FOURTH YEAR

PROGRESS REPORT

concerning

PHYSIOLOGICAL INVESTIGATIONS

in

DEVELOPING WATER CONSERVING MINIMAL MAINTENANCE TURFGRASSES AND CULTURAL SYSTEMS

Volume IV

Submitted by:

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I. EXECUTIVE SUMMARY

This report represents the ~~fourth~~ sixth year of intensive research activity devoted to developing water conserving, minimal maintenance turfgrasses and cultural systems. Thus it seems appropriate at this time to present a definitive set of research milestones that have been accomplished to date. They are as follows:

Scientific Contributions:

1. Based on the development of a sophisticated set of physical experiments proved that canopy resistance is the major factor controlling evapotranspiration rates from turfgrasses rather than stomatal resistance or other internal resistances within the plant.

2. Shown that a high canopy resistance based on a high shoot density and more horizontal leaf orientation plus a low leaf area based on a slow leaf extension rate and narrow leaf width are the plant morphological factors that are most significant in controlling evapotranspiration from turfgrasses. This principal has served as the basis for the system used in developing plant markers in a breeding program for selecting low water use rate grasses and also for a diverse rate of modified cultural practices that ensure lower water use rates.

3. Demonstrated that stomatal density and size had little influence on evapotranspiration rates; thus breeding programs should not place emphasis on this dimension.

4. Developed the first comprehensive understanding of root hair morphology and viability among the major warm-season perennial turfgrass species. Based on this work it is evident that a lack of root hair number, length and/or viability can contribute significantly to reduce drought resistance.

5. Have delineated the environmental factors inducing spring root decline and shown that carbohydrate partitioning away from the roots is strongly associated with the root dieback phenomenon.

6. Identified the specific plant morphological and/or physiological characteristics most important in contributing to drought resistance of individual warm-season turfgrass species.

Breeding Contributions:

1. Have developed a rapid simple method for visually rating the evapotranspiration rates of warm-season turfgrasses in clonal nurseries via the high canopy resistance-low leaf area concept.

2. From a breeding strategy standpoint have shown at both the interspecies and intraspecies levels that those species with the most deep, extensive root systems are characterized by a high verdure and shoot growth rate.

3. Found a great range in diversity at the intraspecies level for the canopy resistance and leaf area components controlling evapotranspiration. This indicates that the genetic material is available to the breeder to develop low water use rate cultivars.

4. Have delineated, among warm-season species, the key limiting factors affecting drought resistance. These vary greatly among the major warm-season turfgrasses including shallow rooting, high evapotranspiration rates, slow stomatal closure, minimal wax covering of the leaf/stomatal surface under water stress, and inferior internal tissue water stress tolerance.

Cultural Contributions:

1. For the first time, developed and published a comparison of the relative and potential evapotranspiration rates of the major warm-season and cool-season turf species which can be used as a guide in selecting grasses with low water use rates.

2. For the first time, characterized and published the comparative rooting potentials of the major warm- and cool-season turfgrass species. Under mowing, the rooting depths range from 12 inches to 8 feet.

3. Have investigated and published on the comparative drought resistance of the major warm-season turfgrass species and cultivars. For the first time this type of information is now available in selecting specific turfgrass species and cultivars for unirrigated turf areas.

4. Based on the high canopy resistance, low leaf area concept, have shown specific cultural practices that can be used in lowering the evapotranspiration rate. For the most part these are based on a low leaf area and slow leaf extension rate. Included are a low cutting height, moderate to low nitrogen fertility level, judicious irrigation and the use of shoot growth inhibitors.

5. Shown the lack of effectiveness of stomatal antitranspirants for use in reducing evapotranspiration from turfgrasses.

6. Developed a set of cultural strategies that can be used in enhancing the rate of a root replacement following spring root decline. This system has resulted in a total change in the spring turfgrass cultural strategy compared to what has been used in the past.

II. INTRODUCTION

The original proposed time table for the seven major turfgrass research objectives in developing water conserving, minimal maintenance turfgrasses and cultural systems is shown on the next page. Also included is a 1987 projection of the completion dates for the respective projects. Our progress is reasonably close to the original schedule when one considers the diversity of unknowns in pursuing research in a pioneering area where the exact types of research that may need to be pursued is unknown. Of course, the lowered level of funding after the first three years has necessitated an extension in the time required to complete certain research objectives. The general summary status for each of the research objectives follows:

1. Minimal Water Use Rate -- This research objective will be completed for the most part within the next six months. One exception is the study concerning the influence and interactions among cutting height, nitrogen nutrition level, and potassium nutritional level on water use rates and drought resistance. Problems in the establishment of the experimental area have delayed our initial studies, which are now scheduled to be initiated in 1988. One additional new area of investigation initiated in the next year will involve the characterization of evapotranspiration rates and drought resistance for the three new bermudagrass cultivars evolving from Dr. Baltensperger's program at New Mexico State University, plus three zoysiagrasses and four St. Augustinegrasses from Dr. Engelke's program at Dallas. Requests for these assessments of evapotranspiration rates and drought resistance have been made by these breeders and we will certainly attempt to accommodate them, although it was not part of our original master plan.

2. Enhanced Water Absorption -- General root characterizations at the species and cultivar levels are well advanced as are the mechanistic studies related to the causes of spring root decline. An area not originally planned but which has become a major section of the research in thrust in rooting is the root hair investigations. This is a very time consuming research endeavor that has extended the length of time projected to complete the rooting investigations.

3. Improved Drought Resistance -- Our progress in developing an understanding of the very complex parameters contributing to the drought avoidance and drought tolerance dimensions of drought resistance is far in excess of my expectations. In fact, we hope to be able to complete the majority of the drought mechanistic investigations at the warm-season interspecies level within the originally projected time frame. It should be pointed out that these investigations also involve a cooperative research effort with Dr. Robert Sherman at the University of Nebraska concerning the cool-season turfgrasses.

4. Physiological Basis of Minimal Maintenance Turfgrasses -- After additional preliminary investigations we are now into basic studies regarding the physiological basis for minimal maintenance grasses utilizing both radioactive carbon and radioactive nitrogen. The projected completion date for this work can only be a rough estimate at this time as we will not have a firm idea as to the exact number and types of studies that will be required to finish this study until our current radioactive studies are completed.

5. Improved Water Stress Hardiness -- The research techniques have been developed. It's now just a matter of pursuing intense greenhouse and stress laboratory activities

to generate the needed data.

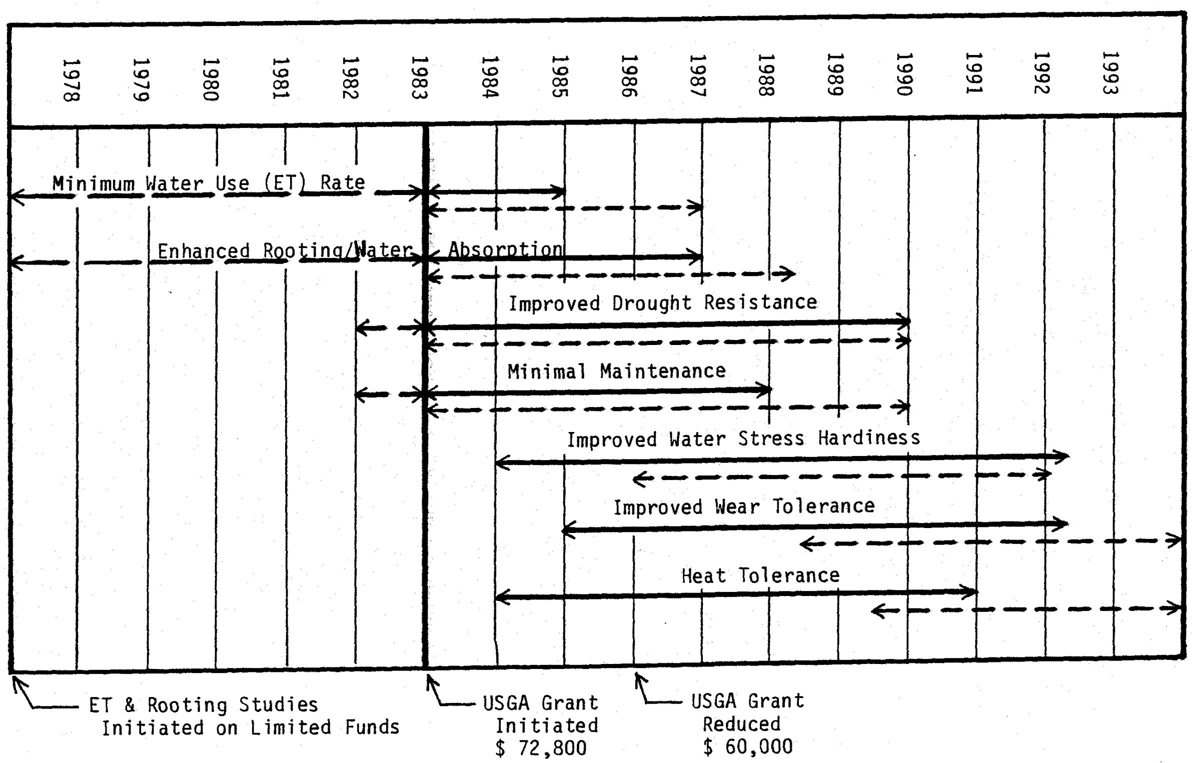
6. Wear Tolerance -- As requested by the USGA Research Committee, we will do our very best to initiate investigations concerning the physiological basis and plant markers for turfgrass wear tolerance on warm-season and cool-season turfgrasses. Initially this will involve primarily field characterizations, followed by laboratory investigations relating to verdure, lignin content, cellulose content, stem structure, stem compression and related morphological characteristics.

7. Heat Tolerance -- A key dimension of the overall research master plan, that has not yet been initiated. The starting date will be dictated by when the higher priority of water stress research is completed as well as the availability of funds.

SCHEDULE OF RESEARCH OBJECTIVES:

Based on original 10 year budget proposal requested (solid line)

Based on reduced 10 year budget now planned (dashed line)



III. IMPLEMENTATION

A. Organization

The research organizational structure has been slightly revised as shown on the following page. 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.

B. Personnel

Dr. Ki Sun Kim has now received his Doctor of Philosophy degree and has assumed the position of Research Assistant formally held by Mr. Steve Griggs. The Agricultural Research Technician position was filled this past spring by Mr. Mark Hall who has a Bachelor of Science degree in the forage area, but has a strong interest in becoming more involved in the turfgrass area. Mr. John Walker formerly held this position.

A very important action taken was the upgrading of position descriptions and salaries for three of the key research positions: Agricultural Research Technician occupied by Mr. Mark Hall, Research Assistant occupied by Dr. Ki Sun Kim, and Research Associate occupied by Mr. Samuel I. Sifers. This judicious action by the administration will give us better assurances of retaining this staff intact which is particularly important for completion of a number of key ongoing investigations. Although their salaries certainly are not competitive with those in the turfgrass industry, they have been brought up to a level where the differential is not exceedingly high and are more nearly in line with their respective contributions to the turfgrass research program.

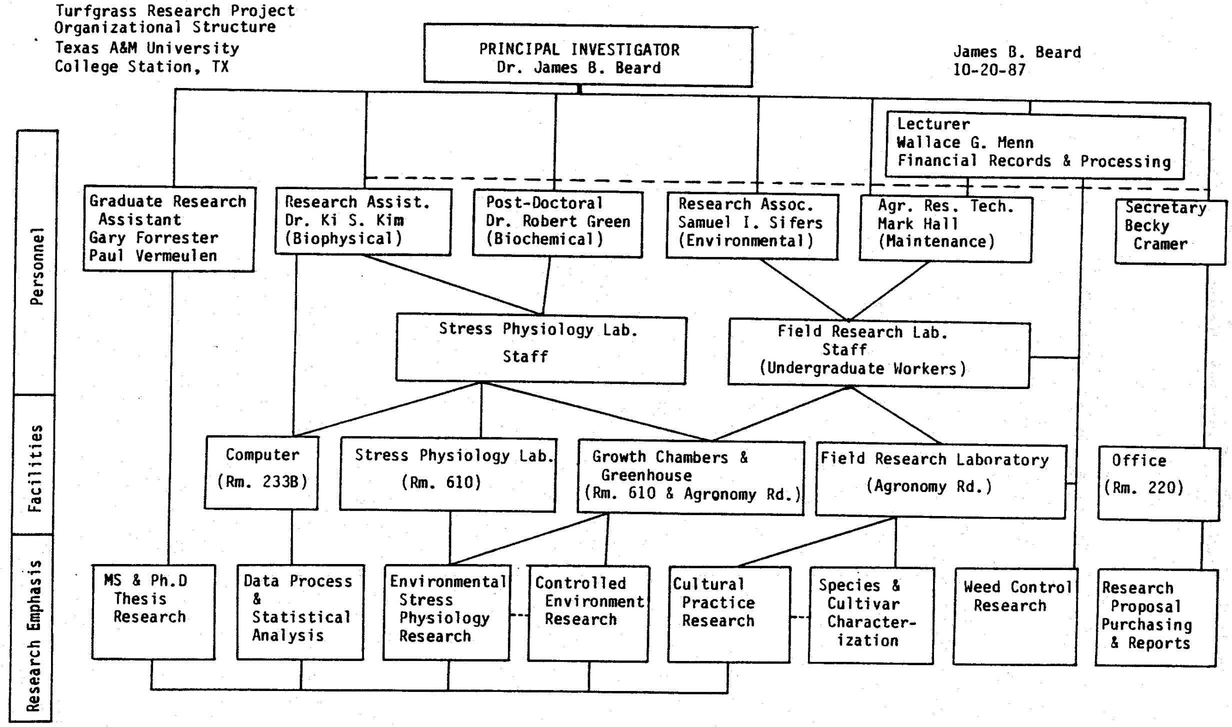
From April through July of 1987, visiting scientist Dr. David Knox from the University of Witwatersrand in Johannesburg, South Africa worked on the turf project. His basic expertise is in the area of turfgrass pathology. A primary goal while at Texas A&M was to become knowledgeable in the establishment and maintenance of a turfgrass field plot laboratory for which he will be given the responsibility upon his return to Africa. While at Texas A&M Dr. Knox pursued investigations concerning the mychorriza populations on representative warm-season turfgrasses. He subsequently characterized their role in water uptake and resultant evapotranspiration rates.

C. Facilities Development

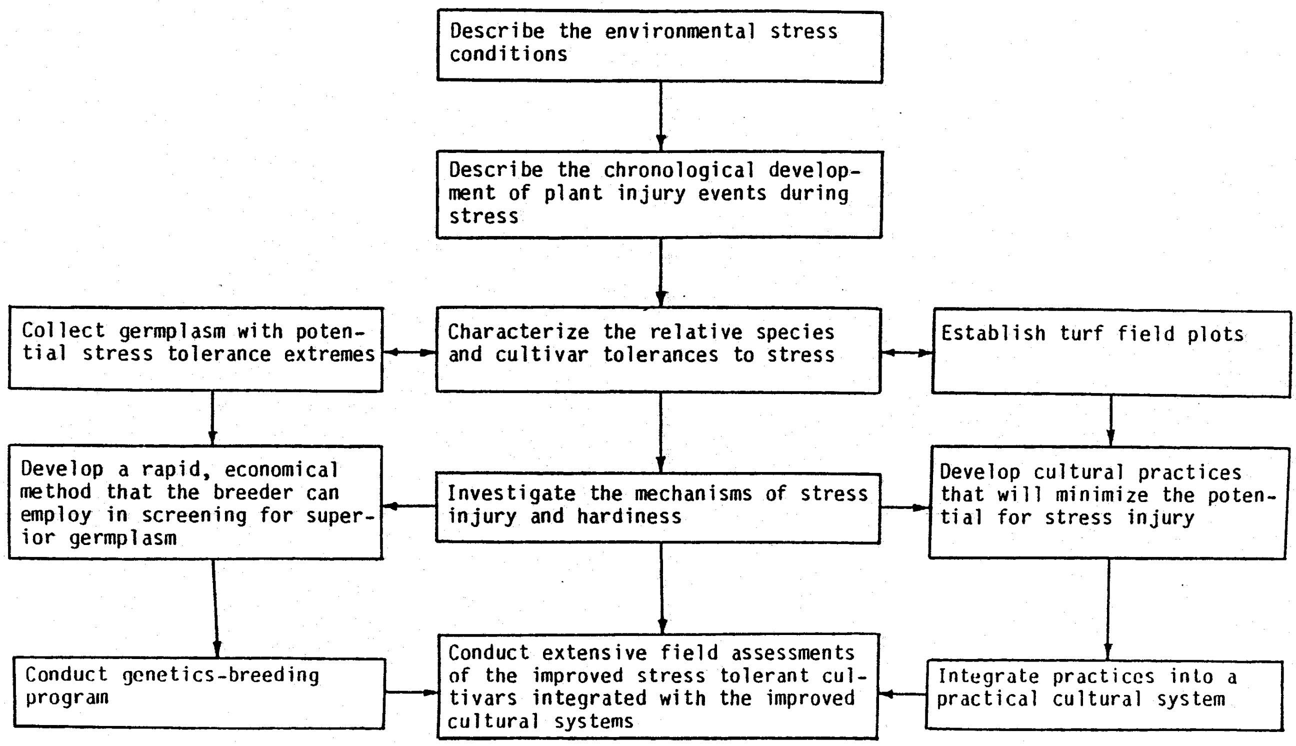
The status of our physical facilities to pursue the key research objectives outlined in this project is good. As originally planned, the relative percentage of our experiments involving greenhouse and laboratory activities has been increasing while the field dimension of our experimental activities has 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.

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

James B. Beard
10-20-87



An environmental stress physiology - genetics model to improve stress tolerance in turfgrasses.



IV. 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 - Eight studies have been completed and five studies are continuing.

B. Enhanced Rooting/Water Absorption - Two studies have been completed, eleven studies are continuing, two are waiting for available space, and one study is on hold.

C. Improved Drought Resistance - Two studies are completed, four studies are continuing and one study is in the planning phase.

D. Mechanistic Basis of Minimum Maintenance Turfgrasses - One study is completed, and four studies have been initiated.

E. Improved Water Stress Hardiness - This is a new research thrust that was part of the overall master plan. The first study was initiated in 1986 and a second study in 1987.

A. OBJECTIVES FOR <u>MINIMAL WATER USE RATE</u>: 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-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.

<u>Status</u> - 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 are now being conducted by Dr. Horst. (Breeding Markers)

Conclusions

1. Visual assessments via the high canopy resistance-low leaf area concept offers a rapid, economical approach for screening large numbers of mowed bermudagrass or mowed zoysiagrass clonal plantings under field conditions for low water use rates.

2. Observer training and enhanced experience with this technique will ensure the best possible accuracy.

A-10 Determine the comparative potential evapotranspiration (PET) rates for 11 zoysiagrasses that have a diverse array of canopy densities, leaf orientations, and leaf extension rates. Initiated in 1985. S. Sifers, R. Green, and M. Engelke.

Status - The first year of a two-year study has been completed, and the initial results analyzed (Tables A-10.1 and A-10.2). The correlations being assessed for seven parameters from 11 zoysiagrass cultivars included the actual evapotranspiration (ET) rates and leaf extension rates (LER) from both the field and those from the environmental simulation chamber, and visual estimates of ET, LER, shoot density (SD), leaf width (LW) and leaf orientation (ORT), together with stomatal densities on the abaxial and adaxial sides of the leaf blades. The second year of confirmation research is now underway. The field studies are completed, results will be analyzed following completion of an environment simulation chamber study this winter. (Intraspecies Comparison and Breeding Markers)

Table A-10.1. Potential Evapotranspiration Rates of 11 Zoysiagrasses Under Well Watered Conditions at the Texas A&M Turfgrass Field Laboratory, College Station, Texas. Based on 1986 Field Data.*

Relating Rate of Evapotranspiration	Zoysiagrass Cultivar
High	KLS 11
	41-21-5
	Korean Common
Medium	FC 13521
	Meyer
	El Toro
	Belair
Low	Emerald
	KLS 13
	KLS 05
	PI 231146

* Caution should be used with this summary as it represents only 1986 data.

Table A-10.2. Stomata Densities of 11 Zoysiagrass Cultivars.

	Number of Stomates per mm²†	
Cultivar	Adaxial Surface	Abaxial Surface
PI 231146	527 a*	334 a
KLS-05	487 ab	268 a
Emerald	470 abc	283 a
Belair	427 bcd	262 a
41-21-5	414 cd	276 a
El Toro	407 cd	289 a
FC 13521	403 d	285 a
Korean Common	394 d	295 a
Meyer	391 d	261 a
KLS-11	381 d	285 a
KLS-13	366 d	257 a

† Means are the average of 5 counts per leaf, 3 leaves per surface, two surfaces per plant, and 3 plants per cultivar.

* Means within the same column with the same letter are not signficantly different, Waller-Duncan K-ratio T test.

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.

<u>Status</u> - 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 are planned for summer 1988. Upon completion of these studies a drought resistance investigation is scheduled (Improved Cultural Systems)

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 - One preliminary greenhouse study was completed assessing 24 unmowed bermudagrass cultivars grown in mini-lysimeters. Three evaluators, Dr.'s Beard, Engelke, and Horst, visually estimated the evapotranspiration rates across three replications of each turf cultivar. These assessments were compared to the actual evapotranspiration rate. Field studies have now been established with assessments planned for the fall 1987. (Breeding Markers)

A-13 Determine the comparative evapotranspiration (ET) rates for 6 centipedegrass cultivars. Initiated in 1986. S. Sifers and M. Hall.

Status - The second year of field studies has been completed. A detailed analysis of the data is under way. It is anticipated that final results will be published after this analysis. (Intraspecies Comparisons)

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 - A new series of studies were initiated in 1986: one each at 65°F (18°C), 75°F (24°C), 85°F (30°C), and 95°F (35°C) using pre-established Penncross creeping bentgrass sod plugs of 1 dm^2 grown in mini-root columns. The 1986 study is completed and the results have been analyzed. Further studies are underway in controlled environment, high-light growth chambers based on the findings from these data. (Mechanistic and Cultural Studies)

Results - Iron, a seaweed extract, and oxamide are showing promise in terms of enhancing creeping bentgrass root growth when under heat stress.

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). Initiated in 1984 with the biochemical studies initiated in 1986. S. Sifers and R. Green.

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. The second phase of experimentation involved two replicated tests for determining the fate of radioactive carbon, assumed to be incorporated into carbohydrate, for St. Augustinegrass turfs, labeled prior to shoot dormancy and then induced into greenup under either SRD or non SRD conditions. If movement of carbohydrate is involved with SRD then the movement of the radioactive labeled carbohydrate between SRD and non SRD treatments should differ. Data from the above experimentation indicate that during maximum spring root decline more radioactive labeled carbohydrate has left the verdure and root sections with SRD plants than non SRD plants. The third phase of this experimentation is to determine the concentrations of total nonstructural carbohydrate and structural carbohydrate along with fate of radioactive carbon in the leaf, verdure, and root sections in St. Augustinegrass. This will involve more analysis of the above mentioned studies. The fourth phase of this experimentation, currently in progress, involves determinations of the fate of ^{14}C radioactive carbon during SRD with St. Augustinegrass and bermudagrass, in leaf bud, stem, and root sections along with concentrations of glucose, fructose, sucrose, starch, and structural carbohydrates. This experimentation refines our understanding of carbohydrate movement during dormancy and SRD. (Mechanistic Study)

Results - Our data indicate the movement of ^{14}C labeled carbohydrate is associated with SRD and is a partitioning phenomenon.

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 initial study and the following study did not give statistically reasonable separations at the interspecies level for the cool-season turfgrasses. A combination of circumstances may have contributed to this, which required some modifications in procedures. Thus, our plans are for the study to be repeated during the fall and winter of 1987. The root-column research facility is being utilized in these studies. (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 - The initial study of rooting capability under heat stress, was conducted during the mid-summer period in Texas. Minimal differentials in rooting capability were found among the twelve major cool-season turfgrasses (see 1985 report). The only exceptions were crested wheatgrass and tall fescue. This study is being repeated under less severe heat stress conditions in 1987 to observe if any additional rooting differentials will occur that would provide a more complete understanding of genetic rooting potentials under varying degrees of heat stress. (Interspecies Comparisons)

B-8 Assess root hair location, density, size, and viability among 13 warm-season turfgrasses under non-limiting moisture conditions (see B-15 for viability). Initiated in 1985. R. Green.

Status - Root Hair Study I and Root Hair Study II were completed in 1986 and were used to develop, test, and refine the growth assembly, cultural and propagation system and the sampling, fixing, and microscopic root hair observation techniques. Root Hair Study II was harvested and analyzed in the Fall of 1986. Root Hair Study III and Root Hair Study IV (confirming studies along with more detailed analyses) were harvested in January of 1987. The plant/root analyses will be completed in December of 1987. (Mechanistic Study)

Results - Results from Root Hair Study II show that significant differences among the major warm-season turfgrasses are evident for the number of primary roots and for root hair density and length (Tables B-8,1-4). Secondly, root hair density along the adventitious root increases as the distance from the root cap increases. Lastly, depending on species/cultivar, root hairs constitute from 72 to 99% of the total adventitious root length and from 5 to 64% of the total adventitious root surface area (Tables B-8,5 and 6).

Conclusions - Root hair density and length are different among the major warm-season turfgrasses. This in turn affects the root surface area available for absorption of water and minerals. Differences also are apparent among the bermudagrass cultivars.

Table B-8.1. Number of Primary Roots Arising from 1-cm Lengths of Adventitious Root, Averaged Over All Depths, Following 77 Days Growth.†

Adalayd seashore paspalum	19 a*
Tifgreen bermudagrass	11 b
Tifway bermudagrass	11 b
Argentine bahiagrass	9 bc
Texturf 10 bermudagrass	9 bc
FB 119 bermudagrass	9 bc
Emerald zoysiagrass	9 bc
Meyer zoysiagrass	9 bc
Common buffalograss	7 bc
Pensacola bahiagrass	6 c

* Means with the same letter are not significantly different, Duncan's Multiple Range Test, alpha = 0.05.

† Determinations are from counts of the adaxial 180° plane.

Table B-8.2. Number of Root Hairs Arising from 1-mm Root Lengths, Averaged Over All Depths, Following 77 Days Growth.†

Adventitious		Primary		Secondary	
Tifgreen	112 a*	Tifgreen	69 a	Tifway	50 a
Adalayd	112 a				
Texturf 10	105 a	Texturf 10	39 ab	FB 119	25 a
		FB 119	36 ab		
Tifway	86 ab	Adalayd	35 ab	Pensacola	10 a
FB 119	64 ab	Tifway	28 b		
C. buffalo	52 abc				
		Emerald	18 b		
Argentine	29 bc	Meyer	16 b		
Emerald	21 c	C. buffalo	13 b		
Meyer	20 c	Argentine	11 b		
Pensacola	16 c	Pensacola	10 b		

* Means within the same column with the same letter are not significantly different, Duncan's Multiple Range Test, alpha = 0.05.

† Determinations are from counts of the adaxial 180° plane.

Table B-8.3. Length of Root Hairs Arising from 1-mm Root Lengths, Averaged Over All Depths, Following 77 Days Growth.

Adventitious		Primary		Secondary	
	mm		mm		mm
FB 119	0.519 a*	Texturf 10	0.345 a	FB 119	0.227 a
Tifgreen	0.428 a	FB 119	0.282 ab	Tifway	0.145 a
Texturf 10	0.371 ab	Tifgreen	0.279 ab		
				Pensacola	0.057 a
Adalayd	0.239 bc	Adalayd	0.144 bc		
		C. buffalo	0.120 c		
Argentine	0.138 c	Argentine	0.073 c		
Meyer	0.138 c	Tifway	0.073 c		
Emerald	0.102 c	Emerald	0.073 c		
Tifway	0.084 c	Meyer	0.061 c		
Pensacola	0.080 c	Pensacola	0.041 c		
C. buffalo	0.068 c				

* Means within the same column with the same letter are not significantly different, Duncan's Multiple Range Test, alpha = 0.05.

Table B-8.4. Summary of Five Root and Root Hair Characteristics, Following 77 Days Growth.

Characteristic	Bermuda†	Adalayd	Zoysia	Bahia	C. buffalo
Mean length of longest adven. root	Long	Medium-Short	Medium-Short	Medium	Short
No. of primary roots	High-Medium	Very High	Medium-Low	Medium-Low	Medium-Low
No. of root hairs	High-Medium	High	Low	Low	Medium-Low
Length of root hairs	Long	Medium	Short	Short	Medium-Short
Development, secondary root hairs	Yes	No	No	Yes	No

† Tifway bermudagrass is lower than other bermudagrasses for mean length longest adventitious root, number of root hairs, and length of root hairs.

Table B-8.5. Four Characteristics of the Mean Longest Adventitious Root, Following 77 Days Growth.

Cultivar	Surface Area of Root†	Total No. of Root Hairs	Length of Root Hairs	Surface Area of Root Hairs¶
	mm^2		m	mm^2
FB 119	2,861	145,536	75.53	3,563
Texturf 10	2,861	238,770	88.58	4,179
Tifgreen	2,461	219,072	93.76	4,423
Argentine	1,421	32,770	4.52	213
Tifway	1,167	79,808	6.70	316
Pensacola	1,089	13,856	1.11	52
Emerald	918	15,330	1.56	74
Meyer	782	12,440	1.72	81
Adalayd	767	68,320	16.33	770
C. buffalo	559	23,088	1.57	74

† Diameter of adventitious root is approximately 0.8 mm.

¶ Diameter of root hair is approximately 0.015 mm.

Table B-8.6. Contribution of Root Hairs to Total Root Length and Total Root Surface Area.

Cultivar	% Root Hair Length of Total Length	% Root Hair Surface Area of Total Surface Area
FB 119	98.5	55.5
Texturf 10	98.1	59.4
Tifgreen	99.0	64.2
Argentine	88.9	13.0
Tifway	93.5	21.3
Pensacola	71.9	4.6
Emerald	81.0	7.5
Meyer	84.7	9.4
Adalayd	98.2	50.1
C. buffalo	87.6	11.7

B-9 Develop a reliable, practical model for determining the cumulative length of all roots on a soil volume basis. Initiated in 1986. R. Green.

Status - Our project is using a Comair Rootlength Scanner (Port Melbourne, Victoria, Australia) for determining the total cumulative root length in a study investigating the effect of preemergence herbicides on rooting of bermudagrass and St. Augustinegrass. Preliminary data indicate that the instrument is very fast, sensitive, and repeatable for measurements of root length up to 100 m. There is some question if fine root branches of bermudagrass are actually being measured, so we will need to verify machine measurements by actual measurements. This hopefully will be done in the next six months. (Mechanistic Study)

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

Status - A root-column facility has been constructed. Turfs were planted during the spring of 1987 and will be harvested in the fall of 1987. The study is progressing quite well. (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 (see B-15 for viability). 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 under refrigeration in jars containing ethanol. Analysis will be initiated during the winter of 1988. A confirming study will be initiated as time allows. (Mechanistic Study)

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

Status - Inoculation experiments were conducted in the summer of 1987 in the greenhouse investigating the effect of mycorrhizal infection on water use rate of the major warm-season turfgrasses. The water balance method, previously described, was used in this experiment which was completed in July. The data are being currently analyzed. (Mechanistic Study)

Results - 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.

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

Status - Our first objective was to find a stain for determining root hair viability. The stain must be fast and simple to use and not require excessive knowledge or technique.

Results - A total of eight vital and mordant stains were surveyed with five giving positive results. These five stains were then tested for their ability to differentiate live and dead root hairs among the major warm-season turfgrass species (Table B-15.1). Evans blue was found to be the best stain and it also allowed for observation of fine root structure, such as age of various layers of root tissue.

The use of Evans blue as a vital stain was verified through other procedures for determining viability. First we found a 95 percent agreement between the use of Evans blue and sucrose (Table B-15.2). Secondly, preliminary work has been completed in the area of comparing Evans blue with the presence or absence of a nucleus as visualized by phase contrast or by staining with a nuclear stain (Table B-15.3). Visualization of the nucleus under phase contrast is difficult and uncertain but our data may suggest the presence or absence of a nucleus does not determine root hair viability. Hopefully, the use of a nuclear stain, such as acridine orange will verify this.

The major warm-season turfgrasses were analyzed for root hair viability (Table B-15.4). Root sections were stored in phosphate buffer from one to three months prior to analysis. To verify our storage technique, fresh root sections were analyzed for root hair viability (Table B-15.5). More work is required to understand the effects and limits of storage in phosphate buffer. Currently it appears that, with some species, root hair viability is decreased while with other species it is increased.

The major cool-season turfgrasses were analyzed for root hair viability from fresh root sections (Table B-15.6). Prior to the analysis, minimum sample sizes were determined (Tables B-15.7 and .8).

Conclusion - A successful technique for determining root hair viability has been developed. Storage techniques and sampling procedures are continuing to be developed.

Table B-15.1. Characteristic staining of five stains on roots of thirteen warm-season turfgrasses.

Species	Cultivar	Stains[a]				
		Evans blue[b]	Phenol saffranin[c]	Neutral red[d]	Congo red[e]	Methylene blue[f]
Bahiagrass	Argentine	+++[g]	+	--	--	--
	Pensacola	+	+	--	--	+++
Bermudagrass	FB119	+++	++	++	++	++
	Texturf 10	+	--	--	+	++
	Tifway	++	+	++	++	--
	Tifgreen	+++	--	--	--	--
Buffalograss	Common	+++	--	++	++	--
	Texoka	+	+	+	--	--
Centipedegrass	Ga. Common	+++	+	--	--	--
St. Augustinegrass	Tx. Common	+++	--	--	--	--
Seashore Paspalum	Adalayd	+++	+	--	++	--
Zoysiagrass	Emerald	+++	--	+	--	+
	Meyer	+++	--	++	+	--

[a]All stains were used at a concentration of 0.1% in 0.5 N phosphate buffer, pH = 7.0, except for Evans blue (0.5%) and congo red (1%). Sections of adventitious roots with primary and secondary branches were placed in stain solutions, daily prepared from 10x stock solutions stored at 4° C, for 15 to 30 min, depending on individual stains, then excess dye washed away by soaking in multiple baths of first water then 0.5 N phosphate buffer, pH 7.0 (total washing time required from 15 min for methylene blue to 45 min for Evans blue). Root sections stained with congo red were washed in 95% ethanol.

[b]Live root hairs were clear or golden; dead root hairs (boiled) were blue.

[c]Live root hairs were pink; dead root hairs (boiled) were red.

[d]Live root hairs were red; dead root hairs (boiled) were pink or clear.

[e]Live root hairs were pink; dead root hairs (boiled) were brown.

[f]Live root hairs were clear; dead root hairs (boiled) were blue.

[g]The stains ability to differentiate live and dead root hairs were graded on the following basis: +++ = easily differentiable, ++ = good contrast, + = can tell a difference, and -- = no difference. Based on four individual observations of root hairs arising from adventitious roots and primary and secondary branches from plants replicated three times and grown for 133 days in PVC columns containing sand. Plants were harvested and sections of adventitious roots with primary and secondary branches were stored in vials containing 0.5 N phosphate buffer, pH 7.0, under refrigeration. Root sections were stored no longer than three weeks.

Table B-15.2. Root hair viability: a comparison of Evans blue and sucrose determinations.

Column	Description[b] Root location:[c]	Texas C. St. Augustinegrass[a] A	1°	2°	Tifgreen bermudagrass A	1°	2°	AVG
A	Live by EB-Live by Sucrose	71[d]	35	42	131	151	--	--
B	Live by EB-Dead by Sucrose	1	6	4	8	7	--	--
C	Dead by EB-Live by Sucrose	4	5	3	6	0	--	--
D	Dead by EB-Dead by Sucrose	84	98	39	78	33	--	--
T	Total Root hairs observed	160	144	88	223	191	--	--
	A+D/T % Agreement	96.9	92.4	92.0	93.7	96.3	--	94.3
	B/T % Disagreement	0.6	4.2	4.5	3.6	3.7	--	3.3
	C/T % Disagreement	2.5	3.5	3.4	2.7	0	--	2.4
	Live by Evans Blue	72	41	46	139	158	--	--
	Live by Sucrose	75	40	45	137	151	--	--
	Dead by Evans Blue	88	103	42	84	33	--	--
	Dead by Sucrose	85	104	43	86	40	--	--

[a]Texas Common St. Augustinegrass and Tifgreen bermudagrass were grown in containers containing sand. Root sections of adventitious roots, along with their primary and secondary branches were harvested from one plant of each species.

[b]Root sections were first stained in 0.5 N phosphate buffer, pH 7.0, containing 0.5% Evans blue (EB) for 15 min. Sections were then washed in multiple baths of water then in 0.5 N phosphate buffer, pH 7.0. Live root hairs were clear to golden while dead root hairs were blue. Next, the sections were placed in a 20% sucrose solution for 15 min. Live root hairs collapsed while dead root hairs remained intact. Root hair counts were made by characterizing root hairs that were either clear or blue and collapsed or uncollapsed.

[c]Root location is A = adventitious root, 1° = primary branch, and 2° = secondary branch.

[d]Numbers reflect the summation of ten counts, 0.25 mm long, per root location.

Table B-15.3. Correlation of Evans Blue Staining Technique with Presence or Absence of Nucleus.

Species[b]		Root Location & Viability (by Evans blue)[a] Adventitious live	Adventitious dead	Primary live	Primary dead	Secondary live	Secondary dead
T. Common St. Augustinegrass	Nucleated hairs[c]	1	1	32	10	3	1
	Total hairs[d]	5	7	42	42	3	1
Tifgreen Bermudagrass	Nucleated hairs	14	1	--	--	--	--
	Total hairs	15	52	--	--	--	--

[a]Location is adventitious root, primary branch, or secondary branch. Live, dead determined by staining with Evans blue: clear or golden, live; blue, dead. Root sections were stained in 0.5% Evans blue in 0.5 N phosphate buffer, pH 7.0, for 15 min then excess dye washed away by soaking in multiple baths of first water, then 0.5 N phosphate buffer, pH 7.0. Root hairs mechanically damaged or obviously injured were not included in this study.

[b]One adventitious root, along with its primary and secondary branches was harvested from one healthy plant of each species grown in containers filled with sand.

[c]Nuclei visualized by phase contrast. Problem: curvature of root hair prevents visualization of any interior structure.

[d]Total represents counts from ten, 0.25 mm long fields along each root location.

Table B-15.4. Root hair viability of 12 warm-season turfgrasses.

Species/Cultivar	Root Location		
	Adventitious	Primary Branch	Secondary Branch
	% Viability[a]		
Bahiagrass - Argentine	68.3	82.7	71.5
Bahiagrass - Pensacola	47.3	63.3	53.0
Bermudagrass - FB119	97.0	97.7	100.0
Bermudagrass - Texturf 10	70.0	79.3	84.3
Bermudagrass - Tifway	62.3	73.0	59.0
Bermudagrass - Tifgreen	60.5	71.5	--
Buffalograss - Common	52.5	91.0	--
Buffalograss - Texoka	76.0	100.0	100.0
Centipedegrass - Ga Common	98.0	73.5	67.0
St. Augustinegrass - Tx Common	81.0	76.0	100.0
Zoysiagrass - Emerald	99.0	97.0	78.0
Zoysiagrass - Meyer	48.0	46.0	65.0

[a]Viability was determined by Evans blue staining of roots of plants grown for 133 days in PVC-columns containing sand. Plants were harvested and root sections stored in vials containing 0.5 N phosphate buffer, pH 7.0, under refrigeration. Root sections were stored 1 to 3 months, depending on species. Percent viability determined by number of live (non-colored) root hairs/total root hairs in 30 individual counts (0.25 mm long) per root location. Each root location was counted from three sections of one individual adventitious root per each plant. Each plant species was replicated 3 times. Root hairs were stained in 0.5% Evans blue in 0.5 N phosphate buffer, pH 7.0, 15 min, then excess dye washed away by soaking in multiple baths of first water then 0.5 N phosphate buffer, pH 7.0. This gentle washing process, insuring minimum damage to the root hairs, may take from several minutes to overnight depending on the density of the root hairs. The characteristic staining will remain for 24 hours with minimum fading and then rapidly disappear as dead root hairs lose cell wall and membrane integrity.

Table B-15.5. Comparison of root hair viability in fresh and stored root sections.

		FRESH[1]					
		Plant 1		Plant 2		Overall	
Species/Cultivar	Root location[3]	L/T[4]	% viability	L/T	% viability	L/T	% viability
Bahiagrass							
Argentine	A	43/43	100	120/160	75	163/203	80.3
	1°	27/27	100	179/188	95.2	206/215	95.8
	2°	21/22	95.5	14/15	93.3	35/37	94.6
	Total	91/92	98.9	313/363	86.2	404/455	88.8
Bermudagrass							
FB119	A	103/103	100	39/45	86.7	142/148	95.9
	1°	42/42	100	26/27	96.3	68/69	98.6
	2°	45/46	97.8	38/38	100	83/84	98.8
	Total	190/191	99.5	103/110	93.6	293/301	97.3
Texturf 10	A	73/73	100	124/125	99.2	197/198	99.5
	1°	113/115	98.3	204/204	100	317/319	99.4
	2°	43/55	78.2	95/97	97.9	138/152	90.8
	Total	229/243	94.2	423/426	99.3	652/669	97.5
Tifgreen	A	75/133	66.4	161/176	82.2	236/309	76.4
	1°	48/68	70.6	206/214	96.3	254/282	90.0
	2°	85/101	84.2	0	0	85/101	84.2
	Total	208/302	68.9	367/390	94.1	575/692	83.1
Tifway	A	163/165	98.8	132/148	89.2	295/313	94.2
	1°	165/168	98.2	73/74	98.6	238/242	98.3
	2°	24/40	60	52/65	80	76/105	72.4
	Total	352/373	94.4	257/287	89.5	609/660	92.3
St. Augustinegrass							
Tx Common	A	34/195	17.4	122/143	85.3	156/338	46.2
	1°	32/87	36.8	82/97	84.5	114/184	61.9
	2°	43/58	74.1	30/40	75	73/98	74.5
	Total	109/340	32.1	234/280	83.6	343/620	55.3
Zoysiagrass							
Emerald	A	83/126	65.9	85/104	81.7	168/230	73.0
	1°	42/45	93.3	33/40	82.5	75/85	88.2
	2°	39/52	75	34/50	68.0	73/102	71.6
	Total	164/223	73.5	152/194	78.4	316/417	75.8

Table B-15.5 (Cont.)

STORED[2]							
Plant 1		Plant 2		Plant 3		Overall	
L/T	% viability	L/T	% viability	L/T	% viability	L/T	% viability
69/138	50	30/33	90.9	79/123	64.2	178/294	60.5
139/174	79.9	70/78	89.7	56/72	77.8	265/324	81.8
0	0	2/3	66.7	39/51	76.5	41/54	75.9
208/312	66.7	102/114	89.5	174/246	70.7	484/672	72.0
48/53	90.6	201/201	100	122/122	100	371/376	98.7
140/147	95.2	237/239	99.2	103/104	99.0	480/490	97.9
75/75	100	230/230	100	69/69	100	374/374	100
263/275	95.6	668/670	99.7	294/295	99.7	1225/1260	97.2
340/386	88.1	500/570	87.7	144/420	34.3	984/1376	71.5
163/173	94.2	484/498	97.2	176/377	46.7	823/1048	78.5
47/50	94	354/374	94.7	110/171	64.3	511/595	85.9
550/609	90.3	1338/1442	92.8	430/968	44.4	2318/3019	76.8
0	0	3/9	33.3	32/36	88.9	35/45	77.8
0	0	29/50	58.0	28/33	84.8	57/83	68.7
0	0	0	0	0	0	0	0
0	0	32/59	54.2	60/69	86.9	92/128	71.9
28/58	48.3	6/12	50	82/92	89.1	116/162	71.6
53/85	62.4	4/5	80	121/158	76.6	178/248	71.8
12/14	85.7	0	0	101/111	90.9	113/125	90.4
93/157	59.2	10/17	58.8	304/361	84.2	407/535	76.1
3/3	100	25/40	62.5	0	0	28/43	65.1
28/37	75.7	0	0	0	0	28/37	75.7
1/1	100	0	0	0	0	1/1	100
32/41	78.0	25/40	62.5	0	0	57/81	70.4
0	0	47/48	97.9	84/84	100	131/132	99.2
0	0	79/84	94.0	75/75	100	154/159	96.9
0	0	40/51	78.4	0	0	40/50	80
0	0	166/183	90.7	159/159	100	325/341	95.3

[1]Fresh plant material consisted of 2 plants, each grown in a container filled with sand. One adventitious root along with its branches was harvested from each plant and immediately stained for viability.

[2]Stored material consisted of 3 plants, each grown in PVC columns (120 cm long), filled with sand (Root Hair Study 4). Three sections of three adventitious roots along with their branches were harvested from each plant and placed in a vial containing 0.5 N phosphate buffer, pH 7.0. The root sections were taken at shallow, medium and deep locations along the adventitious root. Root sections were stored at 4°C for a period of 1 to 3 months, depending on species.

[3]Root location is A = adventitious, 1° = primary branch, and 2° = secondary branch.

[4]L/T = ratio of the number of live root hairs to total number of root hairs. Viability of root hairs was determined by staining root hairs in 0.5% Evans blue in 0.5 N phosphate buffer, pH 7.0, for 15 min then excess dye was washed away by soaking in multiple baths of water then 0.5 N phosphate buffer, pH 7.0. Live root hairs are clear to golden and dead root hairs are blue. Each root section for live and stored material was characterized by counting ten, 0.25 mm long lengths along each root location. This means that for each fresh plant (10 counts) x 1 root section for each root location and for each stored plant (10 counts) x 1 root section x 3 depths for each root location. Data for the 3 depths was combined.

Table B-15.6. Root hair viability of eight cool-season turfgrasses.

Species/Cultivar	Root Location		
	Adventitious	Primary Branch	Secondary Branch
	% Viability[a]		
Chewing's Fescue-Jamestown	93.5 A[b]	96.0 A	97.5 A
Colonial Bentgrass-Highland	93.0 A	98.3 A	97.3 A
Creeping Bentgrass-Penncross	92.3 A	98.0 A	97.0 A
Italian Ryegrass-Annual	94.7 A	97.0 A	97.7 A
Kentucky Bluegrass-Merion	85.3 A	91.0 A	86.7 B
Perennial Ryegrass-Manhattan II	84.0 A	95.0 A	98.0 A
Tall Fescue-Kentucky 31	92.0 A	91.7 A	95.3 A
Tall Fescue-Rebel	87.7 A	93.7 A	95.3 A

[a]Viability was determined by Evans blue staining of roots of plants grown for 124 days in PVC-columns containing sand. Plants harvested immediately prior to staining. All root material was stored in and stained in 0.5 N phosphate buffer, pH 7.0. Percent viability determined by number of live (non-colored) root hairs/total root hairs in 20 individual counts (0.25 mm long) per root location. Each root location was counted from 4 individual adventitious roots per each plant. Each plant species was replicated 3 times except for Manhattan II which was not replicated. Root hairs were stained in 0.5% Evans blue in 0.5 N phosphate buffer, pH 7.0, 15 min, then excess dye washed away by soaking in multiple baths of first water then 0.5 N phosphate buffer, pH 7.0. This gentle washing process, insuring minimum damage to the root hairs, may take from several minutes to overnight depending on the density of the root hairs. The characteristic staining will remain for 24 hours with minimum fading and then rapidly disappear as dead root hairs lose cell wall and membrane integrity.

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

Table B-15.7. Estimation of the number of fields to be counted using known variances from a very large initial sample.[a]

		Root Hairs						
		Total (range = ±2)			Viability (range = ±10)			
Variable		$\bar{x}$	σ^2	n[b]	$\bar{x}$	σ^2	n	range/2 at n=20
Root location	Adventitious	5.89	16.96	16.0	91.7	487.44	18.7	9.7
	Primary branch	5.69	12.59	12.1	93.0	750.61	28.8	12.0
	Secondary branch	6.38	12.44	12.0	96.2	625.72	24.0	11.0
Root No.	1	6.11	15.65	15.0	99.40	166.04	6.4	5.6
	2	4.50	10.04	9.6	89.86	735.55	28.3	11.9
	3	6.03	11.64	11.2	92.18	807.83	31.0	12.5
	4	7.44	17.09	16.4	93.02	848.56	32.6	12.8
	5	6.24	15.42	14.8	96.10	413.06	15.9	8.9
	6	5.53	9.49	9.1	90.70	744.54	28.6	12.0
Plant No.	1	6.28	14.29	13.7	95.35	675.94	26.0	11.4
	2	5.52	10.55	10.1	87.56	741.30	28.5	11.9
	3	6.13	16.92	16.25	97.69	409.14	15.7	8.8
Species No.	1	5.99	14.05	13.5[c]	93.63	625.09	24.0	11.0

[a]All data came from sections of adventitious roots with primary and secondary branches of Kentucky 31 tall fescue grown in PVC columns containing sand for 124 days. The roots were harvested immediately prior to staining. Thiry fields were counted per root location, 3 root locations per root, 6 roots per plant and 3 plants per species. Root locations were adventitious root, primary branch, and secondary branch. The number of counts per field (0.25 mm long) were recorded as the number of live root hairs and the total number of root hairs per field. Percent viability was recorded as L/T x 100. Viability was determined by staining with 5% Evans blue in 0.5 N phosphate buffer, pH 7.0, for 15 min with multiple washes in first H_2O then the buffer. Live root hairs were clear to golden in color while dead root hairs were blue.

[b]N was calculated as follows: $n = (2\ \alpha/2)^2\ \sigma^2/E^2$; where n = number of samples, $z_{\alpha/2}$ is 1.96 at the $\alpha = 0.05$ level, σ^2 is the variance and E = range/2. Ranges were set at 4 or ±2 for the total root hair number and 20 or ±10 for the percent viability.

[c]When n is set at 10 the range becomes 4.5.

Table B-15.8. Check of numerical data -- minimal sample size.[a]

	Total No. Root Hairs		Root Hair Viability	
Variable	n[b]	PR > F	n	PR > F
no. of Fields per root location	14	(α = .05, range = 4)	24	(α = .05, range = 20)
root[c]	4	0.1231	4	0.911
plant[d]	3	0.7470	3	0.510

[a]All data came from sections of adventitious roots with primary and secondary branches of Kentucky 31 tall fescue grown in PVC columns containing sand for 124 days. Plants harvested immediately prior to staining. Thirty fields were counted per root location, 3 root locations per root, 6 roots per plant and 3 plants per species. Root locations were adventitious root, primary branch and secondary branch. The counts per field (0.25 mm long) were recorded as live root hairs, total root hairs counted and percent viability, (L/T) x 100. Viability was determined by staining with 5% Evans blue in 0.5 N phosphate buffer, pH 7.0, for 15 min with multiple washes in first H_2O then the buffer. Live root hairs were clear to golden in color while dead root hairs were blue.

[b]N = sample size.

[c]Error term used was root location (root).

[d]Error term used was root (plant).

B-16 Carbohydrate analysis of warm-season turfgrasses from the actively growing phase through shoot dormancy to shoot greenup phase. Initiated 1987. R. Green.

Status - This project is required for B-5. We are currently developing a technique for the determination of total nonstructural and structural carbohydrates in plant tissue. The second phase will involve a technique for the determination of glucose, fructose, sucrose, and starch concentrations in plant tissues.

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 fall of 1987. (Species Comparison)

Results - Three bermudagrasses and seashore paspalum possessed high drought avoidance, due to the ability to maintain a high leaf water potential (LWP) even after severe water stress. A rooting study (C-4) and a stomatal investigation (C-6) revealed that bermudagrass possessed a relatively deep root system and closed, wax-covered stomata which contributed to drought avoidance. In the PEG study, bermudagrass ranked lower than under field test conditions in terms of the LWP and leaf firing. However, zoysiagrass showed very low leaf firing and also relatively high LWP in the PEG study. St. Augustinegrass, centipedegrass, and seashore paspalum showed very low LWP in the PEG study. Further detailed PEG studies will determine in more depth the type of drought avoidance mechanism of each species.

Conclusions

1. An extensive root system and high wax cover over the stomata contributed to a high level of drought avoidance in bermudagrass, with the latter factor being more important.

2. An extensive root system, especially in terms of the dry weight and the number contributed to the drought avoidance of seashore paspalum and centipedegrass more than the stomatal characteristics.

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 will be conducted during the fall and winter of 1987. (Mechanistic Study)

Results - In the 1985 and 1986 Field Studies, 2 zoysiagrasses, 3 bermudagrasses (Common, Tifgreen, and Texturf 10), and centipedegrass showed good drought resistance as represented by percent shoot recovery. The high drought resistance of bermudagrass and centipedegrass was mainly due to good avoidance in terms of an extensive root system for both species, plus early closure of stomata for bermudagrass.

Zoysiagrass showed excellent drought resistance in spite of the poor drought avoidance, which indicated a very excellent drought tolerance mechanism. These studies revealed that zoysiagrass and St. Augustinegrass showed no leaf firing under LWP of -2.05 MPa, whereas bermudagrasses showed leaf firing around 4.0 [redacted] This means that zoysiagrass and St. Augustinegrass can tolerate water stress to a very low LWP with minimum plant injury. A very extensive root system and this excellent drought tolerance should have resulted in good drought resistance. However, a very high evapotranspiration rate through open stomata even under very low LWP caused St. Augustinegrass to rank very low in terms of drought resistance.

Good shoot recovery of bahiagrass and buffalograss even after very high leaf firing indicated good drought tolerance via "dormancy". However, more detailed studies are needed to draw sound conclusions regarding this dormancy mechanism.

The proline contents in the shoots were measured to investigate the role of proline in the drought tolerance mechanism via internal osmoregulation. The data showed a significant correlation between proline content and leaf firing, but not with overall drought resistance. Proline accumulation apparently is indicative of stress degree rather than a preventive mechanism against water stress.

Conclusions

1. Zoysiagrass, bermudagrass, and centipedegrass showed good drought resistance. The major mechanism involved for each species was distinctly different. The drought resistance of zoysiagrass was mainly due to excellent drought tolerance, whereas the good drought resistance of bermudagrass was due to avoidance mechanisms.

2. Bahiagrass and buffalograss showed fair shoot recovery from high leaf firing. This indicates a "dormancy" mechanism.

3. Proline content seemed to be indicative of the degree of water stress rather than a preventive mechanism against water stress.

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 in a Doctoral Thesis which was mailed to each USGA Research Committee member. Rooting potential of the same grasses when under water stress will be investigated in PVC root columns which are currently being established in the greenhouse. Water stress will be imposed during the winter of 1987. (Mechanistic Study)

Results - The study under non-limiting soil moisture condition showed that Texturf 10, Tifgreen, and Tifway bermudagrasses, and St. Augustinegrass had long root extensions. Centipedegrass, St. Augustinegrass, and seashore paspalum possessed a high total root dry weight; and St. Augustinegrass, zoysiagrass, and centipedegrass showed a high number of roots in the upper 60 cm layer.

Conclusions - Although the drought resistance phase of this root column study has not been completed, several preliminary conclusions can be made by comparing the root column data to field data.

1. Rooting characteristics can not solely explain the drought avoidance of turfgrasses. Even with good rooting potential, St. Augustinegrass showed very poor drought resistance and avoidance, whereas bermudagrasses showed good drought resistance and avoidance.

2. On-going root hair studies will reveal in-depth factors associated with roots in relation to the drought avoidance of each grass.

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.

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. Scientific papers will be drafted after the statistical analyses are completed. (Intraspecies Comparisons)

Results - Three years of field studies were completed with the warm-season turfgrass species and a one year study was finished for 3 cool-season species. The third year of field study revealed a consistent ranking of cultivars for each species in terms of leaf firing and shoot recovery from drought stress.

All cool-season species turned completely brown only 10 days after the initiation of water stress, whereas most warm-season species and cultivars retained their green color more than 50% until 40 days after drought stress was initiated. Among the cool-season species, Kentucky bluegrass showed the slowest leaf firing followed by perennial ryegrass and tall fescue, in that order.

However, there was no shoot recovery among the cool-season grasses. Since the cultural system and temperatures during the study were much different from their native habitat, more studies are needed to determine the comparative drought resistance of cool-season turfgrasses. This is being accomplished through cooperative studies with the University of Nebraska.

Among the bermudagrass entries, 3 selections from New Mexico State University and 'Guyman' showed very excellent drought resistance.

Among St. Augustinegrass selections, two (8401, 8402) out of 3 selections from TAES at Dallas showed good drought resistance but not as good as Floratam and Floralawn. There was no significant difference among centipedegrass cultivars. Among zoysiagrasses, 2 selections from Dallas (8516, 8508) showed the best drought resistance, followed by FC13521, 8501, and El Toro.

Conclusions

1. Significant drought avoidance and resistance differentials were found among the cultivars of bermudagrass, zoysiagrass, and St. Augustinegrass.

2. New selections from the New Mexico State and Dallas TAES breeding programs showed promising drought resistance.

C-7 Assess the relationship between rooting characteristics and drought resistance of 12 major cool-season turfgrasses. To be initiated in 1988. S. Sifers and K. Kim.

Status - In the planning stage. (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 are the parameters being measured and observed. The preliminary status was combined with objective C-5 which was beneficial. However, a separate study will now be required wherein we can allow plant nitrogen depletion and stress to occur before the drought and recuperation events. A more detailed study is planned for 1988. (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. A field study will be conducted in 1988 to verify observations. This study is a duplication of objective D-1, except the target species is zoysiagrass rather than bermudagrass. Root observation columns have been planted with Meyer, Emerald, and El Toro zoysiagrasses. These cultivars were selected as they possess leaf width differentials from narrow to broad and a variety of rooting characteristics. (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 - Preliminary attention is being given to carbon balances and partitioning driven by relative shoot to root growth priorities. (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 - 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 June, 1987. All plant, soil, and fertilizer nitrogen quantitative inputs and final amounts are being determined. All fertilizer nitrogen in the various plant parts and in the soil is being determined to calculate the fertilizer uptake efficiency and loss. The quantities of organic and extractable soil nitrogen are being determined. The analyses will be completed in December of 1987. (Mechanistic Study)

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-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 greenhouse proline investigation will be conducted under PEG solution in the winter of 1987. (Mechanistic Study)

Results - An initial study with 3 species in the controlled environmental growth chamber showed a relationship between the rate of proline increase in the shoot and leaf firing and shoot recovery from drought stress. This suggested that proline may serve as storage compound for recovery after stress rather than as a preventive mechanism for osmoregulation in the tissue. However, in the field study, no significant correlation was found between proline content and shoot recovery among 11 turfgrasses. There existed a significant correlation between proline content and leaf firing.

Conclusions

1. Proline accumulation during water stress seemed to be indicative of water stress rather than a preventive osmoregulation mechanism among warm-season turfgrasses.

2. The relationship between proline content and shoot recovery was not clear and needs more detailed investigation.

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 1987. K. Kim.

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 work will now be initiated during late 1987. The TAMU transmission electron microscope will be used for the cellular investigation. (Mechanistic Study)

V. 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.

A minimal amount of time has been available for drafting research manuscripts during the past winter due to the serious illness of the Project Leader, Dr. J. Beard. Currently, this research project has in the publication phase the following.

A. Minimal Water Use Rate - 5 publications

B. Enhanced Rooting/Water Absorption - 1 publication

C. Improved Drought Resistance - 2 publications

D. Basis of Minimal Maintenance Turfgrass - 1 publication

They are summarized as follows.

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 has been written, approved by the USGA Green Section, and will be published in 1988 March-April issue of Crop Science. 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 has been written, approved by the USGA Research Committee, and by Crop Science for publication. 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, S. Griggs, and R. Green.

Status - The warm-season turfgrass interspecies study was completed in 1985, and the draft of a scientific paper has been written. A final draft has been submitted to CSSA for review and possible publication in Crop Science. The draft will be sent to the USGA Research Committee for review and approval in the near future.

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 has been completed in the water/heat stress environmental simulator. The draft of a scientific paper is now in revision based on Department reviews. (Species Comparisons)

A-6 Determine the potential for using turfgrass leaf growth inhibitors in water conservation. Initiated in 1983. W. Menn and D. Johns.

Status - The scientific paper is in the draft preparation stage. (Improved Cultural Systems)

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. They will be submitted for departmental review and subsequently will be submitted to the USGA Research Committee for approval. (Species Comparison)

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 now in preparation. (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 now in preparation. (Intraspecies Comparisons and Mechanistic Study)

VI. BUDGET STATUS

There has been continued emphasis on cost containment during this past 12 months in view of the reduced budget support by the USGA for the project. An actual shortfall developed which was partially made up by a grant of $10,000 provided by the ChemLawn Services Corp. This was a very welcome contribution.

VII. PUBLICATIONS

The scientific publication activity has been summarized in Section V. In addition to the technical research papers being drafted and/or submitted, oral and published abstracts of research supported by the USGA were presented at the American Society of Agronomy Meetings in December of 1986. They are as follows:

1. "Investigations in Root Hair Size, Number, and Distribution of Seven Species of C-4 Perennial Turfgrasses" by R. L. Green and J. B. Beard. 1986 Agronomy Abstracts. p. 134.

2. "Comparative Drought Resistance of Major Warm-Season Turfgrasses" by K. S. Kim and J. B. Beard. 1986 Agronomy Abstracts. p. 136.

   This paper was presented by K. S. Kim and awarded second place in 1986 Crop Science Society of America Turfgrass Graduate Student Paper Contest.

3. "Visual Assessment of Evapotranspiration Rate of Bermudagrass and Zoysiagrass" by S. I. Sifers, J. B. Beard, M. C. Engelke, and G. L. Horst. 1986 Agronomy Abstracts. p. 138.

Three reports of research supported by the USGA are published in the 1987 Agronomy Abstracts, and scheduled to be presented at the American Society of Agronomy Annual 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.

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.

The following 3 reports will be published in Texas Turfgrass Research - 1987 and released to the public during the 1987 Texas Turfgrass Conference which will be held in Houston in December.

1. "Drought Resistance Mechanism Comparisons Among the Major Warm-Season Turfgrass Species" by K. S. Kim, J. B. Beard, and S. I. Sifers.

2. "Plant Characteristics and Responses of Seven Major Warm-Season Turfgrass Species Associated with Their Respective Drought Resistance Mechanisms" by K. S. Kim, J. B. Beard, and S. I. Sifers.

3. "Investigations of Root Hair Size, Number, and Distribution of Seven Species of Warm-Season Turfgrass" by R. L. Green and J. B. Beard.

VIII. 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 have been given before the following.

1. Missouri Lawn and Turf Conference, St. Louis, MO. November, 1986 by J.B. Beard.
2. Southern Turfgrass Conference - New Orleans, Louisiana. November, 1986 by S.I. Sifers.
3. Texas Turfgrass Conference - San Antonio, Texas. December, 1986. Three talks by S.I. Sifers, R.L. Green, and J.B. Beard.
4. TAMU Turfgrass Field Day - College Station, Texas. May, 1987. Three talks by K.S. Kim, R.L. Green, and S.I. Sifers.
5. Pan Pacific Turfgrass Conference - Honolulu, Hawaii. September, 1987 by J.B. Beard.
6. Southwest Turf Conference - Albuquerque, New Mexico. October, 1987 by J.B. Beard.

APPENDIX

Leaf firing (LF) and shoot recovery from 1985, 1986, and 1987 Field Drought Studies. College Station, Texas.

Relative Classification	St. Augustinegrass Leaf Firing	St. Augustinegrass Shoot Recovery	Zoysiagrass Leaf Firing	Zoysiagrass Shoot Recovery	Centipedegrass Leaf Firing	Centipedegrass Shoot Recovery
High	TX Common Raleigh	Floralawn Floratam DALSA 8402	Korean Common *DALZ 8502 Belair Meyer	DALZ 8516 DALZ 8508 FC 13521 DALZ 8501 Meyer	AU Centennial	GA Common
Medium	Tamlawn *DALSA 8403 *DALSA 8401	DALSA 8401 DALSA 8403 Tamlawn	Emerald	El Toro Emerald DALZ 8502	Tenn Hardy AC 26	Oklawn AC 44 Tenn Hardy
Low	*DALSA 8402 Floratam Floralawn	Raleigh TX Common	FC 13521 *DALZ 8501 El Toro *DALZ 8508 *DALZ 8516	Belair Korean Common	GA Common AC 44 Oklawn	AC 26 AU Centennial

* Selection from Dr. Engelke in TAES-Dallas and tested only in 1987.

(Kim, Sifers, and Beard)

Leaf firing (LF) and shoot recovery of bermudagrass cultivars from 1985, 1986, and 1987. Field Drought Studies. College Station, Texas.

Relative Classification	Leaf Firing	Shoot Recovery
High	Santa Ana	NM S1
	Tifgreen	NM S4
	Tifway	NM 43
	Pee Dee	Texturf 1F
	Tifdwarf	FB 119
	Sunturf	Guyman
	Tifway II	Tiflawn
	Everglades	Bayshore
		Ormond
		U 3
		Midway
		Pee Dee
		Tifgreen
		Tiffine
		Midiron
Medium	AZ Common	Tufcote
	Texturf 10	Tifdwarf
	Tifgreen II	Tifgreen II
	†A 22	A 22
	U 2	A 29
	Tufcote	AZ Common
	Tiflawn	Vamont
	†A 29	Everglades
		Texturf 10
		Sunturf
Low	Texturf 1F	Tifway
	Vamont	Santa Ana
	Bayshore	Tifway II
	Midway	
	Midiron	
	Ormond	
	*NM 43	
	‡Guyman	
	Tiffine	
	FB 119	
	*NM S4	
	*NM S1	

*Selections from Dr. Baltensperger in New Mexico State Univ., and Tested only in 1987.

†,‡Tested 1986 and 1987, and 1987 only, respectively.

(Kim, Sifers, and Beard)

Investigations in Root Hair Size, Number, and Distribution of Seven Species of C-4 Perennial Turfgrasses R. L. GREEN* and J. B. BEARD, Texas A&M Univ.

Research was undertaken to determine root hair characteristics of 13 C-4 perennial turfgrasses. The turfgrasses were grown under greenhouse conditions in PVC columns (5 cm diam, 122 cm long) which housed flexible plastic tubing (5 cm diam, 121 cm long) containing washed sand. Pre-rooted, uniform propagules were planted, watered with automatic drip irrigation, and fertilized semi-weekly. Generally, each species was harvested when the deepest adventitious root neared the bottom of the flexible plastic tube which was removed from the PVC column and cut away from the soil core. The entire root system was separated from the soil core by gentle washing with water. Sections, 2.54 cm long, of adventitious root, along with their branches, were harvested at 15-cm intervals, starting from the root cap. Root sections were placed in vials containing a paraformaldehyde solution, taken through an ethanol series, and then stored in 70% ethanol for future microscopic determination of root hair size, number, and distribution. Results revealed substantial differences among the 13 turfgrasses.

Comparative Drought Resistance of Major Warm-Season Turfgrasses. K. S. KIM* and J. B. BEARD, Texas A&M Univ.

Eleven warm-season turfgrasses were evaluated on their comparative field drought resistances. Possible mechanisms were studied in the field, greenhouse, and growth chamber. Cumulative evapotranspiration rates, stomata characteristics, leaf rolling or folding, leaf firing, and rooting potential were measured as being drought avoidance parameters, while percent recovery after rewatering as being an overall drought resistance parameter. Drought tolerance mechanisms were studied by proline content and also estimated from overall drought resistance and drought avoidance data. 'Emerald' and 'Meyer' zoysiagrasses, 'Arizona Common', 'Tifgreen', and 'Texturf 10' bermudagrasses, and centipedegrass ranked high in drought resistance, whereas St. Augustinegrass and 'Tifway' bermudagrass ranked low. Bahiagrass, seashore paspalum, and buffalograss were in the medium range. Drought avoidance and tolerance mechanisms contributed to the drought resistance of turfgrasses together or individually, depending on the species.

Visual Assessment of Evapotranspiration Rate of Bermudagrass and Zoysiagrass. S.I. SIFERS*, J.B. BEARD, M.C. ENGELKE, AND G.L. HORST, Texas A&M Univ. and Texas Agric. Exp. Stn.

A 2-year study assessing the validity and relative accuracy of a technique for visual estimating evapotranspiration rates of 24 bermudagrass and 11 zoysiagrass cultivars was completed. Visual estimates were based on the high canopy resistance-low leaf area concept using canopy orientation, leaf extension rate, leaf width, and leaf-shoot densities as indicators. Visual ratings were compared to potential evapotranspiration measurements obtained using the water balance method with mini-lysimeters. Four observers made estimates directly on both mowed and unmowed turfs growing in field plots. The scores were then averaged. The estimates correlated at a 75% and a 72% accuracy level with the actual potential evapotranspiration measurement in 1984 and 1985, respectively. Thus, visual assessment via the canopy resistanceleaf extension concept, with possible refinements through observer training, offers a rapid, economical approach for screening large numbers of bermudagrass or zoysiagrass clonal plantings.

Characterization of Nitrogen Economy Among the Major Warm-Season Turfgrasses Using Nitrogen Balance and ^{15}N Assay Methodology. R. L. GREEN* and J. B. BEARD, Texas A&M Univ.

The objective of this study was to begin to understand nitrogen use among the major warm-season turfgrasses maintained under a relatively low N regime (minimal maintenance). Uniform plugs, 7.6 cm diam, were planted in plastic pots, 22 cm diam and 21.5 cm deep, containing fritted clay. Plugs were fertilized weekly with a complete nutrient solution (1% ^{15}N) at a rate of 0.12 kg N are^{-1} $month^{-1}$. All N inputs and losses for the duration of the study were determined. Following eight months growth, plants were harvested by plant part, while the soil was subsampled. Total N and atom % ^{15}N were determined for all plant parts and soil. Exchangeable N from the soil was extracted in KCL and determined. Significant differences for fertilizer N uptake, partitioning, and loss were found among the major warm-season turfgrasses.

Drought Resistance of Eleven Major Warm-Season Turfgrasses Under Water Stress Induced by Polyethylene Glycol (PEG). K. S. KIM* and J. B. BEARD, Texas A&M Univ.

To investigate the relative importance of stomatal control, rooting potential, and drought tolerance in contributing to drought resistance, PEG (Mol. Wt. 3500) was used to induce water stress. The grasses were grown on fritted clay-filled plastic cones immersed in the PEG-nutrient solution. The osmotic potential of the solution was gradually decreased from -0.13 to -2.59 MPa. Visual leaf firing (LF) and leaf water potential (LWP) were monitored. Those species which possessed open stomata and low wax accumulation showed much lower LWP. Examples were St. Augustinegrass, centipedegrass, and seashore paspalum. These data indicate that the water balance of these species was maintained primarily by water uptake via a well-developed root system rather than restricted water loss via stomatal control. In contrast, those species which could not maintain a good water status due to a shallow root system even with positive stomatal and wax characteristics in the field, such as zoysiagrass, could maintain a relatively high LWP. The relatively high LF of bermudagrass suggests that the major drought avoidance mechanism is an extensive root system rather than restricted water loss.

Investigations into Carbohydrate Partitioning of Warm-Season Turfgrasses During Spring Root Decline Using ^{14}C Radioisotope Tracer Methods. S. I. SIFERS*, R. L. GREEN, and J. B. BEARD, Texas A&M Univ.

The objective of this study was to determine if partitioning of carbohydrates is involved in spring root decline (SRD) of C-4 turfgrasses. Texas Common St. Augustinegrass and Tifway bermudagrass were planted in PVC root columns (10 cm diam, 30 cm long) containing fritted clay and grown under standard greenhouse conditions for 6 weeks until coverage was complete and uniform. Columns were placed in a 133-L plexiglass chamber and exposed to $^{14}CO_2$ (exposure period was for 45 min with 18.5 x 10^5 Bq, from sodium carbonate-^{14}C, injected per column) and then placed in a growth chamber and conditioned at 4°C into shoot dormancy. One-half of the columns were conditioned for green-up with SRD and the second half were removed to another chamber and conditioned for green-up without SRD. The turfs were harvested before, during and after SRD by separating into leaf, stem, and root fractions and then each fraction was prepared for radioactivity assay by liquid scintillation. Amounts of radioactivity in leaf, stem, and root sections indicated carbon movement from leaf and root tissue to stem tissue during SRD.

Leaf Blade Stomatal Characterizations and Potential Evapotranspiration Rates of 12 Cool-Season, C-3 Turfgrasses

R.L. Green, J.B. Beard, and D.M. Casnoff

Introduction

Stomata is a term that describes pores or "openings" on the leaf blade surface. They comprise only about one percent of the total leaf blade surface area, but perform an essential role in photosynthesis by serving (1) as the major entry point into the leaf for atmospheric CO_2 and (2) as the exit point for the transpiration of H_2O which is the major driving force for water movement within the plant. Stomata open and close by the movement of adjacent specialized cells, called guard cells. Thus, the water status within a plant is influenced by stomata size, shape, and distribution and the plant's control of stomatal disposition (i.e. opening and closing). A study of evapotranspiration of St. Augustinegrass showed that under adequately watered conditions, 20 to 30 percent of actual evapotranspiration rate was controlled by resistance of the leaf epidermis and stomata disposition; evapotranspiration was influenced to a greater extent by aerodynamic resistance and resistance to air mass exchange within the turf canopy (Johns et al., 1983).

No research has been conducted specifically on stomatal frequencies and/or their association with the water use rates of cool-season turfgrasses. This information will be helpful in determining if stomatal traits should be considered in the development of new cool-season turfgrasses with reduced water use rates. The objectives of this study were (1) to characterize the stomatal densities of 12 cool-season turfgrasses (nine species) and (2) to characterize their associated potential evapotranspiration (PET) 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 include annual bluegrass; chewings fescue; Penncross creeping bentgrass; Waldina hard fescue; Bensun, Majestic, and Meriön Kentucky bluegrass; Manhattan II perennial ryegrass; Sabre rough bluegrass; sheep fescue; and Kentucky 31 and Rebel tall fescue. Three replicates of each turfgrass were established and grown under greenhouse conditions in plastic containers, 21 cm diam and 21 cm deep, filled with fritted clay. Turfs were mowed at a 5-cm cutting height and fertilized biweekly with a complete nutrient solution at a rate equivalent to 0.25 kg N are^{-1} (0.25 lb N 1000 sq. ft.) per growing month. The grasses were grown until turf coverage was complete and uniform.

One week before stomatal and water use rate determinations, the turfs were transferred from the greenhouse to a growth chamber and preconditioned in conditions similar to the environmental simulation chamber; day and night temperatures were 22°C (72°F), photoperiod (day length) was 14 hours, and PAR radiation was 500 μE m^{-2} sec^{-1}.

Following preconditioning, the turfs were mowed, immediately sampled for stomatal characterization, and then placed in the environmental simulation chamber for water use rate determinations. Four of the youngest, fully expanded leaf blades were excised from each turf canopy. Two adaxial (upper) and two abaxial (bottom) leaf blade surface impressions were made by first painting a thin layer of polyvinal 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 (Rice et al., 1979). Each impression was placed under a microscope with a 20x occular and the stomata counted within a 1-cm^2 grid which was placed within a 10x eyepiece. Two to three locations on each leaf blade impression were counted.

Immediately following excision of leaf blades for stomatal characterization, turfs were placed in a controlled environmental simulation chamber to characterize water use rates under uniform temperature, relative humidity, light, photoperiod, and wind speed conditions. Day and night temperature was 22°C (72°F), dewpoint was 12°C (approximately 53% relative humidity), photoperiod was 14 hours, and PAR radiation was 1,080 μE m^{-2} sec^{-1}. Potential evapotranspiration was determined for each pot using mini-lysimetry technique and the water balance method as described in previous work by Johns (1980) and by Kim (1983). This method involved determining the weight of water lost in a 24-hour period by calculating the difference between the initial and final weight of each mini-lysimeter (fully turfed pots).

Results

Significant differences in stomatal density were found among the cool-season turfgrasses on both the adaxial (upper) and abaxial (bottom) surfaces. Density of stomates was greater on the adaxial than abaxial surface for all 12 turfgrasses. Previous work with 10 warm-season perennial turfgrasses found the same difference in stomatal density between the two leaf blades surfaces (Casnoff et al., 1985). Turfgrasses highest for adaxial stomatal density include Waldina hard fescue and Penncross creeping bentgrass, while the lowest included Merion Kentucky bluegrass and Kentucky 31 tall fescue. Turfgrasses highest for abaxial surface stomatal density included Penncross creeping bentgrass and annual bluegrass, while the lowest included Sabre rough bluegrass, chewings fescue, sheep fescue, and Waldina hard fescue. Adaxial and abaxial stomatal densities of the cool-season turfgrasses are considerably lower than those found in a study of 10 warm-season perennial turfgrasses (Casnoff et al., 1985). The stomatal densities of the cool-season turfgrasses ranged from 17 to 51 per mm^2 on the adaxial surface and from 0 to 25 per mm^2 on the abaxial surface, while warm-season turfgrasses had much higher stomatal densities ranging from 108 to 468 per mm^2 on the adaxial surface and from 84 to 348 per mm^2 on the abaxial surface.

No relationship was found between an increase in the potential evapotranspiration rate and a higher stomatal density. Potential evapotranspiration rate was found to be negatively correlated with the stomatal densities found on the abaxial side of the leaf in a collection of 10 warm-season perennial turfgrasses (Casnoff et al., 1985). Further, it was found that stomatal size (length and width) was positively correlated with stomatal density. Conversely, Johns et al. (1983), investigating the resistances to evapotranspiration from a St. Augustinegrass turf canopy, concluded that manipulation of stomatal size or frequency would not be a major factor in a breeding program designed to develop water conserving turfgrasses to be grown under irrigated conditions. Data from this research similarly suggest that manipulation of stomatal characteristics would not significantly reduce water use rates in cool-season turfgrasses. Manipulation of turf canopy characteristics, such as density, leaf size and orientation, and growth rate may provide a more beneficial approach to water conservation.

Acknowledgment

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References

1. Casnoff, D. M., J. B. Beard, D. G. Verwers, and S. D. Griggs. 1985. Leaf blade stomatal characterization of ten warm-season C-4 perennial grasses and their association of the water use rate. Texas Turfgrass Research—1985. Texas Agric. Exp. Sta. PR-4314. pp. 10-13.
2. Johns, D. 1980. Resistance to evapotranspiration from St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze) turf. Ph.D. Dissertation. Texas A&M Univ., College Station, Texas. 88 pp.
3. Johns. D., J. B. Beard, and C. H. M. van Bavel. 1983. Resistances to evapotranspiration from a St. Augustinegrass turf canopy. Agron.J. 75:419-422.
4. Kim, K. S. 1983. Comparative evapotranspiration rates of thirteen turfgrasses grown under both nonlimiting soil moisture and progressive water stress conditions. M.S. Thesis. Texas A&M Univ., College Station, Texas. 64 pp.
5. Rice, J. S., E. M. Glenn, and V. L. Quisenberry. 1979. A rapid method for obtaining leaf impressions in grasses. Agron. J. 71:984-896.

Morphological and Physiological Plant Parameters of Bermudagrass Cultivars with Low Nitrogen Requirements

S.I. Sifers and J.B. Beard

Introduction

There is a major need to develop minimal maintenance turfgrass cultivars that can sustain quality, functional turfs. No data are available to indicate which plant growth characteristics might be used to identify bermudagrass (*Cynodon* spp.) selections adaptable to low nitrogen stresses. The objectives of this investigation were (1) to develop baseline data concerning the minimum acceptable nitrogen nutritional levels and (2) to describe the anatomical and/or morphological characteristics associated with low nitrogen stress tolerant bermudagrass cultivars that might be utilized in a breeding program.

Materials and Methods

Four *Cynodon* cultivars—Midway, Tifgreen, Texturf 10, and FB-119—were maintained at three nitrogen fertility levels in the greenhouse. Ten bi-weekly observations of shoot height, internode length, number of stolons, shoot dry weight, turfgrass quality, and leaf tissue nitrogen content were made and then the nitrogen treatments were terminated, followed by five bi-weekly observations of the same plant parameters to develop baseline data concerning the minimum acceptable nitrogen nutritional level for these four bermudagrass cultivars. The morphological and physiological characteristics associated with low nitrogen stress tolerance were then assessed statistically.

Results

Significant differences in morphological characteristics occurred both when nitrogen was supplied and when nitrogen was withdrawn. *Cynodon dactylon* cultivars were more suitable for low or minimal nitrogen maintenance than were the *Cynodon* hybrids. Shoot height, root-rhizome mass to shoot mass ratio, and the length of the third youngest internode of lateral stems were characteristics useful in predicting bermudagrasses with a minimal nitrogen requirement. The minimum nitrogen level recommended for these cultivars to sustain viability is 0.25 lb/1,000 sq. ft. (0.125 kg N a^{-1}) per growing month. Of the cultivars assessed, Texturf 10 was the best turf for low nitrogen stressed environments followed by FB-119. These cultivars appear to have a mechanism which allows them to sustain growth with low levels of nitrogen and to partition the available nitrogen in a manner that sustains both root-rhizome and shoot growth.

Acknowledgment

A major portion of this investigation has been made possible by a grant from the United States Golf Association Green Section. Two additional studies are now underway that address more specific aspects of these two research objectives concerning the physiological basis of minimal maintenance turfgrasses.

References

1. Sifers, S. I. 1986. Plant responses associated with low nitrogen stresses in selected *Cynodon* cultivars. M.S. Thesis, Texas A&M University, College Station, Texas.

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Criteria for Visual Prediction of Low Water Use Rates of Bermudagrass Cultivars

S.I. Sifers, J.B. Beard, and K.S. Kim

Introduction

One of the key components in a water conservation strategy is the selection of turfgrass species and cultivars possessing low water use rates. Investigations utilizing the water balance method with mini-lysimeters indicated significant differences in evapotranspiration rates occur at both the interspecies and intraspecies levels under both nonlimiting soil moisture and progressive water stress conditions (2). Evapotranspiration rates did not show large relative changes whether maintained under uniform or optimum cultural practices. However, all turfgrass species exhibited higher evapotranspiration rates when maintained at their optimum nitrogen fertility and cutting height (3). This was attributed to a more rapid vertical leaf extension rate. Those turfs with a low leaf extension rate, high shoot density, low leaf area, and prostrate growth habit tended to have low evapotranspiration rates (1, 2, 3, 4, 5). This investigation was undertaken to assess the validity and relative accuracy of a technique utilizing those plant parameters for visually estimating evapotranspiration rates of turfs; thus, providing a rapid method to screen thousands of clonal turfgrass plantings under field conditions.

Materials and Methods

This study was conducted on field plots, established in 1978 at the TAMU Turfgrass Field Research Laboratory in College Station, which contained 24 bermudagrass (*Cynodon* spp.) cultivars in three replications. They have been maintained at a cutting height of 1 inch (2.5 cm) and have received 1 lb N/1,000 sq. ft. (0.5 kg are^{-1}) per growing month, as well as irrigation as needed to prevent visual wilt. No visual disease or insect injury symptoms were evident at the time of the evapotranspiration evaluations.

The evapotranspiration measurements were accomplished using the water balance method with minilysimeters. At the same time these measurements were taken, visual ratings of predicted comparative evapotranspiration rates were made on both the turfs in the mini-lysimeters and the turfs in the field plots. Visual parameters used were canopy orientation, leaf extension, leaf width, and leaf/shoot density. These parameters were combined into a high canopy resistance—low leaf area concept, with the basic underlying premise that turfs with prostrate canopy orientation, low leaf extension rates, narrow leaf widths, and high shoot densities would have low evapotranspiration rates. The visual estimates made by four observers (J. B. Beard, M. C. Engelke, G. L. Horst, and S. I. Sifers) were averaged and statistically compared to the actual evapotranspiration rates measured by the previously mentioned water balance method utilizing mini-lysimeters.

Results

The visual estimates correlated at a 75% accuracy level with the actual evapotranspiration rates with a range among observers of 83% to 62%. The observers were 81% accurate in identifying the six bermudagrass cultivars with the highest actual evapotranspiration rate and 81% accurate in identifying the six cultivars with the lowest actual evapotranspiration rate.

In summary, visual assessment using the high canopy resistance—low leaf area concept offers a rapid, economical approach for screening large numbers of mowed bermudagrass clonal plantings under field conditions for low water use rates. Further testing should be conducted on unmowed bermudagrasses and other turfgrasses to determine if this technique has universal application.

Acknowledgment

A major portion of this investigation has been made possible by a grant from the United States Golf Association Green Section. Additional studies are now underway to evaluate the effectiveness of the prediction technique on other species.

References

1. Biran, I. B. Bravdo, I. Bushkin-Harav, and E. Rawitz. 1981. Water consumption and growth rate of 11 turfgrasses as affected by mowing height, irrigation frequency, and soil moisture. Agron. J. 73:85-90.
2. Hicks, S. K., C. W. Wendt, and M. C. Engelke. 1984. Water use rates and canopy temperatures of turfgrass species. Texas Turfgrass Research—1984. Texas Agric. Exp. Sta. PR 4214. pp. 82-94.
3. Kim, K. S., J. B. Beard, L. L. Smith, and M. Ganz. 1983. Comparative evapotranspiration rates of 13 turfgrasses. Texas Turfgrass Research—1983. Texas Agric. Exp. Sta. PR 4156. p. 39.
4. Kim, K. S. and J. B. Beard. 1984. The effects of nitrogen fertility level and mowing height on the evapotranspiration rates of nine turfgrasses. Texas Turfgrass Research—1984. Texas Agric. Exp. Sta. PR 4213. pp. 77-81.
5. Kim, K. S. and J. B. Beard. 1985. Comparative assessment of wilting tendency of warm-season turfgrasses. Texas Turfgrass Research—1985. Texas Agric. Exp.Sta. PR 4213. pp.77-81.

Comparative Drought Resistances Among Major Warm-Season Turfgrass Species and Cultivars

K.S. Kim, S.I. Sifers, and J.B. Beard

Introduction

More than 50 percent of the water use in urban areas is for the maintenance of landscaping materials which include turfgrass. In Texas alone, there are 3.2 million acres of turf area, and thus the water use by turfgrass is an important water conservation issue in urban areas.

A green lawn area provides an aesthetically pleasing landscape; with a number of functional roles such as evaporative cooling, soil and dust stabilization, safety, and reductions in noise, glare, and air pollution. Without water, turfgrass goes dormant, and may eventually die. A brown turf can add an attractive dimension to landscapes; however, its functional roles such as evaporative cooling, safety, and air pollutant absorption are minimized. Furthermore, dead turf areas may need to be replaced eventually, and probably at a higher cost.

Turf quality ratings (Beard, 1966; Minner and Butler, 1985) and percent shoot recovery (Gaskin, 1966) were the major parameters used to monitor drought resistance of cool-season turfgrasses, mostly at the intraspecific level. They reported intraspecific differences in drought resistance among the turfgrass cultivars (varieties) within species.

Most research on turfgrass drought resistance has been limited to cool-season species. The objective of this study was to evaluate warm-season turfgrass species and cultivars for their comparative drought resistance.

Materials and Methods

During the summer of 1985, eleven turfgrasses for the interspecies study, plus 22 bermudagrass, 6 zoysiagrass, 5 St. Augustinegrass, and 6 centipedegrass cultivars for the intraspecies study, were evaluated for their survival under severe progressive drought stress at the Texas A&M University Turfgrass Research Field Laboratory in College Station, Texas. The turfgrass species and cultivars used are listed in Table 1.

A special site was prepared for this drought study. The root zone consisted of 2 feet (0.6 m) of masonry sand over drain lines with a clay subgrade. The experimental area was divided into 5 subsites for studies involving interspecies, bermudagrass cultivars, zoysiagrass cultivars, St. Augustinegrass cultivars, and centipedegrass cultivars. Each subsite consisted of a randomized block design with four replications. Mature turf plugs 4 inches (10 cm) in diameter were transplanted, 3 feet (0.9 m) apart, from the nearby cultivar characterization plots. The turfs were allowed to root from May to July, or 75 days. Insecticide and nutrient solution were applied during this period. Irrigation was applied by pop-up rotary sprinkler system as needed to prevent visual wilt.

At the end of July, the irrigation was discontinued, and the turfs exposed to progressive drought conditions. Whenever there was a possibility of rain, a plastic cover was installed above the plot area to avoid possible water input. Each turf perimeter was trimmed weekly during this period. Leaf firing was visually assessed daily until the end of the study. The turfs were rewatered 48 days after initiation of the drought stress, and recovery was assessed by the percent green shoot development

Results

Interspecies Study

The shoot recovery and leaf firing of turfgrass species and cultivars during the 1985 drought study are shown in Tables 1 and 2. Shoot recovery represents the relative drought resistances of each grass. Meyer and Emerald zoysiagrasses showed high shoot recovery. Throughout the drought period of 48 days they maintained over 50 percent green shoots. The bermudagrasses also showed high shoot recovery, with the exception of Tifway which showed poor drought resistance. It had 81 percent leaf firing after 34 days of drought and recovered only 46 percent. In contrast, Arizona Common, Tifgreen, and Texturf 10 showed over 95 percent green shoot recovery. Centipedegrass also showed high shoot recovery.

Bahiagrass and seashore paspalum possessed medium drought resistances. Even though they had over 50 percent leaf firing after 34 days of stress, their recovery was over 70 percent after rewatering. Buffalograss also showed medium recovery of 80 percent after over 80 percent leaf firing. St. Augustinegrass had the lowest drought resistance. It exhibited over 90 percent leaf firing, and only 32 percent green shoot recovery.

Bermudagrass Cultivar Study

The highest green shoot recovery among the 22 bermudagrass cultivars was 90 percent by Tiflawn and the lowest was 11 percent in Tifway II. Leaf firing after 34 days of drought stress varied from 100 percent of Tifway II to only 28 percent of Tiffine. Tiflawn, Tiffine, Tufcote, Bayshore, and Texturf 1F showed high green shoot recoveries of over 95 percent. FB-119, Tifgreen II, Midway, U-3, Texturf 10, and Midiron had medium high green shoot recoveries of over 90 percent. Arizona Common, Sunturf, Ormond, Pee Dee, Tifgreen, and

Table 1. Comparative* shoot recovery of warm-season turfgrass observed 18 days after rewetting, following 48 days of drought stress in the summer of 1985. College Station, Texas.

Interspecies	Bermudagrass	St. Augustinegrass	Zoysiagrass	Centipedegrass
High	Very High	High	High	High
Emerald zoysiagrass	Tiflawn	Floralawn	FC 13521	Georgia Common
Meyer zoysiagrass	Tiffine	Floratam	Emerald	Oklawn
Texturf 10 bermudagrass	Tufcote		Meyer	
Tifgreen bermudagrass	Bayshore	Medium	El Toro	Low† (Med.?)
Georgia Common centipedegrass	Texturf 1F	Tx 8262	Belair	AU Centennial
Arizona Common bermudagrass			Korean Common	Tenn Hardy
	Medium High	Low		AC 26
Medium	FB 119	Raleigh		AC 44
Adalayd seashore paspalum	Tifgreen II	Texas Common	All cultivars	
Texas Common buffalograss	Midway		showed over 95%	
Bahiagrass	U-3		green recovery	† Over 70%
	Texturf 10			green recovery
Low	Midiron			
Tifway bermudagrass				
Texas Common St. Augustinegrass	Medium			
	Sunturf			
	Arizona Common			
	Ormond			
	Pee Dee			
	Tifgreen			
	Vamont			
	Medium Low			
	Tifdwarf			
	Everglades			
	Tifway			
	Very Low			
	Santa Ana			
	Tifway II			

* Classification comparisons are valid only within each column.

Table 2. Comparative* leaf firing of warm-season turfgrass observed after 35 days of drought stress during the summer of 1985. College Station, Texas.

Interspecies	Bermudagrass	St. Augustinegrass	Zoysiagrass	Centipedegrass
High	Very High	High	High	High
Texas Common St. Augustinegrass	Tifway II	Texas Common	Korean Common	AU Centennial
Tifway bermudagrass	Santa Ana	Raleigh	Meyer	AC 26
Texas Common buffalograss	Tifdwarf			Tenn Hardy
		Medium	Medium	AC 44
Medium	Medium High	Tx 8262	Belair	
Adalayd seashore paspalum	Tifway			Low
Bahiagrass	Pee Dee	Low	Low	Georgia Common
Georgia centipedegrass	Everglades	Floratam	FC 12521	Oklawn
Tifgreen		Floralawn	El Toro	
	Medium		Emerald	
Low	Tifgreen			
Texturf 10 bermudagrass	Ormond			
Arizona Common bermudagrass	Sunturf			
Emerald zoysiagrass	Arizona Common			
Meyer zoysiagrass	Vamont			
	Midiron			
	FB 119			
	U-3			
	Texturf 10			
	Medium Low			
	Midway			
	Tufcote			
	Bayshore			
	Tifgreen II			
	Tiflawn			
	Texturf 1F			
	Low			
	Tiffine			

* Classification comparisons are valid only within each column.

Vamont showed medium recoveries. Tifway II and Santa Ana had low recoveries, while Tifway, Everglades, and Tifdwarf exhibited medium low recoveries.

St. Augustinegrass Cultivar Study

There were large variations in drought resistance among the five St. Augustinegrass cultivars. Floralawn and Floratam showed high green shoot recovery. They showed less than 50 percent leaf firing after 34 days of drought stress and recoveries of over 90 percent. However, Texas Common and Raleigh showed over 98 percent leaf firing and less than 20 percent recovery. TX 8262 showed medium green shoot recovery. The performance of Floratam and Floralawn was excellent throughout the study in terms of shoot color, turgidity, and uniformity.

Zoysiagrass Cultivar Study

All six zoysiagrass cultivars showed very high recovery from drought stress. Their shoots recovered by over 95 percent after rewatering, even though Korean Common showed over 50 percent leaf firing after 34 days of drought stress. In contrast, El Toro had less than 10 percent leaf firing.

Centipedegrass Cultivar Study

Centipedegrass also showed high shoot recovery from drought stress upon rewatering. All six cultivars showed over 75 percent green shoot recovery; with the recoveries among cultivars not found to be statistically different. Oklawn and Common had less than 50 percent leaf firing after 34 days of drought stress, while AU Centennial had over 70 percent leaf firing.

Acknowledgment

A major portion of this investigation has been made possible by a grant from the United States Golf Association Green Section. Additional follow-up studies are underway in the greenhouse and were conducted for 1986 in the field.

References

1. Beard, J. B. 1966. Selected turfgrass variety evaluation: winterkill and drought tolerance. Michigan Turfgrass Report. 3(1):7-9.
2. Gaskin, T.A. 1966. Testing for drought and heat resistance in Kentucky bluegrass. Agron. J. 58:461-462.
3. Minner, D. D. and J. D. Butler. 1985. Drought tolerance of cool-season turfgrasses. Proc. of Fifth International Turfgrass Res. Conf. 5:199-212.

An Assessment of Cutting Height and Nitrogen Fertility Requirements of Seashore Paspalum

S.I. Sifers, J.B. Beard, K.S. Kim, and J.R. Walker

Introduction

Preliminary assessments indicate that certain seashore paspalum cultivars show promise in Texas as turfgrasses for use in highly saline conditions where bermudagrass growth is impaired (2). Several characteristics in terms of growth and morphology were compared with bermudagrass (1, 2). This is the initial report of an ongoing investigation concerning the cutting height and nitrogen fertility requirements of *Paspalum vaginatum* Sw. Literature references cite the common names of 'Adalåyd', 'Excaliber', 'sand knotgrass', and 'seashore paspalum'. The latter is now more commonly accepted.

Materials and Methods

This investigation was conducted at the Texas A&M Turfgrass Research Field Laboratory in College Station, Texas. The plot area was stolonized on April 26, 1984 at a rate of 10 bushels of sprigs per 1000 sq ft (36 m^3 ha^{-1}). The stolons were provided by Coastal Turf, Inc. Bay City, Texas. The soil was a sand modified fine sandy clay. Prior to planting, the soil was rotary tilled and fumigated with methyl bromide. The soil pH was maintained between 7.0 and 7.8 based upon an annual soil test. The plot size was 6 x 5 ft (1.8 x 1.5 m) with three replications of each treatment. Mowing was twice weekly with clippings removed. The cutting height treatments were 0.5, 1.0, 1.5, and 2.0 inches (1.5,2.5, 4.0, and 5.5 cm, respectively). Nitrogen was applied monthly during the growing season with nitrogen treatments of 0.25, 0.5, 1.0, and 1.5 lbs N/1.000 sq.ft.(13, 25,50, and 75 kg ha^{-1}, respectively) per month. The four cutting heights and four nitrogen fertility levels were imposed in all possible combinations. Phosphorus and potassium were applied as needed based on annual soil tests. Irrigation was applied as needed to prevent visual wilt. Herbicides, fungicides, and insecticides were applied as needed to prevent the serious loss of turf quality and stand. No vertical cutting or other cultivation technique was practiced.

Visual turfgrass quality and shoot density were assessed bi-weekly. The visual quality rating was based upon a 1 to 9 scale with 1 = poor and 9 = excellent. A ranking of 5 was the minimum acceptable turf quality.

Results

Two visual turfgrass quality ratings were made in late 1985. However, these data were not conclusive. The observers noted that quality differences were very difficult to obtain. The highest rating was 5 and lowest was 3. No significant differences were obtained in shoot density measurements affected by nitrogen fertility level. However, the trend indicated that higher shoot densities were associated with the lower mowing heights.

References

1. Beard, J. B., S. M. Batten, S. R. Reed. K. S. Kim, and S. D. Griggs. 1982. A preliminary assessment of Adalayd *Paspalum vaginatum* for turfgrass characteristics and adaptation to Texas conditions. Texas Turfgrass Research—1982. Texas Agric. Exp. Sta. PR-4039. pp. 33-34.
2. Henry, J. M., V. A. Gibeault, V. B. Youngner, and S. Spaulding. 1979. *Paspalum vaginatum* 'Adalayd' and 'Futurf'. Calif. Turfgrass Cult. 29:9-12.