying conditions (pH 5.8-7.2) (3, 14) and reliable, giving the same consistent differences between live and dead root hairs over all the warm-season perennial grasses tested. It not only gave the most consistent live/dead color difference, it gave on average the largest live/dead color difference (Table 3).

Some of the more important observations from this study are that NR is an exceedingly poor stain to determine root hair viability over several genotypes of warm-season perennial grasses. Phenosafranin stained the interiors of living cells, so its action is different than that observed by Widholm (14) with respect to warm-season perennial grass root hairs (Table 1). Secondly both PS and MB can reverse live/dead indicator colors for root hairs, depending on genotype. These last two observations reemphasize the need for control (dead) roots during every observation in this kind of investigation.

Preliminary studies with Evan's blue have shown its usefulness as a whole root stain in observing root morphology and growth. Further work in defining the parameters of EB as a root hair vital stain is currently under way. Plasmolysis with 2 M sucrose confirmed that EB stains only dead cells, and we will confirm its observed 94% efficiency in sucrose with comparative nuclear staining. We also are initiating a study to determine whether or not these roots can be stored for future observation of root hairs and their viability. This is important because all of the observations in this paper are from fresh material. One often does not have the facilities and/or time to immediately (24-48 h) stain and observe root sections in more complex experiments.

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TABLES

1. Indicator colors and mode of action of five vital stains assessed in this study.
2. Number of plants per genotype per stain in which dead root control sections stained inconsistently.
3. Characteristic staining patterns of 12 warm-season perennial grass genotypes, in which viability is recorded as a value from 1 to 4, where 1 is no difference and 4 is an extreme difference in color.
4. Determination of minimal sample size for characterizing root hair viability of 12 warm-season perennial grasses using five different vital stains.

Table 1. Indicator colors and mode of action of five vital stains assessed in this study.

Stain Name	Indicator Colors: live	Indicator Colors: dead	Mode of Action	Ref
Evan's Blue	colorless or golden	blue	The molecule is too large to pass through pores of a living cell's wall, so it stains by accumulation in dead cells; areas with large pores or slime can also trap it.	2, 5
Neutral Red	red	pink	It stains living cell walls and cell interiors by electroadsorption.	12
Phenosafranin	red[a]	pink	It stains live cell walls (and possibly cell interiors) by electro-adsorption.	8, 14
Congo Red	red	brown	Stain molecules are directly deposited inside the submicroscopic pore system of the cell walls.	12,13
Methylene Blue	blue	colorless	It stains living cell walls (and possibly cell interiors) by electro-adsorption.	12

[a]Indicator colors for phenosafranin are the reverse of those previously reported by Widholm (14).

Table 2. Number of plants per genotype per stain in which dead root control sections stained inconsistently.[1]

Species/Cultivar	Stains				
	Evan's blue	Phenosafranin	Neutral red	Congo red	Methylene blue
Bahiagrass:					
Argentine	0	4	0	0	4
Pensacola	1	1	1	3	2
Bermudagrass:					
FB119	0	0	0	0	0
Texturf 10	0	0	0	0	0
Tifdwarf	0	0	0	0	0
Tifgreen	0	0	0	0	0
Tifway	0	0	0	0	0
Centipedegrass:					
Ga. Common	0	0	0	0	0
St. Augustinegrass:					
Tx. Common	0	0	0	0	0
Seashore Paspalum:					
Adalayd	0	0	0	0	0
Zoysiagrass:					
Emerald	0	3	1	3	3
Meyer	0	3	2	3	4

[1] There were a total of 240 observation slides, each slide representing one plant stained with one stain; there were four replicates of each genotype. Each slide had 6 root sections each originating from a different adventitious root from the same plant; one adventitious root section was boiled to represent the dead root control section.

Table 3. Characteristic staining patterns of 12 warm-season perennial grass genotypes, in which viability is recorded as a value from 1 to 4, where 1 is no difference and 4 is an extreme difference in color.

Species/Cultivar	Stains				
	Evan's blue	Phenosafranin	Neutral red	Congo red	Methylene blue
Bahiagrass:					
Argentine	3.36 a[a]	1.00 c	2.21 b	2.63 a,b	1.00 c
Pensacola	1.87 a	1.32 a	0.36 a	1.03 a	1.60 a
Bermudagrass:					
FB119	2.50 a	1.66 b,c	1.10 c	1.76 b	1.82 b
Texturf 10	3.50 a	2.66 b	1.46 c	2.22 b	2.34 b
Tifdwarf	3.14 a	1.10 b	1.76 a,b	2.24 a,b	0.72 b
Tifgreen	4.00 a	-2.66[b]c	1.31 b	1.31 b	-2.45 c
Tifway	3.57 a	1.27 b	1.16 b	0.13 b	-2.64 c
Centipedegrass:					
Ga. Common	3.74 a	2.21 b	1.33 c	2.50 b	2.14 b
St. Augustinegrass:					
Tx. Common	3.88 a	2.02 c	1.00 d	2.70 b	2.74 b
Seashore Paspalum:					
Adalayd	3.21 a	2.83 a	3.07 a	2.71 a	-3.48 b
Zoysiagrass:					
Emerald	3.46 a	1.19 b	1.37 b	1.09 b	1.16 b
Meyer	3.70 a	1.00 b	1.13 b	1.14 b	1.11 b

[a] Means followed by the same letter, within the same row are not significantly different, Duncan's Multiple Range Test ($\alpha = 0.05$).

[b] Negative sign indicates a reversal of staining color between live and dead root sections.

Table 4. Determination of minimal sample size for characterizing root hair viability of 12 warm-season perennial grasses using five different vital stains.

Species/Cultivar	Stains														
	Evan's blue			Phenosafranin			Neutral red			Congo red			Methylene blue		
	ℓ	r	p[a]	ℓ	r	p	ℓ	r	p	ℓ	r	p	ℓ	r	p
Bahiagrass:															
Argentine	4.1[b]	0.9	5.0	0[c]	0	0	5.9	8.0	10.7	6.5	8.5	2.2	0	0	0
Pensacola	7.2	7.1	7.0	3.2	1.2	2.7	2.2	1.4	32.4	0.5	0.06	0.04	0.2	0.9	22.1
Bermudagrass:															
FB 119	6.3	15.4	3.9	6.9	3.2	2.2	1.3	1.0	0.3	7.2	2.3	4.0	9.0	6.1	1.7
Texturf 10	3.3	3.7	2.5	9.3	5.1	3.9	3.3	2.1	2.8	6.0	8.3	1.5	6.2	5.4	7.9
Tifdwarf	7.0	0.9	11.7	2.2	1.6	0.6	6.3	1.9	11.5	8.0	8.6	5.7	5.2	0.7	65.9
Tifgreen	0	0	0	7.5	5.1	3.7	3.2	6.7	1.2	3.4	2.0	0.9	9.2	13.1	11.4
Tifway	2.3	1.4	2.7	2.6	1.6	1.9	2.0	0.7	0.4	6.3	2.8	45.6	6.5	3.4	15.0
Centipedegrass:															
Ga. Common	2.7	3.6	0.4	7.7	5.5	2.3	4.0	3.0	2.8	8.3	7.7	2.6	8.6	5.6	6.9
St. Augustinegrass:															
Tx. Common	1.5	0.5	0.4	10.1	3.6	5.2	0	0	0	8.4	4.9	1.5	3.6	7.2	4.1
Seashore Paspalum:															
Adalayd	7.2	1.2	0.1	8.6	3.8	6.3	6.8	1.5	1.6	6.5	2.7	7.3	6.7	1.3	0.4
Zoysiagrass:															
Emerald	4.0	3.1	0.04	2.6	1.0	2.2	4.2	1.5	1.2	1.5	0.8	0.4	1.9	1.6	1.6
Meyer	3.5	2.0	0.2	0	0	0	1.6	1.1	0.5	0.4	3.7	1.2	2.4	0.4	0.7
Overall Mean	4.1	3.3	2.8	5.1	2.6	2.6	3.4	2.4	5.5	5.3	4.4	6.1	5.0	3.8	11.5

[a] ℓ = looks; r = roots; p = plants.

[b] Minimum sample sizes were determined from the equation, $n = (z_{\alpha/2})^2\sigma^2 / E^2$, where n = minimum sample size, $z_{\alpha/2} = 1.96$ at the $\alpha = .05$ level, σ^2 = the variance of real data, and E = one half the acceptable confidence interval. In this case all differential staining data were recorded as one of the following integer values, 1, 2, 3, or 4. Since the data must be recorded as one integer or another, the confidence interval is 1 and E = 0.5.

[c] Zero sample sizes occur when all the differential staining data for all the roots of all the plants for that genotype-stain combination were the same.

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INVESTIGATIONS OF ROOT HAIR SIZE, NUMBER, AND DISTRIBUTION OF SEVEN SPECIES OF WARM-SEASON TURFGRASSES

R. L. Green, J. B. Beard, and M. J. Oprisko

INTRODUCTION

Developing an enhanced rooting capability will allow the turfgrass plant to absorb moisture from a greater portion of the soil profile. Delineation of the rooting dimension will contribute to our understanding of the avoidance component of drought resistance. Root hairs make up a large portion of the total root length and total surface area and thus represent a significant site for water and mineral absorption (Dittmer, 1937, 1938, 1949). A root hair is a tubular outward extension of a root epidermal cell. Commonly in research, roots are described in terms of mass (weight) with no consideration of total root length or root hairs. There is a need to characterize the root systems of turfgrasses in terms of total root length including the contribution from root hairs. The objectives of this research, which encompasses several studies are 1) to assess root hair location, density, and size among 13 warm-season turfgrasses, encompassing 9 species, under non-limiting moisture conditions, 2) assess root hair viability, and 3) quantify the degree that root hairs increase total root length and surface area.

Root Hair Instrastructure, Morphology, Development and Distribution

A root hair is a tubular extension of a root epidermal cell. One region is dominated by a huge vacuole where cell-limiting membranes are in contact with very little cytoplasm, while another, normally the growing tip (Tanaka and Woods, 1972) is dominated by the main cytoplasmic mass in which the nucleus is generally found. Root hairs are produced by internal pressure on weaker portions of an equally hardened cell wall. Cellulose and pectic substances are generally considered to be the chief structural components of the root hair wall (Cormack, 1962). Cormack feels that the root hair wall consists of two distinct layers, an inner layer of cellulose and an outer layer of calcium pectate, continuous with corresponding layers in the hair forming cell.

Root hairs have been reported to increase the absorbing surface by a factor of 5 to 18 (Dittmer, 1937). In one study surveying 37 species of field-grown monocots and dicots, root hairs varied from 5 to 17 μ in diameter (1 inch = 25,400 μ) and 80 to 1,500 μ in length (Dittmer, 1949). In a second study Dittmer recorded measurements of both roots and root hairs on a single winter rye (*Secale cereale*) plant grown for four months in a greenhouse. From careful counts of this winter rye plant, he determined that it had approximately 13,800,000 roots with a total length of over 387 miles and a surface area of about 2,550 square feet. The root hairs of this plant numbered approximately 14,000,000,000 with a total length of over 6,600 miles and a surface area of about 4,320 square feet. The total surface area of roots and root hairs was over 130 times the total exposed surface of the top, even when counting both sides of the blades. In a later study, Dittmer (1938) measured root and root hairs of 3-inch diameter and 6-inch deep plugs of field grown Kentucky bluegrass (*Poa pratensis* L.). Based on his measurements, he estimated that Kentucky bluegrass would have approximately, per cubic inch of soil, 2,000 roots and 1,000,000 root hairs with a combined length of over 4,000 feet and a surface area of about 65 square inches.

There are a number of observations on the effect of environmental factors on root and root hair development. Dittmer (1937) found that a single winter rye plant grown in the greenhouse had a total root length of approximately 385 miles. Rye plants grown in the field under competition had a total root length of about one percent of plants grown in the greenhouse. These findings are in close agreement with data published by Pavlychenko (1937). He found that the root system of a wild oat (*Avena fatua*) plant grown out of doors in competition had a total length of 0.6 miles while that of a nearby plant grown free of competition measured 54.3 miles. In the same study Dittmer (1937) observed that the number of root hairs also differ considerably for plants grown in the greenhouse and those grown under field conditions. There were 10 times as many root hairs per unit length on main roots of field rye as on the indoor plants, while the secondary roots on outdoor plants had 3 times as many, and the tertiary roots had twice as many. Snow (1905) working with *Zea mays* and *Pisum satium* and Roberts (1916), who also studied both monocotyledonous and dicotyledonous plants, state that root hair production is in inverse proportion to the elongation of the epidermal cells. They maintain that root hairs will be produced on practically all epidermal cells if these cells are suppressed. They attribute this to diminished oxygen supply, low temperature, greater abundance of water, or increase of osmotic pressure in the adjoining cortical cells.

Other factors observed to influence root hair formation include oxygen concentration (Maroti, 1950), growth medium (Rosene, 1954), and accumulation of bicarbonate ions (Kopp, 1948).

Root hairs usually are assumed to be short-lived, being destroyed in a few days or weeks by changes associated with secondary thickening (Tanaka et al., 1972). In some species, however, root hairs may become suberized or lignified and persist for months or even years (McDougall, 1921; Hayward and Long, 1942).

Water Absorption by Root Hairs

Much work has been done on the physiological aspects of water absorption by individual root hairs. Hayward et al. (1942) with their device for measuring entry of water into roots, reached the conclusion that the absorbing zone can be roughly superimposed on the root hair producing zone. Rosene (1943) and Cailloux (1943) proved by actual measurements on individual root hairs that they possess the ability to absorb water. Cailloux (1972) has defined parameters of absorption of water from experiments of measuring water absorption of individual root hairs. Several include 1) root hairs do absorb water, 2) once absorption of water is initiated, absorption rate is not altered by increasing the water stress within root hairs, 3) young root hairs absorb vast quantities of water compared to their size, 4) absorption of water is not proportional to the surface of a root hair in contact with water, but rather cytoplasmic mass must be in contact with outer cellular membranes for absorption to take place, 5) the capacity for absorption decreases with age, and 6) though not included as a parameter, an impressive number of published papers show that metabolism is involved in absorption of water.

Ion Absorption by Root Hairs

A significant amount of work has been done describing nutrient uptake as affected by soil and root properties. Bouldin (1961) estimated mathematically that the total flux across root hair surfaces may be 3 to 10 times greater than the flux across

the surface of the central root cylinder. Using a similar rational Nye (1966) stated that root hairs increase absorption by the root because they can rapidly exploit the soil between the hairs and therefore they have the effect of extending the effective root surface to their tips. This argument was assisted by the discovery that root hairs accumulate ions intensively (Lauchli, 1967), and by the calculation that the presence of root hairs of Italian ryegrass (*Lolium multiflorum*) enhanced potassium uptake by 77% compared with roots without root hairs (Drew and Nye, 1969).

Root hairs have been shown to contribute to phosphate uptake by several plant species, including Russian thistle (*Salsola kali* L.), tomato (*Lycopersicon esculentum* Mill), and lettuce (*Latuca sativa* L.), but not wheat (*Triticum aestivum* L.), carrot (*Danchus carota* L.), or onion (*Alluim cepa* L.) (Itoh and Barber, 1982). Their calculations from a model show that a large part of the root hair zone of wheat was within the P depletion zone due to uptake by the main root. These findings concerning wheat are in agreement with work of Bole (1973) who indicated that ion diffusion does not appear to be a limiting factor when root demand is low and hairs can then add little to the efficiency of the root system. Thus root hairs facilitate ion uptake by the root only when this process is limited by diffusion of ions from the medium to the root surface. Roots with root hairs therefore have an advantage over hairless roots in soil, but not in a water culture. Length of root hairs, root hair density, and root hair radius all influence predicted P uptake, with root hair length being the most significant factor (Itoh and Barber, 1982; Foehse and Jungk, 1983). Caradus (1981) indicated longer root hairs do have a positive effect on white clover (*Trifolium repens* L. cv. Tamar) plant growth and in the field, this effect may be unimportant since it appears that mycorrhiza have an overriding effect.

MATERIALS AND METHODS

The 13 warm-season turfgrasses characterized in the root hair investigations included Adalayd seashore paspalum (*Paspalum vaginatum* Swartz), Argentine and Pensacola bahiagrass (*Paspalum notatum* Flugge), FB 119 and Texturf 10 bermudagrass (*Cynodon dactylon* [L.] Pers), Tifgreen and Tifway bermudagrass (*C. dactylon* x *C. transvaalensis*), Common and Texoka buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.), Georgia Common centipedegrass (*Eremochloa ophiuroides* [Munro] Hack), Texas Common St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze), Emerald zoysiagrass (*Zoysia japanica* x *Z. tenuifolia* Willd. ex Trin), and Meyer zoysiagrass (*Z. japonicia* Steud). They were grown under greenhouse conditions in PVC columns, 5-cm (2 inch) diameter by 122-cm long (48 inches), which housed flexible plastic tubings, 5-cm diameter by 121-cm long, containing screened and washed masonry sand. Pre-rooted, uniform plant propagules were transplanted, watered via automatic drip irrigation, and fertilized semi-weekly. Four replications of each cultivar were grown.

All species were harvested following 76 days growth. The entire root system was separated from the soil core by gentle washing with water. The longest adventitious root (a root arising from the crown) was located and root sections, 2.54-cm (1 inch) long, along with their primary branches (branches arising from the adventitious root) and secondary branches (branches arising from primary branches), were sampled at 15-cm (6 inch) intervals, starting from the root cap. Each root section was placed in a vial and sequentially submerged in a paraformaldehyde solution, 25% ethanol, and 50% ethanol, and then stored under refrigeration in 70% ethanol for subsequent microscopic determination of number of primary branches, and root hair number, size, and

distribution on adventitious roots, and primary and secondary branches.

RESULTS

Significant differences among the warm-season turfgrasses were evident for number of primary branches and for root hair density. The number of primary branches arising from 1-cm (0.4 inch) long sections of adventitious root, averaged over all depths, following 77 days growth, ranged from 12 for Pensacola bahiagrass to 38 for Adalayd seashore paspalum. Number of root hairs arising from 1-mm (1 inch = 25.4 mm) root lengths of adventitious root, averaged over all depths, ranged from 32 for Pensacola bahiagrass to 224 for Tifgreen bermudagrass. Root hair density along the adventitious root increased as the distance from the root cap increased for most species. Apparently, root hair density along adventitious roots of warm-season turfgrasses is related to age with older sections (closer to the crown) having a greater root hair density than younger sections (closer to the root cap). Root hair number on primary and secondary branches were similar but lower than on adventitious roots. Number of root hairs arising from 1-mm root lengths of primary branches, averaged over all depths, ranged from 20 for Pensacola bahiagrass to 138 for Tifgreen bermudagrass.

Length of root hairs arising from adventitious roots varied considerably among the warm-season turfgrass species. Average length ranged from 0.068 mm for Common buffalograss to 0.519 mm for FB 119 bermudagrass. Root hairs on primary and secondary branches were generally shorter than on adventitious roots, ranging from 0.041 mm for Pensacola bahiagrass to 0.345 mm for Texturf 10 bermudagrass.

The turfgrass rooting characteristics when grown under favorable growth conditions can be summarized as follows.

*Bermudagrass had long adventitious roots with a high-medium number of primary branches and a high-medium number of root hairs on all roots and branches. Root hairs were long.

*Adalayd seashore paspalum had medium-short adventitious roots with a very high number of primary branches and a high number of root hairs on all roots and branches. Root hairs were medium in length.

*Zoysiagrasses had medium-short adventitious roots with a medium-low number of primary branches and a low number of root hairs on all roots and branches. Root hairs were short.

*Bahiagrasses had medium-length adventitious roots with a medium-low number of primary branches and a low number of root hairs on all roots and branches. Root hairs were short.

*Common buffalograss had short adventitious roots with a medium-low number of primary branches and a medium-low number of root hairs on all roots and branches. Root hairs were medium-short.

Depending on the species/cultivar, root hairs made up from 72 to 99% of the total

adventitious root length and from 5 to 65% of the total adventitious root surface area. The mean longest adventitious root of FB 119 bermudagrass, following 77 days growth, had a length of 1.14 m (3.7 ft) and a surface area of approximately 2,861 mm^2 (4.4 in^2), while the length and surface area of all root hairs arising from this individual adventitious root was 75.53 m (247.8 ft) and 3,563 mm^2 (5.5 in^2), respectively. The mean longest adventitious root of Meyer zoysiagrass had a length of 0.31 m (1.0 ft) and a surface area of approximately 918 mm^2 (1.4 in^2), while the length and surface area of all root hairs arising from this individual adventitious root was 1.72 m (5.6 ft) and 81 mm^2 (0.1 in^2), respectively.

Turfgrasses with well developed root and root hair structure (bermudagrass and Adalayd seashore paspalum) also have been found to have a large drought avoidance component contributing to total drought resistance (Kim, 1987); while turfgrasses with a minimally developed root and root hair structure (zoysiagrass and buffalograss) have been found to have a small drought avoidance component that contributes to total drought resistance. Bermudagrass and zoysiagrass are the most drought resistant warm-season turfgrasses (Kim, 1987). However, their drought resistance mechanisms are different because bermudagrass has high drought avoidance and low drought tolerance whereas zoysiagrass has low drought avoidance and high drought tolerance.

Development of an enhanced rooting structure contributes to the drought avoidance dimension of drought resistance. All turfgrass species, particularly those with a small drought avoidance component would benefit from the development of enhanced rooting structure. Our studies indicate there is great variability among the warm-season turfgrasses for root structure development. In most turfgrass areas, wilting is considered unacceptable turf quality. Enhancement of drought avoidance, more so than drought tolerance, is the most likely answer to this problem. Thus, there is a need for the development of an enhanced rooting structure in many turfgrass species and cultivars.

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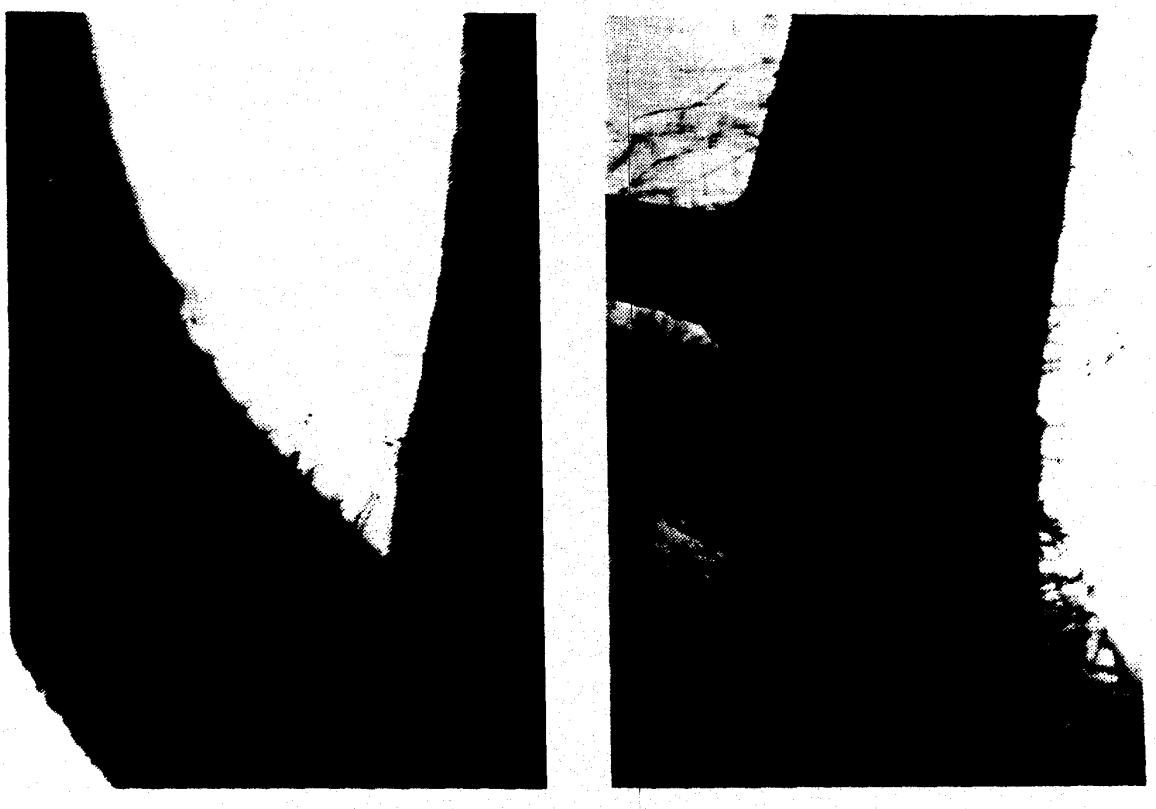
Bermudagrass had a high-medium number of root hairs on all roots and branches; root hairs were long(right). Bahiagrass had a low number of root hairs on all roots and branches; root hairs were short (left).



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TURFGRASS MORPHOLOGICAL CHARACTERISTICS ASSOCIATED WITH THE EVAPOTRANSPIRATION RATE

K. S. Kim and J. B. Beard

With the increasing demand and limited supply of water, many urban areas in Texas are vulnerable to serious water shortages in the immediate future, especially moderate to severe drought conditions (1). In this situation, it is important to use a turfgrass with a low water use rate and/or to introduce cultural practices by which the water use rate can be reduced in existing turfgrass species or cultivars. It is essential to understand the relationship between the plant morphological characteristics and turfgrass water use rates in order to select the best water conserving grasses.

From 1982 through 1984, a series of evapotranspiration rate studies were conducted at the Texas A&M University Turfgrass Field Research laboratory, greenhouses, and controlled environmental growth chambers. During the evapotranspiration rate assessments, key shoot morphological characteristics were also investigated. They included vertical leaf extension rate and leaf width as leaf area components; and short density, the number of leaves per area, shoot/leaf orientation, and the presence of hairs on the leaf surface which represent canopy resistance components.

The evapotranspiration rate was determined by the water balance method, utilizing minilysimeters. The number of shoots and leaves per unit area were counted. Shoot/leaf orientation from 0 to 90 degrees and the presence of hairs were visually rated. Leaf extension rate was determined by measuring the shoot height daily. Leaf width was measured from the third fully expanded leaf blades.

The relative contribution of each characteristic to reducing the evapotranspiration rate and the relative evapotranspiration rate of each grass are shown in Table 1. The sum of each may indicate the comparative water use rate of each grass. However, the relative influence of each characteristic for each grass should also be considered.

Most bermudagrass cultivars possessed a high shoot density, large number of leaves, and relatively slow shoot growth. However, St. Augustinegrass showed a sparse shoot density, and small number of fast-growing large leaves which are fully exposed to the atmosphere. These parameters are considered to be very favorable to more rapid evapotranspiration. The low and high water use rates of bermudagrass and St. Augustinegrass, respectively, were strongly correlated with the above characteristics. Bahiagrass and tall fescue showed the same phenomena as in St. Augustinegrass.

However, buffalograss showed somewhat contradictory characterizations. It possessed a low shoot density, small leaf number, rather vertically oriented shoot/leaf growth, and relatively fast leaf extension, but resulted in low evapotranspiration rate. It is suggested that even with these negative factors, this minimal maintenance grass has narrow leaves, a low total leaf area, and the presence of hairs on the leaf surface which contribute substantially to a lower evapotranspiration rate. Seashore paspalum showed a medium water use rate. The rapid shoot growth might nullify the other positive morphological effects on evapotranspiration rate.

Even though Emerald zoysiagrass possessed a high shoot density, large number of leaves and narrow leaf width it showed a high evapotranspiration rate. Almost vertical leaf orientation caused most of the leaf blades to be totally exposed to the atmosphere,

which might result in a high evapotranspiration rate. A rather horizontal leaf orientation and very slow leaf extension during the 1982 study resulted in a low evapotranspiration rate.

The evapotranspiration rate is the function of water loss from the above ground tissue (shoots) and water uptake from the below ground tissue (roots). Therefore, the previously mentioned above ground plant morphological characteristics cannot fully control the evapotranspiration rate. Still the visual shoot characterizations can provide a relatively good and quick estimate of evapotranspiration rates of turfgrasses. This visual evapotranspiration rate estimate technique has been used successfully at the intraspecies level with both bermudagrass and zoysiagrass cultivars (5).

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Table 1. Canopy resistance and leaf area components for nine warm-season turfgrasses which are associated either positively or negatively with the evapotranspiration rate.

	Relative Evapotrans-piration Rate	Canopy Resistance Components				Leaf Area Components	
		Shoot Density	No. of leaves per area	Shoot/ Leaf Orientation	Hairy Leaves	Leaf Extension Rate	Leaf Width
'Tx Common' Buffalograss	Low	--*	--	--	++		+
'Ga Common' Centipedegrass	Low	-	-	++	-	++	-
'Az Common' Bermudagrass	Low	+				-	+
'Tifgreen' Bermudagrass	Low	++	++	+		++	++
'Tifway' Bermudagrass	Low	++	++		+	+	++
'Adalayd' Seashore Paspalum	Medium	+	+	+		--	
'Meyer' Zoysiagrass	Medium	-	-	--	+	-	
'Tx Common' St. Augustinegrass	High	--	--				--
'Emerald' Zoysiagrass	High	++	++	--			+
'Argentine' Bahiagrass	High	--	--	-	+	--	--
'Ky 31' Tall Fescue	High	-	--	--		-	-

* ++: strongly positive contribution to low ET rate.
+: positive contribution to low ET rate.
-: negative contribution to low ET rate.
--: strongly negative contribution to low ET rate.

TEXAS A&M UNIVERSITY
DEPARTMENT OF SOIL & CROP SCIENCES
COLLEGE STATION, TEXAS 77843-2474
(409) 845-7110

November 12, 1987

Dr. Milt Engelke
Texas Agr. Exp. Station
17360 Coit Rd.
Dallas, TX 75252

Dear Milt:

Enclosed please find the data on assessment of drought avoidance and drought resistance for 10 zoysia and 8 St. Augustinegrass cultivars and selections. Included were 4 experimental zoysiagrasses and 3 experimental St. Augustinegrasses which you requested that we evaluate. You will note that 2 of the zoysiagrasses performed very well in terms of both drought avoidance and drought resistance and that 1 of the St. Augustinegrasses performed quite well. As I recall the St. Augustinegrass DALSA 8402 also was one of the more cold hardy selections in our earlier low temperature stress studies. In addition, I recall that the zoysiagrass DALZ 8516 is a selection out of a PI which had exhibited superiority in terms of low evapotranspiration rates in our earlier assessment test. I am sure you are pleased with the results to date. I should point out that this is only one year's data and that a second year's assessment is required before final published conclusions can be made. I should also indicate that this cooperative work is being supported under a grant from USGA Green Section. Please do not hesitate to contact me if you have any questions.

Sincerely yours,

James B. Beard

James B. Beard
Professor

cc: E.C.A. Runge
B. Merrifield
B. Bengeyfield
C. Smith

enclosure

Leaf firing (primarily drought avoidance) and percent shoot recovery (drought resistance) of 10 zoysiagrasses during the 1987 Drought Resistance Field Study. College Station, TX.

Cultivar	Leaf Firing (0-9) on day = 40	Cultivar	Percent Shoot Recovery on day 12 after watering reinitiated
*DALZ 8516	2.8	DALZ 8516	100
*DALZ 8508	3.0	DALZ 8508	100
FC 13521	3.3	FC 13521	100
*DALZ 8501	4.3	DALZ 8501	99
El Toro	4.3	Emerald	95
Emerald	5.0	El Toro	94
Kor. Common	5.0	DALZ 8502	93
*DALZ 8502	5.3	Kor. Common	93
Meyer	6.5	Meyer	91
Belair	7.5	Belair	71
CV	44.3	CV	9.4

*Selections from Dr. M. Engelke of TAES-Dallas.
†Means connected with the same line are not significantly different at P = 0.05 level by Duncan's Multiple Range Test.

NOTE: Represents only the first year of data.

(Kim, Sifers, and Beard)

Leaf firing (primarily drought avoidance) and percent shoot recovery (drought resistance) of 8 St. Augustinegrasses during the 1987 Drought Resistance Field Study. College Station, TX.

Cultivar	Leaf Firing (0-9) on day = 40	Cultivar	Percent Shoot Recovery on day 12 after watering reinitiated
Floratam	0.0	Floralawn	100
Floralawn	0.3	Floratam	100
*DALSA 8402	1.0	DALSA 8402	96
*DALSA 8401	5.3	DALSA 8401	81
Tamlawn	6.3	Tamlawn	73
*DALSA 8403	6.5	DALSA 8403	63
Raleigh	7.3	Raleigh	50
TX Common	7.8	TX Common	48
CV	45.9	CV	23.5

*Selections from Dr. Engelke of TAES-Dallas.
†Means connected with the same line are not significantly different at P = 0.05 level by Duncan's Multiple Range Test.

NOTE: Represents only the first year of data.

(Kim, Sifers, and Beard)

TEXAS A&M UNIVERSITY
DEPARTMENT OF SOIL & CROP SCIENCES
COLLEGE STATION, TEXAS 77843-2474
(409) 845-7110

November 12, 1987

Dr. Arden Baltensperger
Dept. of Agronomy
Box 30
New Mexico State University
Las Cruces, NM 88001

Dear Arden:

Enclosed please find a table summarizing the results of our drought avoidance and drought resistance assessments of 28 bermudagrass cultivars and selections including the 3 selections which you submitted to us early this past summer. I am sure you will pleased at the performance of the New Mexico Sl. I would caution you that this represents only one year's data and that a second year's results are needed before any significant public statements should be made. If you have any questions after reviewing that data please do not hesitate to contact me. You will note that this work is being done on a cooperative basis under support provided by a grant from the United States Golf Association Green Section.

Sincerely yours,

James B. Beard

James B. Beard
Professor

cc: E.C.A. Runge
R. Merrifield
B. Bengeyfield
C. Smith

enclosure

Leaf firing (primarily drought avoidance) and percent shoot recoveries (drought resistance) of 28 bermudagrasses during the 1987 Drought Resistance Field Study. College Station, TX.

Cultivar	Leaf Firing (0-9) on day = 40	Cultivar	Percent Shoot Recovery on day 12 after watering reinitiated
*NM S1	1.3	Ormond	100
FB 119	1.8	NM S1	100
*NM S4	2.5	Tifdwarf	100
Ormond	2.5	Texturf 1F	100
Midiron	3.8	NM 43	100
Tifway II	4.0	NM S4	100
Guyman	4.3	Santa Ana	99
*NM 43	4.8	Guyman	99
A 29	4.8	FB 119	99
Tiffine	4.8	Midiron	98
Midway	5.5	Bayshore	98
Bayshore	6.0	A 22	96
A 22	6.0	Tifway II	96
Vamont	6.0	Pee Dee	96
Tifway	6.0	Tifgreen	95
Texturf 1F	6.0	U 3	94
Tiflawn	6.3	Tiflawn	93
Tifdwarf	6.3	Midway	91
Everglades	6.5	A 29	91
Pee Dee	6.5	Everglades	88
U 3	6.5	Tiffine	85
Santa Ana	6.8	Tifway	80
Texturf 10	6.8	Tifgreen II	75
AZ Common	7.3	Tufcote	73
Tufcote	7.5	AZ Common	73
Tifgreen	7.5	Vamont	72
Tifgreen II	7.8	Sunturf	68
Sunturf	8.0	Texturf 10	65
CV	35.5	CV	15.8

*Selections from Dr. Baltensperger of New Mexico State University.
†Means connected with the same line are not significantly different at P = 0.05 level by Duncan's Multiple Range Test.

NOTE: Represents only the first year of data.

(Kim, Sifers, and Beard)