1997

ANNUAL REPORT

BREEDING AND DEVELOPMENT OF ZOYSIAGRASS

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Jointly Sponsored by:

The United State Golf Association
and
Texas Agricultural Experimental Station

1 December 1997

NOT FOR PUBLICATION

Volume 97-2Z

INDEX

1997 RESEARCH REPORT
BREEDING AND DEVELOPMENT OF ZOYSIAGRASS

Executive Summary

1997 Annual Zoysiagrass Report - Final

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Assistant Research Scientist

Research Period: November 1996 to February 1998

The Zoysiagrass breeding program was initiated in 1984 and during the past 13 years has enjoyed a long productive relationship with the United States Golf Association. This constitutes the final report for the joint research project between Texas A&M and the United States Golf Association as funding from the USGA will be redirected from where it has been known in the past.

The success of the breeding program is measurable. I believe our success is notable to the extent that the greatest contributions of this association between the University and Industry is marked in both the cultivars which have been developed and released into the market and in the training and development of new young scientists. The young scientists involved in this program over the years includes Dr. Michael Kenna, now Director of Research, United States Golf Association; Dr. David Huff, Assistant Professor, Pennsylvania State University; Dr. Richard White, now Associate Professor, Texas A&M University; Dr. Bridget Ruemmele, now Assistant Professor, University of Rhode Island; Dr. Ken Marcum, now Assistant Professor University of Arizona; Dr. Ikuko Yamamoto, now married and serving as a foreign language interpreter in Boston Mass; and Dr. Yaling Qian, soon to be Assistant Professor, Colorado State University. Additionally we have enjoyed the interaction and significant contribution of a host of technical support staff including Mr. Sam Riffell, now Ph.D. Student Zoology Department, Michigan State University and Ms. Sharon (Morton) Anderson presently pursuing her Ph. D. Degree in zoysiagrass taxonomy at Texas A&M University.. With the close interaction and contribution of each of these individuals, we have successfully developed and released into the industry four unique zoysiagrass cultivars each targeting a niche of the environment.

'DIAMOND' a Z. matrella is noted for its fine texture, close mowing tolerance, excellent rhizome production, and unsurpassed salinity tolerance and tolerance to low light conditions. Diamond is targeted for shaded tees, bentgrass green surrounds to reduce bermudagrass encroachment and possible use as a putting surface and sports field. Diamond will be limited to the gulf coast states under natural environmental conditions.

'CAVALIER' a Z. matrella is noted for its fine texture, cold hardiness in comparison to Diamond, excellent shade tolerance, salinity tolerance, and good recuperative ability and high turf quality when maintained under fairway conditions. Cavalier is adapted to turf conditions through Southern Illinois, Missouri and Kansas area southward to the Gulf and eastward through the Carolinas.

'PALISADES' a medium coarse textured Z. japonica has excellent turf quality, shade tolerant and low water needs and is targeted for use on fairways, and rough areas of golf courses, home lawns, industrial parks and general use areas where a low maintenance quality lawn is desired. Palisades is adapted to a region from Central Kansas, Missouri and Illinois southward to the gulf and eastward through the Carolinas.

'CROWNE' a coarse textured Z. japonica is the most cold hardy of the four grasses with low water use and highly competitive against weed invasion, adapted to low maintenance conditions through the transition zone south.

The success of this program will be judged on the long-term success of the individuals involved and the acceptance of the cultivars into the industry. The USGA's participation and contributions to research are acknowledged and greatly appreciated.

1997 ANNUAL RESEARCH REPORT
BREEDING AND DEVELOPMENT OF ZOYSIAGRASS

M. C. Engelke and Y. L. Qian

I. Introduction

The primary goal of the zoysiagrass breeding program sponsored by USGA was to develop new zoysiagrass with reduced resource input and better adaptation to the environments. After 13 years of selections, evaluations, and extensive examinations, we have released four zoysiagrass cultivars. The fifth will be released in 1998. This report addresses project activities between Nov. 1996 to Nov., 1997.

II. Technical Support Personnel

Dr. Yaling Qian has served as an Assistant Research Scientist in the Turfgrass Program since February 1996. Dr. Qian's primary responsibility is to examine the stress responses, relative stress tolerances, and stress tolerance mechanisms of zoysiagrasses. Her research also includes the development of special management approaches to grow turfgrass under heavy shade. Dr. Qian has accepted a position at Colorado State University as Assistant Professor of Turfgrass Science effective January 1998.

Mr. Sean Reynolds has joined the program as research assistant since May 26, 1997. A graduate of Kansas State University, Sean has the strong interest in molecular biology and turfgrass science.

Ms. Mary Jane Foster has joined the program since April 1, 1997 and provides part-time technical assistance for Dr. Qian.

III. Greenhouse and Laboratory Progress

Germplasm Library

The zoysiagrass germplasm library inventory continues to be updated. Select hybrids from crosses among the GPIN are entered into the library, and are further subjected to routine selection and screening tests to include root growth, salinity, shade, cold and heat tolerance along with insect and disease resistance.

Germplasm in Quarantine

Texas A&M Research and Extension Center at Dallas serves as a working quarantine import facility in cooperation with APHIS and the USDA-ARS Plant Quarantine Facility. In this capacity, and under the direction of Dr. Engelke, plant materials collected or shipped from overseas are simultaneously introduced into the United States through APHIS, and TAES-Dallas for purposes of scientific studies under isolated conditions. Any vegetative materials introduced from other countries are subjected through two time spaced viral screening (serology) procedures by the ARS Plant Quarantine Lab. The process generally requires 2+ years to accomplish. At TAES-Dallas, any agronomic increase or evaluations are conducted in the quarantine space only. Limitation imposed on the use of material restrict manipulations to include floral initiation studies, self-pollination, hybridizations, and seed harvest. Seed harvested from the plants are not subject to isolation; hence, they can be moved into the mainstream research program. Using the seed harvested, and in cooperation with ARS, only a limited number of plants require full serological tests.

Hybridization of Zoysiagrasses

Twenty-six hybrids from single crosses between DALZ8501 (♀) x Crowne (♂); Crowne x DALZ8501; Crowne x Diamond; DALZ8501 x Diamond; and Diamond x DALZ8501 were made. Approximately 35 hybrids with Diamond as maternal were selected. All hybrids were planted in the greenhouse. Based on the greenhouse observation, 25 promising hybrids were selected and planted in the field for long term evaluation.

Rapid Shade Resistance Evaluation

Considering 25-40% of turfgrasses are exposed to some degree of shade, the shade resistance and adaptation certainly merit more research than in the past. Field plot evaluation of this type are costly and must usually be carried on for several seasons before conclusions can be drawn. Therefore we designed a greenhouse test for shade tolerance selection. A detailed report and current data is presented in **Appendix A.**

Salinity Tolerance

Introduction: Increased need for salt tolerant turf continues due to increased restrictions on potable water resources, increased requirements of using low quality secondary water sources for golf courses, and the occurrence of salt water intrusion into ground water. Previous studies showed that considerable variability exists among zoysiagrass species and germplasms. More information is needed for the newly developed zoysiagrasses and experimental lines.

Objectives: 1) determine relative salt tolerance for the newly developed zoysiagrasses and experimental lines; 2) estimate the possibility of developing salt tolerant zoysiagrass through hybridization and selection.

Results: A greenhouse hydroponic salinity experiment has been completed on 30 zoysiagrasses, including most of hybrids of *Z. japonica* and *Z. matrella*. Data were presented **in Appendix B**. Percent leaf firing ranged from 2% to 50% among entries, indicating great difference of relative salinity tolerance within *zoysia* genus (Table B1). Shoot mass, root mass, leaf sap Na^+ content, and the activity of leaf Na^+ secretion for salt treated and the control plant were presented in Table B2. Correlation coefficients among above parameters were listed in Table B3.

Percent leaf firing due to salinity stress was highly and negatively correlated to shoot and root growth, but was positively correlated with leaf sap Na^+ content.

In agreement with previous study, Diamond was the most salinity tolerant zoysiagrass. More interestingly, 9 out of 11 hybrids with Diamond as maternal exhibited excellent salinity tolerance. This result indicates that salinity tolerance is highly heritable and it is promising to develop highly salt tolerant zoysiagrass using conventional breeding techniques.

Growing Zoysiagrass under Heavy Shades

Many researches have shown that shaded turf exhibited low density and poor persistence. Growing turfgrass under heavy shade (over 85% shading) or indoors is a fantasy for most people. Currently, appropriate management approach is lacking due to the lack of physiological and biochemical understanding of low light stress. More research is needed to evaluate the morphological and physiological adaptations of turfgrass under heavy shade and to define management strategy to improve the turf performance under heavy shade.

Diamond zoysiagrass exhibited good shade tolerance in previous field trial. To better define the utilization of this new grass, greenhouse and field studies were complete to evaluate rooting, turf performance and adaptation of Diamond under different light intensities. A manuscript has been submitted to Crop Science for publication (**Appendix C**).

Studies have been completed to evaluate selected plant growth regulator on shade tolerance of Diamond zoysiagrass. Diamond photosynthesis, carbohydrate status, and root activity under heavy shade were significantly improved by using anti-gebberellic acid as specific management approach. A Manuscript from this study has been completed and submitted to *Crop Science* for publication (**Appendix D**).

Development of Insect Resistant Cultivars

Dr. Jim Reinert continues to screen existing and newly developed hybrids for insect resistance. Promising results are being obtained for identifying sources of resistance for the army worm, and tropical sod web worm. Three cultivars, recently released by TAES-Dallas (Diamond, Cavalier, and Crowne) and two experimental lines (DALZ8501 and DALZ8516) were selected as our experimental genotypes. The cultivars differ in the intensity of resistance to the specific diseases and pests. For example, although Cavalier is resistant to tropical sod webworm (TSW) and the fall armyworm, it is susceptible to zoysia mites. Diamond, which possesses better agronomic characteristics than DALZ8501, is susceptible to TSW and zoysia mites. On the contrary, DALZ8501 is highly resistant to TSW and moderately resistant to zoysia mites (see 1995 Annual Report). We are attempting to transfer the insect-resistant gene(s) from resistant lines to susceptible lines by conventional recurrent selection techniques and also examining advanced molecular genetic techniques which theoritically have the potential to transfer the genetics within a much shorter time period. Determination of the mode of inheritance and identification of the resistant gene(s) are the next significant aspects in this project.

IV. Field Evaluation and Production Trials

National Turfgrass Evaluation Program (1996 NTEP Trials)

The 1996 NTEP Zoysiagrass trials were planted in July. A single Texas A&M entry, DALZ9601, was included in the national trial. Six additional zoysiagrass hybrids were included in the Dallas planting. They are all hybrids *(Zoysia japonica x Z. matrella)* and are identified as DALZ9602, DALZ9603, DALZ9604, DALZ9605, DALZ9606, and DALZ9607, along with the three newly released cultivars (Cavalier, Crowne and Palisades).

Data collected to date is presented in **Appendix E**. Results indicate that two zoysia hybrids, DALZ9604 and DALZ9603 had the highest establishment rate. Seventy days after planting the turf coverage was 68% and 58% respectively whereas the ground cover for Meyer was only 20%. Cavalier and Palisades continually exhibited good genetic color and quality. Along with Zeon and Cavalier, DALZ9601 had the highest turf quality.

Zoysia matrella trials
Four zoysia matrella, Diamond, DALZ9608, DALZ9609, and DALZ9610 were plug planted in field plots for evaluation under close mowing. Data collected to data indicated that a new experimental line, DALZ9609 and DALZ9610 had a faster turf establishment rate and reasonable winter hardiness, and excellent turf quality

V. Sod Production and Availability

Four zoysiagrasses were released by Texas A&M in 1996. Initial production fields where established in 1997 with the first commercial sales anticipated for 1998.

DIAMOND has been exclusively licensed to Southwest Turf Farms -Kaufman, Texas for production in Texas and to West Coast Turf -Palm Desert, CA with regional licenses for production in California and Arizona. Initial planting were made in California in September 1996, and in Texas in May 1997. The first commercial production will be available in 1998.

CAVALIER, CROWNE AND PALISADES:

The Texas Sod Producers Association (TSPA) has successfully negotiated a license for the production of all three of these grasses within the state of Texas. The TSPA in turn sub-licenses each of the varieties to interested growers for certified production. Presently a total of 10 growers have entered the program and are receiving sufficient foundation planting stock to establish Registered production for future increase and up to a total of 10 acres of certified production. At the present time Cavalier is also under a regional license with Quail Valley Turf Farms, Little Rock AK with production license for Tennessee, Arkansas and Mississippi.

Contracts are under negotiation in other states for the release of each of the grasses and should be completed early this summer.

ROYAL:
Royal (DALZ9006) zoysiagrass has been completed for its evaluation, and will be submitted for release in 1998. Royal is a fine textured vegetatively propagated *Z. matrella* noted specifically for its uniformity, distinct fall color retention, and good salinity and shade tolerances. It will be quite suitable for uses as golf course fairways, tee boxes, and parks throughout the south. An approximately 3000-m^2 breeder field has been planted in Aug. 1997. The field will be ready for harvest in 1998.

Appendix A

EVALUATION OF ZOYSIAGRASS GENOTYPES FOR SHADE TOLERANCE

Y. L. Qian and M. C. Engelke

Abstract

Nineteen selections of zoysiagrasses were evaluated for lateral budding ability, root and shoot production, and other turf characteristics under three levels of shade. Palisades, Diamond, TAES4373, TAES4377, Jamur, and DeAnza had higher shade tolerance by producing a) greater number of buds; b) shorter internode length; c) less decrease in shoot or root mass; d) less increase in shoot:root ratio; or e) persistent green color. Selections including TAES4366, TAES4355 performed poorly under shaded condition.

Introduction

Growing turfgrasses in the shade is one of the biggest challenges for turf managers and turfgrass scientists. Considering 25-40% of turfgrasses are exposed to some degree of shade, the shade resistance and adaptation certainly merit more research than in the past. Only a limited number of investigations have been reported on shade tolerance of zoysiagrass. Growing turf in natural deciduous shade with only 10% of incident sunlight, Morton et al. (1994) observed a high level of variability among zoysiagrass cultivars. Field plot evaluation of this type are costly and must usually be carried on for several seasons before conclusions can be drawn. With the large number of zoysiagrass cultivars appearing on the market, and as a tool to the turfgrass breeding program, short duration tests are needed for shade tolerance selection.

Shaded turf generally exhibits low density, inferior recuperative ability, and poor persistence, due to the reduced lateral budding (or stolon and rhizome branching) ability. Stolons and rhizomes arise from the axillary buds. An axillary bud that is assumed to be present in the axil of each leaf may grow into a branch rhizome or stolon, remain inactive, or grow into an inflorescence. The developmental fate of a bud is affected by its genotype and its environment. Light intensity is an important component of the environment.

Reductions in turf shoot and root dry weight and shoot:root ratio, lighter green color and higher internode length were frequently reported in the shade environment (Reid, 1933; Juska, 1963). It has been suggested that short internode length (McBee and Holt, 1966, Wilkinson and Beard, 1974), low shoot/root ratio (Reid, 1933), green leaf color (Coffey and Baltensperger, 1989) might be useful guides in identifying grasses for shade tolerance. The objective of this study was to screen the shade tolerance of zoysiagrass genotypes by determining the lateral budding ability, the plant growth pattern, the level of decreasing in shoot and root growth, shoot:root ratio, and grass color at different light intensities.

Materials and Methods

A total of ninteen zoysiagrass cultivars and experimental lines, representing *Zoysia japonica, Z. matrella* and interspecies hybrid (*Z. japonica x Z. matrella or Z. matrella x japonica*) were tested (Table 1). Grasses, sampled from 1996 NTEP field or greenhouse trays, were vegetatively planted via rhizomes into 9 x 9 x 8 cm plastic pot containing sterilized greenhouse soil medium (Redi-earth). To achieve uniform growth condition, all pots were maintained in the greenhouse at 70% sunlight for more than 30 days before shade treatments. During this period, grasses were uniformely fertilized biweekly with a 20-8.7-16.6 N-P-K fertilizer to provide a 24 kg N ha^{-1}. On Dec. 11, 1996, 1 or 2 stolons containing a total of 4 visible axillary buds were washed free of existing soil and transformed to new pots. The size and soil medium were same as previously described. Soil medium were pre-mixed with a 14-6.7-16.6 N-P-K resin coated fertilizer to provide an N level of 5 g m^{-2}. Irrigation was applied as needed to prevent drought stress.

Immediately after planting, shade treatments were imposed. Shade treatments were obtained by covering 0.5 x 1.5 x 0.5 m frames with 47% or 73% black shade clothes. Each shade cloth was drapped on all sides to prevent the effect of incline light. Accounting for the filtering effect of the glass roof of the greenhouse, the three levels of shade were: 60% of sun-light (40% shade), 25% of sun-light (75% shade), and 12% of sun-light (88% shade). The experimental design was a split-plot with levels of shading as whole plots and cultivars as sub-plots. There were 3 replications. The pots were rotated weekly to minimize the effect of a localized condition at any one place. The turfgrasses were not clipped during the period of study. The duration of shade treatments were 11 weeks. When the study ended, data were collected on number of visible buds per pot, turf color, turf height, length of second internode, maximum root extension (the length of the longest root), and shoot and root dry mass. Shoot:root ratio was calculated by dividing shoot dry mass by root dry mass. All data were analyzed using the General Linear Models procedure, and means were seperated using a protected LSD at $P < 0.05$ (SAS, 1987).

Results and Discussion

The number of visible buds produced is a good measure of zoysiagrass growth rate within its texture type. At greenhouse light condition, TAES4375, TAES4373, and HT-210 produced the highest number of buds. Among medium-textured entries, hybrid TAES4365 had faster development of lateral bud than DeAnza and Victoria. Among the coarse-textured entries, hybrid TAES4366 ranked highest in the number of buds produced (Table 2). The budding abilities of all cultivars declined with the increasing of shade level (Table 2). However, the degree of decline varied with cultivars. Under 88% shade, TAES4366, TAES4375 ,TAES4355, TAES4367, TAES4370, TAES4375 and HT-210 only produced < 9% buds of their controls. Diamond, TAES4377, TAES4373, TAES4365, DeAnza, and Palisades produced the highest bud numbers at 88% shade, suggesting their good shade tolerances. J-14 had a extremely low tiller number across all levels of shade. This is due to the fact that 50% to 100% of axillary buds of J-14 sampled from the field developed into flowers. The flower tiller lost the ability to produce rhizome or stolon.

Zoysiagrasses displayed growth habit shift (from horizonal growth to upright growth) as the level of shade increased. Thus, turf vertical growth increased with decreased light intensity (Table 3). This was partially due to the increase in the length of internodes. Although all cultivars responded similarly, turf height and internode length of TAES4366 was much greater than others under 75% and 88% shade. Generally, Hybrids exibited higher turf vertical growth and internode length. The extreme upright growth might lessen the shade tolerance of turfgrass, because more photosynthetically active, young leaf tissue will be removed by mowing.

Shoot dry matter yield varied considerably among cultivars and shade levels (Table 4). In general, shoot dry weight across shade levels were highest for *Z.japonica or Z. japonic x Z. matrella* hybrid, followed by the *Z. matrella x Z. japonica* hybrid. *Z. matrella* had the lowest shoot dry weight. Most cultivar decreased shoot weight by 50% or more under 75% shade. Exceptions were TAES 4373, TAES4377, and Palisade, which produced 53%, 54%, and 58% of the yields of control, respectively. Under 88% shade, TAES4373, TAES4377, TAES4361, DeAnza and Palisades produced a higher percentage of shoot mass (over 20%) than other entries.

There were wide variations in root dry mass at each shade level (Table 5). Under natural greenhouse conditions, Palisades, El-Toro, Crowne, Jamur and TAES 4366 produced the highest root mass. Root dry mass decreased as shade level increased. For most entries, root mass under 88% shade were only 3 to 10% of those of control (40% shade). However, Palisades, TAES4373, TAES4377, and Diamond had 13% to 21% root mass of their control. Diamond had the least root mass reduction when shade level increased from 40% to 88%. As the level of shading increased from 40% to 88%, the reduction in root mass production was generally sharper than shoot mass production; this resulted in the increase of shoot:root ratio for most entries (Table 6). Only Diamond showed a trend of decrease in shoot:root ratio with increasing shade. Shoot:root ratio of Jamur, TAES4366 responded inconsistently to increasing shade. Compared to root mass, MRE was less affected by the level of shading (data not shown).

Effect of shade on color was variable (Table 7). Color of TAES4355, TAES4366, and TAES4370 tended to deteriorate with increased shade, but there was relatively little effect on the other grasses.

This short-duration study suggested that Palisades, Diamond, TAES4373, TAES4377, Jamur, and DeAnza had higher shade tolerance by producing a) greater number of buds; b) shorter internode length; c) less decrease in shoot or root mass; d) less increase in shoot:root ratio; or e) persistent green color. Further evaluation should examine the persistence of the selected cultivars under more naturalized shade setting.

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Table A1. Selections of zoysiagrasses for shade tolerance study.

Entry	Species	Origin
Fine Textural Entries		
Diamond	*matrella*	Texas A&M University-Dallas
HT-210	*matrella*	Horizon Turfgrass
Zeon	*matrella*	Bladerunner Farms
TAES4355	DALZ8501(*matrella*) x Crowne	Texas A&M University-Dallas
TAES4361	DALZ8501(*matrella*) x Crowne	Texas A&M University-Dallas
TAES4373	DALZ8501(*matrella*) x Diamond	Texas A&M University-Dallas
TAES4375	DALZ8501(*matrella*) x Diamond	Texas A&M University-Dallas
TAES4377	DALZ8501(*matrella*) x Diamond	Texas A&M University-Dallas
Medium Textural Entries		
DeAnza	Emerald x El-Toro	Thomas Bros. Grass Co.
TAES4365	Crowne x DALZ8501	Texas A&M University-Dallas
Coarse Textural Entries		
Crowne	*japonica*	Texas A&M University-Dallas
El-Toro	*japonica*	Univ. Of California
J-14	*japonica*	Jacklin Seed Company
Jamur	*japonica*	Bladerunner Farm
Palisades	*japonica*	Texas A&M University-Dallas
TAES4366	Crowne x DALZ8501	Texas A&M University-Dallas
TAES4367	Crowne x DALZ8501	Texas A&M University-Dallas
TAES4370	Crowne x Diamond	Texas A&M University-Dallas
TAES4372	Crowne x Diamond	Texas A&M University-Dallas

Table A2. Number of visible buds produced by 19 zoysiagrasses under three levels of shade in the greenhouse [1].

	Tiller No			% Tiller of control	
Entry	40%shade	75%shade	88%Shade	75%shade	88%Shade
	Fine Textural Entries				
TAES4355	101.0	26.7	8.5	26.4	8.4
TAES4361	84.0	27.6	10.3	33.5	11.9
TAES4373	116.0a	51.5a	14.5a	44.4	12.5
TAES4375	139.0a	40.0a	9.0	28.8	6.5
TAES4377	102.0	38.7	15.7a	37.9	15.4
Diamond	101.0	39.3	15.7a	38.9	15.5
HT-210	128.0a	32.7	9.7	25.5	7.6
Zeon	73.7	26.7	5.3	36.2	7.2
	Medium Textural Entries				
DeAnza	42.7	16.0	11.3a	37.5	26.5
TAES4365	98.0	29.7	11.5a	30.3	11.7
	Coarse Textural Entries				
TAES4366	109.0	38.0	9.3	34.9	8.5
TAES4367	95.3	26.7	7.7	28.0	8.1
TAES4370	70.7	22.5	5.7	31.8	8.1
TAES4372	40.8	25.2	5.7	61.3	14.0
Crowne	55.3	17.0	5.3	30.7	9.6
Palisades	67.3	32.7	11.0a	48.6	16.3
El-Toro	88.7	30.3	8.3	34.2	9.4
J-14	17.0	6.0	2.0	35.3	11.8
Jamur	75.0	20.0	8.7	26.7	11.6
LSD (0.05)	27.7	11.9	5.7		
CV (%)	20.3	24.3	30.5		

[1] Within columns, means in the top statistical group are indicated by an 'a'.
[2] LSD is the minimum significant difference between entry means based on Fisher's protected LSD at $P < 0.05$.

Table A3. Vertical growth and length of second internode of nineteen zoysiagrasses grown at three different shade level in the greenhouse.

Entry	Vertical growth (cm) 40%	75%	88%	Length of second internode (cm) 40%	75%	88%
	Fine Textural Entries					
TAES4355	2.6	5.5	9.3	0.32	0.40	0.65
TAES4361	3.0	6.1	8.9	0.31	0.28	0.68
TAES4373	2.8	6.5	12.0	0.35	0.50	0.60
TAES4375	3.3	5.8	10.0	0.38	0.37	0.60
TAES4377	2.0	2.0	7.3	0.33	0.35	0.50
Diamond	1.6	2.2	4.4	0.15	0.20	0.23
HT-210	1.3	1.7	6.2	0.17	0.18	0.30
Zeon	1.2	2.4	3.3	0.20	0.22	0.23
	Medium Textural Entries					
DeAnza	2.2	6.4	7.6	0.27	0.37	0.53
TAES4365	4.5a	9.2	14.5	0.47	0.50	1.00a
	Coarse Textural Entries					
TAES4366	5.5a	12.7a	18.3a	0.70a	0.70a	1.70a
TAES4367	4.3a	8.1	12.3	0.40	0.63	0.77
TAES4370	2.6	4.0	5.2	0.28	0.40	0.37
TAES4372	4.3	9.7	12.7	0.47	0.47	0.70
Crowne	2.2	4.8	7.7	0.33	0.40	0.43
Palisades	3.9	6.7	8.8	0.47	0.43	0.53
El-Toro	2.3	4.7	8.5	0.37	0.43	0.60
J-14	3.2	4.0	8.0	0.28	0.20	0.30
Jamur	2.6	4.3	8.0	0.32	0.30	0.47
LSD (0.05)	1.3	2.6	3.3	0.16	0.16	0.38
CV (%)	26.9	24.4	19.6	27.8	27.2	33.9

[1] Within columns, means in the top statistical group are indicated by an 'a'.
[2] LSD is the minimum significant difference between entry means based on Fisher's protected LSD at $P < 0.05$.

Table A4. Shoot dry mass and percent of shoot mass of 19 zoysiagrasses under three levels of shade in the greenhouse.

Cultivar	Shoot Dry Weight (g) 40%shade	75%shade	88%shade	%Yield of Control 75%shade	88%shade
	Fine Textural Entries				
Diamond	0.47	0.19	0.09	39.8	19.1
HT-210	0.61	0.16	0.08	25.6	12.6
TAES4355	0.65	0.19	0.09	28.9	14.4
TAES4361	0.57	0.26	0.11	45.1	20.1
TAES4373	1.05	0.56	0.29a	52.9	27.1
TAES4375	0.98	0.35	0.13	35.5	13.3
TAES4377	0.58	0.31	0.13	54.0	21.9
Zeon	0.62	0.27	0.08	44.0	12.4
	Medium Textural Entries				
DeAnza	0.71	0.23	0.16	32.0	23.0
TAES4365	1.96	0.61	0.33a	31.1	16.8
	Coarse Textural Entries				
Crowne	1.20	0.37	0.15	30.6	12.8
El-Toro	1.81	0.76	0.26a	41.8	14.2
J-14	0.40	0.13	0.09	32.3	22.3
Jamur	1.49	0.49	0.21	32.7	13.9
Palisades	1.47	0.85a	0.32a	57.6	21.6
TAES4366	2.47a	0.99a	0.27a	40.0	11.1
TAES4367	1.69	0.52	0.22	30.6	12.8
TAES4370	1.00	0.22	0.08	21.6	7.7
TAES4372	1.39	0.64	0.18	46.3	13.2
LSD (0.05)	0.30	0.15	0.10		
CV (%)	17.0	21.6	32.1		

[1] Within columns, means in the top statistical group are indicated by an 'a'.
[2] LSD is the minimum significant difference between entry means based on Fisher's protected LSD at $P < 0.05$.

Table A5. Root dry mass and percent of root mass of 19 zoysiagrasses under three levels of shade in the greenhouse.

Entry	Root Dry Weight (g)			% Root of Control	
	40%shade	75%shade	88%shade	75%shade	88%shade
	Fine Textural Entries				
TAES4355	0.063	0.014	0.004	22.2	6.3
TAES4361	0.110	0.029	0.010	27.9	9.3
TAES4373	0.170	0.065	0.027b	38.2	15.9
TAES4375	0.097	0.020	0.008	20.6	8.2
TAES4377	0.083	0.031	0.014	37.3	16.9
Diamond	0.057	0.025	0.012	43.9	21.1
HT-210	0.083	0.019	0.006	22.9	7.2
Zeon	0.090	0.038	0.008	42.2	8.9
	Medium Textural Entries				
DeAnza	0.070	0.011	0.009	15.7	12.9
TAES4365	0.147	0.041	0.016	27.9	10.9
	Coarse Textural Entries				
TAES4366	0.250a	0.113	0.019	45.2	7.6
TAES4367	0.207	0.045	0.012	21.7	5.8
TAES4370	0.167	0.030	0.005	18.0	3.0
TAES4372	0.193	0.067	0.017	34.7	8.8
Crowne	0.227a	0.052	0.021	22.9	9.3
Palisades	0.283a	0.130a	0.040a	45.9	14.1
El-Toro	0.273a	0.097	0.023	35.5	8.4
J-14	0.023	0.010	.	43.5	.
Jamur	0.237a	0.056	0.027	23.6	11.4
LSD (0.05)	0.074	0.023	0.011		
CV (%)	30.8	28.8	40.0		

[1] Within columns, means in the top statistical group are indicated by an 'a'.
[2] LSD is the minimum significant difference between entry means based on Fisher's protected LSD at P <0.05.

Table A6. Shoot:root ratio of 19 zoysiagrasses under three levels of shade in the greenhouse.

Entry	40%shade	75%shade	88%shade
	Fine Textural Entries		
TAES4355	10.6	13.2	23.1
TAES4361	5.4	19.1	11.1
TAES4373	6.2	8.5	10.4
TAES4375	11	16.7	16.7
TAES4377	7.1	10.2	13
Diamond	8.3	7.2	7.6
Emerald	7.7	12.9	10.4
HT-210	7.4	8.4	12
Zeon	6.8	7.7	9.8
Medium Textural Entries			
TAES4365	15.6	15.6	23.4
DeAnza	11.2	21.3	22.4
Victoria	5.5	9.9	9.8
Coarse Textural Entries			
TAES4366	10	8.8	15.1
TAES4367	8.4	11.7	19.3
TAES4370	6	7.2	12.9
TAES4372	7.5	10.1	10.7
Crowne	5.4	7.1	10.5
Palisades	5.5	6.6	8.7
El-Toro	6.6	7.8	11.4
J-14	19	13	.
Jamur	6.5	9.5	7.8

Table A7. Turf color of nineteen zoysiagrasses under three level of shades in the greenhouse.

Entry	40%Shade	75%Shade	88%Shade
Fine Textural Entries			
TAES4355	6.9	6.9	5.9
TAES4361	7.6	8.0a	7.1
TAES4373	7.7	8.0a	7.7
TAES4375	7.8	7.9a	7.0
TAES4377	7.5	7.5	7.0
Diamond	7.9a	8.1a	8.0a
Emerald	8.3a	8.3a	8.5a
HT-210	8.1a	8.2a	7.9
Zeon	8.1a	8.4a	8.1a
Medium Textural Entries			
DeAnza	7.7	7.4	7.2
Victoria	7.8	7.9a	7.8
TAES4365	7.3	7.3	7.2
Coarse Textural Entries			
TAES4366	6.7	6.3	6.1
TAES4367	7.2	7.4	6.8
TAES4370	7.6	7.3	7.1
TAES4372	6.3	6.4	6.3
Crowne	8.0a	8.1a	8.1a
Palisades	8.1a	8.0a	8.2a
El-Toro	8.2a	8.2a	8.2a
J-14	8.0a	8.0a	8.0a
Jamur	8.1a	8.1a	8.3a
LSD (0.05)	0.38	0.49	0.51
CV (%)	2.89	3.58	3.64

[1] Within columns, means in the top statistical group are indicated by an 'a'.
[2] LSD is the minimum significant difference between entry means based on Fisher's protected LSD at $P < 0.05$.

Appendix B

Evaluation of Salinity Tolerance of Twenty-Nine Zoysiagrasses

Table B1. Relative salinity tolerance (indicated by % leaf firing in relative to the control) of 29 zoysiagrasses exposed to 600 mM NaCl hydroponic solution for 3 weeks.

Cultivar	Species or Origin	%leaf firing
Diamond	*matrella*	2.2
TAES 4377	DALZ8501(*matrella*) x Diamond	2.8
F1-26	hybrids of Diamond	3.3
TAES 4375	DALZ8501(*matrella*) x Diamond	4.9
DALZ 8501	*matrella*	7.3
F1-23	hybrids of Diamond	7.8
TAES 4373	DALZ8501(*matrella*) x Diamond	8.5
TAES4376	DALZ8501(*matrella*) x Diamond	8.8
TAES4370	Crowne x Diamond	15.7
F1-15	hybrids of Diamond	17.4
F1-18	hybrids of Diamond	18.6
El-To	Japonica	19.8
Crowne	Japonica	22.0
F1-96-1	hybrids of Diamond	22.6
TAES4361	DALZ8501 (matrella) x Crowne	23.5
Victoria	Emerald x El-Toro	27.3
DeAnza	Emerald x El-Toro	30.0
TAES4357	DALZ8501 (matrella) x Crowne	30.1
Jamur	japonica	30.3
Emerald	japonica x tenuifolia	33.6
F1-24	hybrids of Diamond	34.0
TAES4355	DALZ8501 (matrella) x Crowne	34.0
TAES4366	Crowne x DALZ8501	38.9
Palisades	japonica	39.3
TAES 4365	Crowne x DALZ8501	42.6
Meyer	japonica	45.1
Zeon	matrella	45.4
Cavalier	matrella	48.3
TAES4364	Crowne x DALZ8501	50.1
LSD (0.05)		8.5
CV (%)		18.8

Table B2. Shoot mass, root mass, leaf sap Na^+ content, and leaf Na^+ secretion of 29 zoysiagrass grown in 600mM NaCl for 3-week period and leaf Na^+ secretion of 29 zoysiagrasses grown in the Hoagland solution.

Cultivar	shoot (mg)	root (mg)	leaf sap Na^+ (ppm x 10^3)	Leaf Na^+ secretion (mg g^{-1})	Leaf-surface Na^+ (mg g^{-1})
TAES4370	940	130	4.3	3.1	1.2
DALZ8501	910	56	5.8	9.7	3.3
F1-23	910	97	7.1	5.2	3
Diamond	840	180	5.2	9.2	4.1
F1-26	750	120	4.8	4.7	3
TAES4376	710	130	4.3	14.8	4.3
TAES4361	700	57	5.7	9.3	3.6
El-Toro	630	170	6.4	4.8	1.3
TAES4377	620	118	6	15.9	3.5
TAES4373	600	130	7.6	14.7	4
F1-24	530	125	11.6	7.1	3.9
TAES4375	510	43	7.4	12.1	4.2
F1-96-1	490	47	6	12	3.5
Meyer	480	90	5.6	4.7	1.8
Jamur	460	90	6	6.5	2.6
TAES4366	410	87	7.2	8.3	2.3
F1-15	380	115	7.8	7.5	2.8
F1-18	370	56	10	11.8	2.9
Crowne	360	62	6.2	8	2.6
TAES4364	350	90	4.8	7	1.9
TAES4355	310	28	10.8	13.8	4.5
TAES4365	300	54	9.8	12.1	3.5
Palisades	230	76	5	11.1	1.8
Emerald	220	29	10.4	6.2	2.7
DeAnza	190	31	6.9	10.8	2.1
TAES4357	170	67	5	8.6	2.2
Cavalier	130	3	7.4	9	3.9
Victoria	110	10	8.6	14.8	2.8
Zeon	50	10	13.6	9.9	2
LSD (0.05)	318	72	6.2	5.8	2.4

Table B3. Simple correlation coefficients for relative salinity tolerance (indicated by % injury), shoot growth, root growth, leaf sap Na^+ content, leaf Na^+ secretions of salt treated and control plant among 29 zoysiagrasses grown in the greenhouse hydroponic solution.

Parameter	Shoot growth	Root growth	Sap Na^+ content	Secretion Na^+(Salt)	Secretion Na^+ (control)
% injury	-0.72****	-0.56***	0.43**	-0.15	-0.36*
Shoot growth		0.68****	-0.49**	-0.26	-0.17
root growth			-0.49**	-0.29	-0.06
Sap Na^+ content				0.19	0.19
Secretion Na^+-Salt					0.58***

*, **, ***, **** correlation coefficients significantly different from 0 at the 0.05, 0.01, 0.001, and 0.0001 probability levels, respectively.

Appendix C

Turf Performance, Rooting, and Carbohydrate Status of Diamond Zoysiagrass as Affected by Light Intensity

Y.L. Qian and M.C. Engelke

ABSTRACT

'Diamond' zoysiagrass [*Zoysia matrella* (L.) Merr.] is a new release from the Texas Agricultural Experimental Station, which has a fine texture with excellent density. To better define the utilization of this new turfgrass, more information is needed on the responses of Diamond to variable shade levels. Greenhouse and field studies were conducted to evaluate rooting, turf performance and adaptation of Diamond under different light intensities. In the greenhouse, turf was sodded on a bench under four or five shade treatments ranging from 30% to 95% and maintained for 6 weeks. The soil temperature was maintained between 23° to 28°C. Turf under 30% and 60% shade had the highest turf quality and color scores. As shading increased further, turf and color quality decreased. Ranking of treatments for maximum root extension (MRE) was 60% shade = 81% shade > 90% shade = 95% shade in Study I and 30% shade ≥ 60% shade = 81% shade > 90% shade in Study II. Root mass and root number decreased with increasing shade levels. In the field, well established turf was subjected to four shade treatments. Acceptable turf quality was obtained up to 73% shade for 5 months. Turf density was negatively correlated with light intensity. Shading resulted in increased clipping yield. Total nonstructural carbohydrate content (TNC) decreased linearly with increasing shade level, but 47% shade maintained a relatively stable TNC level after an initial decline.

INTRODUCTION

Turf managers often report that shade is one of the major problems in growing quality turfgrass. It has been reported that 20 to 25% of turf is maintained under some degree of shade (Dudeck and Peacock, 1992). Turfgrasses differ dramatically in their shade tolerance. It is generally considered that zoysiagrasses have intermediate shade tolerance (Dudeck and Peacock, 1992), though there can be great variation in shade tolerance within the *Zoysia* genus (Morton et al., 1992). Diamond zoysiagrass, a new cultivar developed by Texas Agricultural Experimental Station, is a vegetative clone. Diamond is distinguished from existing cultivars by its very fine texture, excellent density, and superior adaptation to close mowing. In a preliminary 3-year study, Diamond ranked at the top for its turf performance among 25 commercial and experimental varieties under dense oak trees (Riffell et al., 1995).

Low light intensity reduces turf performance and persistence by affecting many plant physiological processes, including root development and growth, and carbohydrate synthesis and allocation. Rooting ability is a critical issue to establish turf under low light conditions. Karnok and Augustin (1981) reported that 'Glade' and 'Merion' Kentucky bluegrass (*Poa pratensis* L.) exhibited no measurable vertical root growth from sod under low light intensity (150 uE m^{-2} sec^{-1} PAR), while roots of these grasses grew at a rate of 1.3 cm day^{-1} under a high light level (1000 uE m^{-2} sec^{-1} PAR). Reduced light intensity has also been found to inhibit the root development and growth of ryegrass (*Lolium spp.*), velvet bentgrass (*Agrostis canina* L.), and creeping bentgrass (*Agrostis palustris* Huds) (Mitchell, 1954; Reid, 1933). The effect of shade on root growth may partially result from low soil temperatures that can retard root growth and function. No information is available on the rooting ability of Diamond zoysiagrass under low light intensities at its optimum root growth temperature.

Reduced light intensity decreases photosynthesis. Therefore, total nonstructural carbohydrate content (TNC) is expected to decrease dramatically under shade. Few studies, however, have investigated the carbohydrate status in turfgrass rhizomes and roots under shade. Burton et al. (1959) reported that 70% shade reduced the available carbohydrate content by 43% compared to the unshaded check for Coastal bermudagrass (*Cynodon dactylon* (L.) Pers.). Measurements of net photosynthesis and respiration revealed that a positive CO_2 flux contributed to the better shade tolerance of 'Pennlawn' red fescue (*Festuca rubra* L.) compared to 'Merion' Kentucky bluegrass (Wilkinson et al., 1975). Knowledge of the carbohydrate level under different light conditions could be useful information to determine the extent of turfgrass shade adaptation and tolerance, and to predict long term turf persistence.

Our objective was to evaluate performance of Diamond zoysiagrass under shade by: 1) determining rooting characteristics during sod establishment, 2) evaluating turf quality and color, and 3) quantifying the carbohydrate status.

MATERIALS AND METHODS

Greenhouse study

A greenhouse heat bench (Engelke et al., 1985) was filled with sterilized sand premixed with 17-2.6-8.3 N-P-K resin-coated fertilizer (Osmocote) to provide 24 Kg N ha^{-1}. Root zone temperature was regulated by circulating controlled-temperature water through a copper pipe grid system, which was embedded at 15 cm under the soil surface. Twenty-five clear, acrylic root-observation tubes (ROT)(51-mm i.d. by 50-cm long, 3-mm wall) were inserted into a predrilled holes at a 20° angle from vertical to 55 cm below the soil surface. Root observation tubes were arranged in such a way that a minimum 30-cm space was present between ROTs. After ROT were installed, the sand profile was saturated to provide uniform setting. The ROT projected 2-cm above the soil surface.

Sod pieces measuring 240-cm long by 40-cm wide, and 2.5-cm thick were sampled from the Diamond breeder field. Soil was hand washed from the sod pieces. Turf was sodded on the soil surface of the bench 2 days later (Study I) or immediately (Study II) after sod was cut. Holes to accommodate ROT were cut, so that each ROT could pass through sod. Periodic root observations were made using a dental mirror (attached with a 2-w D.C. powered light bulb and a 8 mm tubular rule (Fig. 1). The exposed 2 cm top of ROT was normally covered with aluminum foil to maintain the dark environment of the root system. Greenhouse air temperature ranged from 24° to 34°C. Soil temperature was controlled between 23° and 28°C. Turf was watered daily to prevent drought stress. One week after sodding, a 20-20-20 N-P-K soluble fertilizer was applied to provide 4.9 g N m^{-2}.

Immediately after sodding, shade treatments were imposed above each ROT. Treatments consisted of black nylon screen with 47%, 73%, 86%, and 92% light screening properties [as measured with a quantum radiometer (model LI-170, Li-Cor, Lincoln, NE] and an unshaded greenhouse control. Accounting for the filtering effect of the glass roof of the greenhouse, the five levels of light intensity were: 70% (control), 37%, 19%, 10%, and 5% of outside incident light, i.e. 30% (control), 63%, 81%, 90%, and 95% shading. Shade cloth was mounted on a wooden frame and supported 15 cm above the turf canopy. The shade cloth was draped on the west and east sides of the frame to prevent the effect of incline light.

Turf was clipped weekly at a 2.0-cm height. Turf quality, color, and turf density were visually assessed weekly on scales of 1 (worst) to 9 (best); ratings of less than 6 were considered unacceptable. Weekly shoot growth rate was determined by measuring canopy height and calculating the difference between the canopy height and mowing height. Maximum root extension was determined by measuring the length of the deepest root visible at the soil/ROT interface as described previously. Turf of 60 cm^2 area under each treatment was harvested with a core sampler at the termination of the study, day-45. Immediately after harvest, turf was washed free of soil, the number of roots developed from nodes of rhizome was counted, and data were collected on root mass and tiller number.

Five treatments in Study I and four treatments in Study II were arranged in a completely randomized block design with 5 replications. Analysis of variance was conducted to test the treatment factors. Mean differences of shade treatments were separated using a protected LSD test at the 0.05 level of probability. Data were also subjected to regression analysis to determine the significant linear or quadratic effects of shade level on each measured parameter.

Field Study

This study was conducted over two seasons in 1995 and 1996 at Texas A&M University - Dallas Research Center. Diamond zoysiagrass (400 m^2) was planted in 1992 on a Houston clay (fine, montmorillonitic thermic Udic Pellustert), and was fully established prior to the initiation of the study. Irrigation with an automatic system was performed weekly to provide approximately 6-mm water. Turf received 146 kg N ha^{-1} yr^{-1} from a 40-0-0 N-P-K fertilizer applied between May and Sept. Treatments imposed were four shade levels (0, 47%, 73% and 86% shade) with a completely randomized design with four replications. The shade structure was constructed with a 2.3 m^2 PVC frame covered with black nylon shade material and supported 0.4 m above the soil level. Light intensity was quantified on several clear days measuring PAR beneath shade structures with a radiometer(model LI-170, Li-Cor, Lincoln, NE) and expressed relative to incident PAR above the shade structure. Shade clothes were placed on 1 July and removed on 1 December. Grass was mowed weekly at 1.6 cm. Turf quality, color, and density were assessed weekly as described for the greenhouse study. In 1996, clippings were collected weekly using a 66 cm wide reel mower equipped with a basket. Only the center 0.81 m^2 of each plot was used for clipping yields to minimize plot border effects. Clippings were weighed immediately for fresh weight, and then dried at 70°C for 24 h for dry weight. Clipping water content was calculated as [(clipping fresh weight -clipping dry weight)/clipping fresh weight] X 100.

To quantify energy reserve status, total nonstructural carbohydrate content (TNC), water soluble carbohydrate content, and starch content were determined for under-ground tissues (rhizome + root). Two cores were taken from each plot on 1, 3, 5, 7, 9, 11, 13, 16, 19, and 22 weeks after shade treatments were imposed in 1996. The core had a 7.0 cm^2 cross-sectional area, and was extracted to a depth of 7.5 cm. Soil and foreign matter were removed from rhizomes and roots. Above ground plant material was excised at the thatch-soil interface. The cleaned tissues were placed in an oven at 100°C for 1 h and then dried at 70°C to constant weight. Samples were ground in a Wiley mill to pass through a 40 mesh screen. Approximately 30 mg of the ground sample was placed in a test tube with 10 ml deionized water. The flasks were autoclaved for 1 h to extract the soluble carbohydrates and gelatinize starch. After cooling, 250 ul supernatant was used to determine the soluble sugar content. The remaining sample was added with acetate buffer (pH 5.0) and 50 units of amyloglucosidase, and incubated for 1 h at 55°C. The reaction was terminated by placing samples in a boiling water bath for 10 min. After centrifugation, 250 ul supernatant was used for TNC analysis. The analysis of TNC and soluble carbohydrate was performed using procedures after Nelson (1944) and Somogyi (1952). Starch content was calculated as the difference between TNC and soluble carbohydrate content.

Leaf chlorophyll content was determined 4, 8, 12, 16, and 20 weeks after the shade treatments were imposed in 1996, by modification of the technique of Arnon (1949). Total chlorophyll, and chlorophyll a and b were calculated using Arnon's formula. Chlorophyll was expressed as mg of chlorophyll per unit of leaf fresh weight. The chlorophyll a:b ratio were calculated.

Results of two years of field experiments were consistent, and only data from the 1996 run are presented in this paper. Data for turf quality, TNC, starch content, and soluble sugar content were analyzed on individual dates to test for differences among treatments. Data for chrolophyll content and growth rate were analyzed over all dates using a repeated measures analysis. Differences among treatment means were separated by the LSD at a 0.05 level of probability.

RESULTS AND DISCUSSION

Greenhouse Study

Turf Quality, Color, and Density

Analysis of combined data from studies I and II indicated a significant study x shade treatment interaction. Therefore, data from each study were analyzed and presented separately. In Study I, stunting, chlorosis and growth suppression were observed during the experimental period for the control, which suggests that turfgrass may have suffered drought stress during the experiment, or more likely, delayed sodding (2-d after sod harvest) had a negative effect on sod establishment for the control. Therefore, turf quality of the control was low (Table 1). Turf under 63% shade produced the highest turf quality throughout Study I.

In Study II, the control and 63% shade treatment exhibited the best turf quality (Table 1). With shade level increasing further, turf quality decreased, and the decrease magnified with time (data not shown). Compared to the control, turf under 81% and 90% shade decreased quality by 18% and 33% at the end of the Study II. Turf produced acceptable quality with up to 81% shade. Turf under 63% shade had the highest color ratings in studies I and II. With the shade level increased further, color decreased linearly and progressively. Shade effects on turf quality and color were best fit to quadratic models.

A linear model best described the relationship between shade and turf density (Table 1). Turf density was negatively correlated with shade level. Loss of acceptable density was noted at 90% and 95% shade. Reduction in density of turf has been reported for shade intolerant bermudagrass (McBee and Holt, 1966), and shade tolerant fine fescue (*Festuca* spp.) and St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] (Smalley, 1981; Peacock and Dudeck, 1986).

Shoot and Root Growth

Shoot vertical growth was stimulated by all levels of shade in both studies. The higher the level of shade, the greater degree of vertical growth (Table 1). As shade level was increased from 30% to 90%, the vertical growth rate increased from 0.2 mm d^{-1} to 2.1 mm d^{-1} in Study I and from 0.5 mm d^{-1} to 2.7 mm d^{-1} in Study II. However, shade level was negatively correlated with tiller number in both studies. Shade at 63%, 81%, and 90% caused 17%, 32%, and 40% reductions in tiller numbers, respectively, in Study II (Table 1).

In Study I, maximum root extension (MRE) of Diamond under 63% and 81% shade were four and three times higher than that for the control (Table 2). The difficulty of rooting for the unshaded control may likely be due to drought stress, or the slow recovery from the effect of delayed sodding. In Study II, 63% and 81% shade treatments had higher MRE than the control only at wk-2. Thereafter, rooting was accelerated for the control. The control exceeded 63% shade for MRE at the end of study. Both studies showed that MRE was inhibited by 90% and 95% shading.

Root mass and root number, which were only determined at the end of the study, were more sensitive in response to shade than MRE. In Study I, root number under 90% and 95% shade was at least 41% lower than those for the control and moderated shade (63% and 81%), and turf under 95% shade had a significantly lower root mass than that under 63% shade. In Study II, root number and root mass were negatively correlated with shade level. Compared to the control, 63%, 81%, and 90% shade exhibited 27%, 46%, and 61% reductions in root number, and 43%, 63%, and 84% reductions in bulk root mass. Results indicated MRE was less affected by shade than root number and mass. The reduction of root number and mass under shade may partially be contributed to a decrease in the number of active nodes, since the reduction in root and tiller number were highly correlated (r=0.80).

In conclusion, shade enhanced vertical growth, but decreased lateral growth of both roots and shoots of Diamond zoysiagrass. Reduction in tiller or stolon number has been reported for turfgrasses generally considered the most shade tolerant, such as fine fescue and St. Augustinegrass (Smalley, 1981; Peacock and Dudeck, 1981).

Field Study

Turf Performance

In the field, turf under 47% shade consistently produced quality ratings > 8 (Fig. 2). With shade level increasing further, turf quality decreased, and the decrease magnified with time (Fig. 2). Compared to full sun, 73% and 87% shade treatments decreased turf quality by 11% and 47%, respectively, at the end of the study. However, only turf quality under 87% shade was unacceptable. Moderate shade (47%) actually enhanced the turf quality in relation to full sun. This might have been because 1) the formation of seedhead in Sept. and Oct. was markedly reduced by shade treatments (Table 3); and 2) 47% and 73% shading enhanced turf color compared to the control. Inosake et al. (1977) also reported that shading delayed heading of bahiagrass (*Paspalum notatum* Flugge.) and buffelgrass (*Cenchrus ciliaris* L.). In agreement with the turf color rating, 47% and 73% shading resulted in increased chlorophyll concentration (Table 3). Both reductions and increases in turf green color and chlorophyll concentration as a result of shading have been reported (Beard, 1965; Guassion, 1983; Peacock and Dudeck, 1981). The discrepancies by researchers may be due to the severity of the light treatments employed and the variability among the genotypes tested. The increased chlorophyll content observed in our study suggested that Diamond elevated proton-absorbing ability to compensate for low light intensities (Boardman, 1977).

Shoot Growth and Carbohydrate Reserves

For the duration of this study, shade greatly increased the clipping yield (Fig. 3). Cumulative total clipping dry weights were 231, 304, and 298 g m^{-2} for 47%, 73%, and 87% shades, which were 1.4x, 2.1x and 2.0x greater than that of the control. Diamond differed with many other turfgrasses, such as Kentucky bluegrass, red fescue, ryegrass, St. Augustinegrass, and centipedegrass [*Eremochloa ophiurodides* (Murro.) Hack.] which produced less clippings under shade than in full sunlight (Wilkinson and Beard, 1974; Mitchell, 1954; Barrios et al., 1986).

Total nonstructural carbohydrate and soluble carbohydrate contents for 0%, 47%, and 73% shade increased during late Sept. and continued increasing until Dec., 1996 (Fig. 4). Increases in TNC and starch probably occurred because growth and metabolism were slowed in the fall, which resulted in a positive energy balance. Brown and Blaser (1965) reported that when growth was reduced by low nitrogen, temperature, or moisture, Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) and orchardgrass (*Dactylis glomerata*) accumulated carbohydrates. Dunn and Nelson (1974) indicated that TNC levels in bermudagrass increased during the fall as a cold acclimation process.

No differences in the soluble carbohydrate content were detected among shade treatments until 22 weeks after treatment, when soluble carbohydrate content for 87% shaded turf was 32% lower than that for 47% shaded turf (Fig.4). Starch and TNC content in rhizome+root tissue were sensitively responsive to light intensity. Mean starch contents at 0%, 47%, 73% and 87% shade levels were 71, 52, 33, and 1.7 mg g^{-1}, respectively. Reserved starch was completely depleted when turf was grown under 87% shade for 11 weeks. Total non-structural carbohydrate content of underground tissue decreased linearly with increasing shade. The measured TNC at the end of study were 145, 100, 55, and 22 mg g^{-1} for 0%, 47%, 73%, and 87% shade, respectively. At 47% shade, TNC was reduced 32% relative to full sun within the initial 4 weeks, but maintained at or above that level as the study continued. Total non-structural carbohydrate decreased dramatically at 87% shading. The low TNC contents under shade may have resulted from 1) the decreased photosynthetic capability as a result of low light intensity, and/or 2) the comparatively higher shoot growth, which was removed by regular mowing. With TNC reserves implicated in regrowth and persistence of perennial grasses, results suggested that heavy shading may fail to maintain long term stand persistence, and tolerances to stress (such as wear and freeze) would likely be lessened. A higher percentage of winter damage was recorded on previously 73% and 87% shaded plots after the winter of 1995 and 1996 (data not shown).

Beard (1965) observed that disease incidence was the major factor influencing the adaptation of cool-season turfgrasses to shade conditions. No disease or pest problems were observed in this study with Diamond. Turf quality reduction under heavy shade was due to the loss of color and density, the critical and sensitive parameters in response to heavy shade.

In all the performance characteristics evaluated, Diamond performed well from 47% to 63% shade; with shade level higher than 63%, turf quality decreased. A substantial decline in turf performance occurred only with continuous heavy shade conditions. Warren (1962) stated that none of the turfgrass will survive for long term when grown under 75% shade. Our results suggest that Diamond zoysiagrass is sufficiently shade tolerant to warrant consideration for further research, which should evaluate the effects of different management approaches on turf performance under heavy shade level.

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Table C1. Effect of shade levels on Diamond zoysiagrass quality, color, shoot density, shoot growth rate, and tiller number in the greenhouse[†].

Shade (%)	Quality	Color	Density	Shoot Growth (mm day^{-1})	Tiller (no. cm^{-2})
				Study I	
30 (control)	6.3c[‡]	6.1c	7.4b	0.2d	6.4a
63	8.5a	8.4a	8.4a	1.3c	6.6a
81	7.0b	7.5b	7.0b	1.9bc	5.9ab
90	6.1c	6.3c	6.1c	2.1b	4.8b
95	5.1d	5.5c	5.1d	2.8a	4.2b
Shade effect[§]					
Linear	ns	ns	***	***	**
Quadratic	***	***	***	ns	**
				Study II	
30 (control)	8.4a	8.2a	8.5a	0.5c	8.3a
63	8.1a	8.2a	8.0a	1.6b	6.9ab
81	6.9b	7.0b	7.0b	2.3ab	5.6bc
90	5.6c	5.6c	5.9b	2.7a	4.9c
Shade effect					
Linear	***	**	***	***	**
Quadratic	***	***	*	ns	ns

[†] Turf quality, color, and shoot density were rated 6 weeks after the initiation of shade treatments on 1-9 scales, where 9 = best. Shoot growth was measured weekly, and converted to mean daily growth. Tiller number was counted 6 weeks after the initiation of shade treatments.

[‡] Means followed by same letter within a column are not significantly different at the 0.05 probability level using Fisher's LSD test.

[§] ns, *, **, and *** indicate non-significant or significant linear or quadratic regression at P = 0.05, 0.01, and 0.001 level, respectively.

Table C2. Effect of shade levels on maximum root extension (MRE), root mass, and root number of Diamond zoysiagrass in the greenhouse.

Shade (%)	MRE by week 1	2	3	4	5	6	Root mass	Root number
	--------------------cm--------------------						(mg)	(no.)
				STUDY I				
30 (control)	0.8	1.4b†	2.2c	3.3c	3.6c	3.8b	110a	34ab
63	1.6	8.8a	15.9a	19.1a	22.1a	22.3a	160a	40a
81	0.7	6.9ab	11.3ab	14.9a	19.4a	16.6a	120a	27ab
90	1.0	4.6ab	7.2bc	8.1b	10.9b	6.1b	60b	20b
95	0.8	2.1b	2.9c	2.8c	2.3c	2.0b	40b	14b
Shade effect‡								
Linear	ns	ns	ns	ns	ns	ns	*	ns
Quadratic	ns	**	***	***	***	***	**	*
				STUDY II				
30 (control)	1.9ab	5.0b	8.6ab	12.4a	16.3a	20.2a	510a	105a
63	2.0ab	8.8a	11.4a	13.2a	14.0ab	16.7a	290b	77b
81	2.4a	6.3ab	10.7a	11.3ab	13.5ab	13.5ab	190c	57bc
90	0.3b	1.5c	3.7b	5.8b	8.5b	10.0b	80d	41c
Shade effect								
Linear	ns	ns	ns	ns	*	***	***	***
Quadratic	ns	***	*	ns	ns	ns	ns	ns

† Means followed by same letter within the same column are not significantly different at the 0.05 probability level using Fisher's LSD test.
‡ ns, *, **, and *** indicate non-significant or significant linear or quadratic regression at $P = 0.05$, 0.01, and 0.001 level, respectively.

Table C3. Effect of shade on chlorophyll content, ratio of chlorophyll a:b, and seedhead density of Diamond zoysiagrass in the field.

Shade (%)	Chlorophyll† (mg g^{-1})	Chlorophyll a:b ratio	Seedhead‡ (no. dm^{-2})
0 (full sun)	1.87b§	1.08	35a
47	2.44a	1.04	1b
73	2.58a	1.02	0b
87	2.19ab	1.08	0b

† Mean monthly chlorophyll content.

‡ Seedheads were counted on 1 October, 1996.

§ Means followed by same letter within the same column are not significantly different at the 0.05 probability level using Fisher's LSD test.

Appendix D

Influence of Trinexapac-ethyl on Diamond Zoysiagrass in a Shade Environment

Y.L. Qian and M.C. Engelke

ABSTRACT

'Diamond' zoysiagrass (*Zoysia matrella* (L.) Merr) has excellent shade tolerance. However, due to excessive shoot growth and carbohydrate depletion, turf stand declines over time when shade levels exceed 80%. Two separate studies were conducted to determine if the plant growth regulator trinexapac-ethyl (TE), which suppresses shoot growth, could improve turf performance of Diamond zoysiagrass under shade conditions. Well established turf was subjected to a constant 86% and 88% shade in the greenhouse and polyhouse, respectively. Trinexapac-ethyl treatments included monthly applications at 0.048 kg ai ha^{-1} (MTE), bimonthly applications at 0.096 kg ai ha^{-1} (BTE), trimonthly applications at 0.192 kg ai ha^{-1} (TTE), and the untreated control. Treatments in 1997 were made from January through August for the greenhouse study, and from April to September for the polyhouse study. Diamond receiving MTE and BTE maintained acceptable turf quality throughout the study period, while turf quality of the control deteriorated to unacceptable levels less than 3 months after shading. Diamond treated with TTE maintained better turf quality than that of the control, but was inferior to MTE and BTE treatments. Compared to control plots, turf receiving MTE and BTE had 1) 75-70% less shoot vertical growth and 77-75% less clippings, 2) 40-38% higher total non-structural carbohydrate content, 3) 60-50% higher root mass and 51-46% higher root viability, and 4) 48-42% higher photosynthesis. Results suggested that monthly or bimonthly repeated application of Trinexapac-ethyl at 0.048 kg ai ha^{-1} or 0.096 kg ai ha^{-1} greatly enhanced the shade tolerance of Diamond zoysiagrass.

INTRODUCTION

Shade, whether from trees or buildings, presents a problem in the management of turfgrasses. Few turfgrasses could survive long term when shading exceeds 75% (Warren, 1962). 'Diamond' zoysiagrass has been noted for its good shade tolerance (Riffel et al., 1995). Qian and Engelke (1997) demonstrated that acceptable turf quality of Diamond was maintained for over 5 months under 73% shade, but not for 86% shade.

Shade level of 86% resulted in a 4-fold increase in shoot vertical growth and 2-fold increase in clipping yields (Qian and Engelke, 1997). Increased shoot growth is also promoted by gibberellic acid (GA) in most plants (Endo et al., 1989). Though no research has been done on turfgrasses, Gawronska et al. (1995) found that increased biosynthesis of GA partially contributed to excessive shoot growth of *Pisum sativum* L. in response to low light intensity. It is possible that a similar physiological process occurs in zoysiagrass under heavy shade. Increasing shoot growth is a shade avoidance mechanism of plants, but it is ineffective and undesirable in turfgrass because of regular mowing. Rapid vertical shoot growth leading to more clippings accelerates the energy depletion of turfgrass tissue. Qian and Engelke (1997) observed a complete depletion of reserved starch after 10-11 wks under 86% shade, which led to decreased turf density and stand persistence.

Therefore, we hypothesize that shade tolerance may be increased by suppressing the elevated production of GA. Trinexapac-ethyl (TE) is an anti-gibberellin acid type of plant growth regulator (PGR). Trinexapac-ethyl exerts its effect by blocking the formation of 3β-OH late in the GA biosynthesis pathway, thus inhibiting plant elongation (Adams et al., 1992). Trinexapac-ethyl has been widely used to suppress turfgrass shoot growth and reduce mowing frequency to lower maintenance costs. While much research has been done under natural sunlight conditions (Marcum and Jiang, 1997; Johnson, 1992; Johnson, 1993a; Johnson, 1993b; Johnson, 1994), no studies have been done under heavy shaded environments. Information is needed about the effects of TE on the rooting, carbohydrate status, and photosynthesis characteristics of turfgrass subjected to heavy shade conditions. The objective of this study was to evaluate the influence of TE at various rates on turfgrass shade tolerance by 1) determining the growth habit and turf performance; 2) measuring root production and root viability; and 3) determining the effects of TE on photosynthesis rate and non-structural carbohydrate status of Diamond zoysiagrass grown in heavy shade conditions.

METHODS AND MATERIALS

Greenhouse Study

This study was conducted at the Texas A&M University - Dallas Research Center. Sod of mature Diamond zoysiagrass was harvested on 22 Nov., 1996 from a field of Houston black clay soil (fine, montmorillonitic thermic Udic Pellustert). Washed sod was transplanted on a 2.8- by 1.6- by 0.6-m heat bench. The bench was filled with sterilized sand soil premixed with 17-2.6-8.3 N-P-K resin-coated fertilizer (Osmocote) to provide 24 Kg N ha^{-1}. A 20-20-20 N-P-K soluble fertilizer was applied monthly to provide 2.4 g N m^{-2}. To stimulate an active growth of Diamond, root zone temperature was maintained between 23° and 26°C from December 1996 to March 1997. The heat bench was designed to circulate controlled-temperature water through a copper pipe grid system, which was embedded at 15 cm under the soil surface. Greenhouse air temperature ranged from 24° to 34°C. Turf was watered daily to prevent drought stress.

Shading was imposed on 4 January, when turf was well established. A shade cloth with 75% light filtering property was mounted on a PVC frame and supported 50 cm above the turf canopy. The shade cloth was draped on all sides to prevent the effect of incline light. Photon flux densities in umol $m^{-2}s^{-1}$ were taken under shade and outside of the greenhouse with a quantum radiometer (model LI-170, Li-Cor, Lincoln, NE). Shade level was expressed as $[(PAR_{\text{outside of the greenhouse}} - PAR_{\text{under the shade cloth}})/PAR_{\text{outside of the greenhouse}}]\times 100\%$.

Trinexapac-ethyl treatments were first applied on 12 January, 1997. Treatments included: 1) monthly TE application at 0.048 kg ai ha^{-1} (MTE), the applications were made on 12 January, 14 February, 24 March, 9 April, 9 May, 9 June, 9 July, and 4 August ; 2) bimonthly application at 0.096 kg ai ha^{-1} (BTE), the applications were made on 12 January, 24 March, 9 May, 9 July; 3) trimonthly TE application at 0.192 kg ai ha^{-1} (TTE), the applications were made on 12 January, 9 April, and 9 July; and 4)the untreated control. Trinexapac-ethyl was applied with a CO_2-pressurized sprayer that delivered 518 liters ha^{-1} at a pressure of 1.5 kg cm^{-2}. Treatments were arranged in a randomized complete block design and replicated three times. Turf was clipped weekly at a 2.0-cm height.

Turf quality was visually assessed weekly on a 1 (worst) to 9 (best) scale; ratings of less than 6 were considered unacceptable. The estimation of turf quality was based on primary components of color, density, and uniformity. Turf canopy height was measured before the clipping event. Weekly shoot growth rate was calculated as the difference between the canopy height and mowing height.

Tiller number, root mass, and percentage of living roots were determined using a core sampler (3.2-cm diam. by 60-cm deep) to remove two cores per plot on 10, 15, and 20 wks after initial TE treatment. Immediately after harvesting, cores were cut along the soil thatch interface and the tiller number was counted. The underground sections were transferred to the laboratory, roots were washed free of soil, blotted dry, and the root fresh weight was determined. Then, 10 to 15 root tip segments of approximately 2-cm were randomly selected and cut. The segments were transferred to test tubes and immediately covered with 5 ml 0.6% 2,3,5-triphenyltetrazolium chloride (TTC) in 0.05 M phosphate buffer (pH 7.4)(Joslin and Henderson, 1984). Samples were vacuum infiltrated and incubated at 30°C for 20 hr. Viable roots were able to reduce TTC (colorless) to Formazan (red). The number of root segments which turned to red were counted under a microscope, and the percentage of living roots was calculated as the indicator of root viability.

Total nonstructural carbohydrate content (TNC) was determined for underground tissue (rhizome + root) as described by Qian and Engelke (1997). Samples were taken from each plot on 5, 10, 15, and 20-wks after initial treatments.

Photosynthetic measurements were determined using a portable infrared gas analyzer system (Model LCA-3, ADC Ltd., Hoddesdon, Herts, UK) equipped with a plexiglass canopy chamber. The chamber had a 10-cm inside diam. and an 8-cm height. Chamber air was mixed with an electric fan, and the Tygon tubes and pumps allowed the entrance of reference air and exit of sample air. The bottom of the chamber was open so that it could be positioned over a 78-cm^2 area of turf, and pressed 2 mm down to the soil. The chamber allowed close measurement of apparent canopy photosynthesis (Pn) with minimum disturbance of natural turf surface. Measurements were generally made 1 day per week (1-2 days after clipping event) between 13 to 21 wks after the initial TE application. The majority of these measurements were performed from 1100 to 1300 h on a fairly constant PAR condition. Part of the data were taken when shade cloth was uncovered and part were taken with shade covering on, so that Pn data were collected at a wide range of PAR (from below light compensation to solar noon levels). The chamber was set and allowed 60 sec for each Pn reading. Measurements of incident PAR were made within 10 sec. of the Pn measurements. This was done by placing a light quantum sensor (model LI-170, LI-COR, Lincoln, NE) next to the canopy chamber. No attempt was made to measure turf respiration due to the difficulty of excluding soil respiration in this experimental setting.

Data on turf quality, tiller number, root mass and viability, and TNC from each measurement date were analyzed using GLM procedure. Treatment means were separated using Fisher's protected LSD (SAS Institute). Non-linear regression analysis, where PAR was the independent variable and Pn the dependent variable, was performed for each treatment and each replication to describe the relationship between Pn and PAR. Through a preliminary screen, a segmented (quadratic with plateau) model was found to best describe the data; when PAR was less than the saturation point, the relation between Pn and PAR was quadratic, when PAR was greater than saturation point, the Pn was constant. The model fitting procedure required partial derivatives of the unknown parameters. Since three replications were used, three regression equations were generated for each treatment. Light compensation point, light saturation point, and maximum Pn were calculated or derived from the fitted equation. These parameters were then treated as response variables and subjected to an analysis of variance to test for differences among treatments.

Polyhouse Study

This study was conducted between April and September, 1997 in a polyurethane-roofed house (polyhouse) at Texas A&M University - Dallas Research Center. Diamond zoysiagrass (6 m by 6 m) was originally sodded in 1991 on a 10-cm sand based root zone mixture above a plastic barrier. The plastic was placed atop a 10-cm gravel layer above the natural soil. Shading was imposed on 1 April, 1997 using a shade cloth with 75% light filtering property mounted on a metal frame and supported 2 m above the turf canopy. The shade cloth was draped on all sides to prevent the effect of incline light. Trinexapac-ethyl treatments were started on 9 Apr., 1997. The components of treatment, maintenance of turf, and procedures of data collection were identical to those of the greenhouse study with the following exceptions:

1) There was a relatively wide range of air temperature fluctuation (18° to 45°C) due to the inefficient temperature control system.
2) Turf was mowed weekly at the height of 1.2 cm and clipping yield was collected.
3) Due to root restriction from the plastic barrier, no data were collected on rooting characteristics.
4) Canopy photosynthesis was only measured on three dates, 14, 84, and 154 days after the initial PGR treatments. All measurements were done with the shade covering on.

Data collected were analyzed using GLM procedure. Treatment means were separated using Fisher's protected LSD (SAS Institute).

RESULTS AND DISCUSSION

Mid-day light intensity under shade cloth in the greenhouse ranged from 55 $u$mol $m^{-2}s^{-1}$ on an overcast day in January to 560 $u$mol $m^{-2}s^{-1}$ on a clear day in July. On July 8, the range of light intensity was 144 u mol $m^{-2}s^{-1}$ at 0800 hour and 560 $u$mol $m^{-2}s^{-1}$ at 1300 hour. Despite the great seasonal and diurnal fluctuations of light intensity, the light level under shade cloth in the greenhouse was consistently at 14±2% natural sunlight, i.e., 86±2% shade.

Mid-day light intensity under shade cloth in the polyhouse ranged from 120 $u$mol $m^{-2}s^{-1}$ on an overcast day to 490 $u$mol $m^{-2}s^{-1}$ on a clear day. On July 8, the range of light intensity was 130 u mol $m^{-2}s^{-1}$ at 0800 hour and 490 $u$mol $m^{-2}s^{-1}$ at noon. The light level under shade cloth in the polyhouse was at 12±2% natural sunlight, i.e., 88±2% shade. However, 108 days after initiating the study, a storm removed the plastic roof. This resulted in a shade level of only 75% during the rest of the study period.

Shoot Growth

Greenhouse Study

In agreement with the previous study (Qian and Engelke, 1997), shade at 86% highly stimulated the vertical shoot growth of Diamond compared to full sun condition. The excessive vertical shoot growth induced by shade was markedly inhibited by TE at all described rates 7 to 10 days after application, with the duration of suppression appearing to depend on treatments and environments (Fig.1A). Monthly TE (0.048 kg ai ha^{-1}) provided the most consistent growth suppression; the mean shoot growth rate over the study period was only 22% of the control.

Bi-monthly TE (0.096 kg ai ha^{-1}) exhibited a similar level of shoot growth suppression (26% of the control) as MTE. However, 57, 73, and 80 days after the initial treatment BTE had higher shoot growth than that of MTE, whereas 31 and 38 days after the initial treatment the inverse was true. Tri-monthly application suppressed shoot growth for approximately 2-month after each application. Thereafter it became evident that the effectiveness of growth suppression was reduced. Shoot growth rates of TTE treated and the control were not different 73 to 105 and 165 to 193 days after the initial application.

Polyhouse Study

Compared to the control, MTE, BTE, and TTE resulted in a mean reduction of shoot vertical growth by 64%, 43%, and 57%, respectively (Fig. 2A). MTE and BTE exhibited relatively consistent shoot growth suppression. TTE produced < 10% vertical shoot growth of the control for 2-months, but vertical shoot growth was not different with the control 70 to 90 days after TE application. The mean fresh clipping yields were 9.0, 2.5, 2.5 and 2.9 g $m^{-2}wk^{-1}$ for the control, MTE, BTE and TTE, respectively (Table 2).

Both greenhouse and polyhouse results indicated that the most consistent suppression of shoot growth under shade was obtained by frequent application with low rates of TE.

Turf Quality

Weekly turf quality for the greenhouse study was presented in Fig.1B. For the control, turf exhibited acceptable quality only in the first 6 wks, thereafter, quality declined to a commercially unacceptable level (<6). The slight recovery in turf quality of the control between June and August may have been due to the seasonal improvement of light conditions. All TE treatments remarkably improved the quality of shaded Diamond. Mean turf qualities during the 8-month-period were 8.0, 7.9, and 7.3 for Diamond receiving MTE, BTE, and TTE treatments, respectively. Enhanced vigor, color, and density were consistently observed for turf receiving MTE and BTE. TTE caused slight foliar injury 1 to 2 wks after application, but subsequent turf quality was significantly enhanced compared to the control. Ten to 12-wk after treatment, when the response of shoot growth suppression was diminished for TTE, turf quality declined by 0.5-1.0 units. Twelve of 26 ratings indicated that MTE or BTE treatments were more effective for increasing shade tolerance of Diamond than that of TTE in terms of turf quality.

In the polyhouse, the control plots exhibited acceptable quality only in the first 10 wks after shading, thereafter, quality declined to unacceptable levels (Fig. 2B). In contrast to the greenhouse, turf of the control declined greatly between June and July in the polyhouse. The higher temperature presented in the polyhouse may have accelerated depletion of carbohydrate reserves despite the improved light conditions in mid-summer. Quality of the control recovered slightly when shade level reduced from 88% to 75%. Treatments of MTE and BTE remarkably improved the quality of shaded Diamond 2 months after the initial TE treatments. Mean turf qualities during the study period were 8.0, 7.9 for Diamond receiving MTE and BTE. Trinexapac-ethyl at 0.192 kg ai ha^{-1} caused severe foliar injury 2 to 6 wks after application, reducing turf quality by $\approx$1.0 unit, but subsequent turf quality was significantly enhanced compared to the control. Mean turf quality was 7.4 for TTE treated turf. The root restriction in the polyhouse may have partially resulted in greater phytotoxicity compared with the greenhouse study.

Turf quality was negatively correlated with shoot vertical growth ($P < 0.0001$ and $r = -0.55$). This suggested that TE increased the turf quality of Diamond by offsetting the excessive growth stimulated by the heavy shade conditions.

Tiller Number

Diamond control exhibited gradual declination in tiller number 5 to 15 wks after shading in the greenhouse (Table 1). Twenty weeks after the initial treatment, increased tiller number was observed due to the seasonal improvement of light condition. Turf treated with MTE, BTE and TTE exhibited higher tiller numbers than that of the control 10 wks after treatments. Fifteen weeks after the initial treatment, turf receiving MTE and BTE had a higher tiller number than both the control and TTE treatment. Turf receiving MTE and BTE had 27% more tillers than that of the control 20 wks after the initial treatment.

In the polyhouse, tiller number declined over time for each treatment after shading (Table 2). Trinexapac-ethyl did not increase tiller number 2-wk after the initial treatments. However, 7 and 12-wk after the initial treatment, turf receiving MTE produced 34% and 56% higher tiller number than that of the control.

Increasing tiller number has been reported for other turfgrass when treated with anti-gibberellin PGRs (Dernoeden, 1984; Watschke et al., 1992). However, this response was magnified under our heavy shaded conditions. Another study with three light regimes and two PGR treatments indicated that the greatest suppression of vertical shoot growth and the most significant increase in tiller number and turf quality occurred at the highest shade level when environmental conditions favored rapid growth (Qian et al., 1997). Trinexapac-ethyl caused little reduction in vertical shoot growth and little or no increase in turf quality and tiller number when conditions favored slow growth.

Root Production and Root Viability

In the greenhouse, turf receiving MTE, BTE, and TTE exhibited 100%, 67%, and 116% higher root mass than that of the untreated control 10 wks after the TE treatments, (Table 1). The root mass production of MTE treated turf was superior to BTE, TTE, and the control 15 wks after treatments. Twenty weeks after the initial treatment, MTE and BTE had > 70% root mass than that of the control. Though TE has been reported to decrease total root length of 'Kentucky-31' tall fescue under natural greenhouse light conditions (Marcum and Jiang, 1997), our results indicated that TE increased root mass of Diamond zoysiagrass under heavy shade.

Considerably increased root viability was also detected for all TE treatments 10 wks after first application in the greenhouse study (Table 1). Decreased shoot growth and increased root mass and root viability suggested that TE decreased the sink strength of the shoot but increased the sink strength of roots, and shifted limited assimilates to the root system. The altered partitioning of assimilates resulted in more root mass as well as higher root viability under heavy shade. Increased TNC in root tissue was observed for Tifway bermudagrass (*Cynodon dactylon x transvaalensis*) 2 and 6 weeks after application of TE at 0.015 kg ai ha^{-1} (Waltz et al., 1996). Steffens and Wang (1984) and Steffens et al. (1985) observed shifted growth patterns and the reallocation of more nonstructural carbohydrates to fibrous roots when apple seedlings were treated with plant growth regulator paclobutrazol. However, 'Majestic' Kentucky bluegrass exhibited a reduced photosynthate partitioning to roots 4 wks after the application of paclobutrazol and Flurprimidol (Hanson and Branham, 1987).

Carbohydrate Reserve Status

Total non-structural carbohydrate content of Diamond grown under 86% shade in the greenhouse was extremely low, especially between January and March when the natural light intensity was low (Table 3). Increased TNC between 16 and 20 wks after the initial treatment may have been due to the improvement of light conditions during summer. Trinexapac-ethyl treatments significantly increased the TNC in rhizome+root tissue. Compared to the control, MTE increased TNC by 142% and

74%, 10 and 16 weeks, respectively, after the initiation of treatment. Bimonthly TE treatment resulted in 100% higher TNC 10 weeks after treatment.

Despite the improved light conditions in mid-summer, TNC across all treatments in the polyhouse study was decreased over time (Table 3). Trinexapac-ethyl treatments significantly improved TNC status. Combining all sampling dates, MTE, BTE and TTE had 24%, 33%, and 28% higher TNC than that of the control.

Increase of TNC in TE treated turf probably was due to higher rate of photosynthesis per unit of turf area, as we will discuss. Decreased shoot growth may also partially account for the carbohydrate build-up in TE treated turf (Brown and Blaser, 1965).

Canopy Photosynthesis and its Light Response Pattern

Greenhouse Study

The general light response pattern of apparent photosynthetic rate was similar to that reported for many other plant species; increased Pn at a diminishing rate as light intensity was increased until light saturation was achieved (Fig. 3). Using a segment nonlinear regression model, three specific parameters (light compensation point, light saturation point and maximum Pn) were calculated.

Light compensation point (the amount of light where photosynthesis balances respiration) of the control was approximately 270 u mol m^{-2} sec^{-1}. Light levels below this value were frequently measured under shade during rainy or overcast days. Hence, turf deterioration occurred, especially when turfgrass exhibited excessive growth. Trinexapac-ethyl treatments significantly reduced light compensation points, calculated as 175, 135, and 180 u mol m^{-2} sec^{-1} for MTE, BTE, and TTE, respectively. The advantage of the reduced light compensation point led to a more positive energy balance.

Light saturation points (the amount of light required to maximize the photosynthetic rate of turf community) were not significantly different among treatments. The mean light saturation point for all treatments was 1333 u mol m^{-2} sec^{-1}.

Maximum photosynthetic rates among treatments were different. Diamond treated with TE had a significantly higher maximum Pn than that of the control. Maximum photosynthetic rates of MTE, BTE, and TTE treated turf were 5.8, 6.0, and 5.9 u mol m^{-2} sec^{-1}, which is 38%, 42% and 39% higher than that of the control, respectively. Though estimates of maximum photosynthesis rates under heavy shade were not as meaningful as compensation point (since the former is rarely achieved under heavy shade conditions), this result suggests that TE increased the photosynthesis capacity of Diamond grown under heavy shade.

Polyhouse Study

Apparent canopy photosynthesis rates among the treatments were not different 2 wks after the initial treatments (Table 2). Twelve weeks after the initial treatment, Pn of the control was at least 66% lower than that of TE treated turf. Twenty-two weeks after the initial treatment, Diamond receiving MTE and BTE provided 42% and 48% higher Pn than that of the control.

The increased Pn and reduced light compensation point compared to the control suggested that TE increased the light absorption efficiency of Diamond grown under heavy shade. This may have resulted because of a more prostrated shoot orientation and a higher chlorophyll content observed for TE treated turf. The higher tiller number, which resulted in greater amount of tissue, may also contribute to the higher photosynthesis rate and increased CO_2 consumption for TE treated Diamond. Morgan and Brown (1982) reported that Pn of bermudagrass increased with the leaf area index..

CONCLUSIONS

Shade caused an excessive vertical shoot growth and resulted in an upright canopy structure. We have documented with these experiments that monthly TE application at 0.048 kg ai ha^{-1} or bimonthly TE at 0.096 kg ai ha^{-1} could effectively suppress the excessive shoot elongation and convert the more upright canopy structure to a more prostrate canopy structure. Resulting benefits included 1) improved plant carbohydrate reserve status, 2) improved root system by attracting more metabolites, 3) increased canopy photosynthesis capacity, and ultimately enhanced turf quality compared to the control under heavy shaded conditions. Our work demonstrated that trinexapac-ethyl can be used as an effective management tool for turf managers to achieve dual benefits of reducing mowing requirements and increasing shade tolerance of Diamond zoysiagrass.

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Table D1. Influence of trinexapac-ethyl (TE) treatments on root mass, % living root, and tiller number of Diamond zoysiagrass grown under 86% shade in the greenhouse.

Treatment	Root mass (mg), WAT†				% living root, WAT				Tiller (no. cm^{-2}), WAT			
	10	15	20	Av..	10	15	20	Av..	5	10	15	20
Control	60c‡	120b	110b	100b	35b	61[ns]	52[ns]	49	5.5[ns]	4.7b	4.3b	4.7b
MTE §	120ab	200a	200a	160a	72a	77	74	74	5.8	6.7a	6.0a	6.0a
BTE	100b	130b	190a	150a	75a	71	75	73	5.6	6.6a	5.4a	5.8a
TTE	130a	140b	160ab	140ab	71a	67	62	67	5.7	6.2a	4.7b	5.4ab

Table D2. Influence of trinexapac-ethyl treatments on clipping yield, tiller number, and canopy photosynthesis rate (Pn) of Diamond zoysiagrass grown under 88% shade in the polyhouse.

Treatment	Clipping yield	Tiller, WAT†			Pn, WAT		
		2	7	12	2	12	22
	--($g\ m^{-2}\ wk^{-1}$)--	-----no cm^{-2}-----			--umol $m^{-2}\ sec^{-1}$--		
Control	9.0a‡	10.4[ns]	8.1b	6.3b	2.8[ns]	0.9b	3.1b
MTE§	2.5b	11.1	10.9a	9.8a	2.6	2.7a	4.6a
BTE	2.5b	11.4	9.3ab	8.4ab	2.3	2.8a	4.4a
TTE	2.9b	10.8	10.0ab	9.0ab	2.2	3.0a	4.0ab

Table D3. Influence of trinexapac-ethyl treatments on total carbohydrate content (TNC) of Diamond zoysiagrass grown on sand soil under 86% shade in the greenhouse and 88% shade in the polyhouse.

Treatment	Greenhouse ---------WAT†-------					Polyhouse -------WAT†------			
	5	10	16	20	Av..	3	8	13	Av..
	--------------------TNC (mg g^{-1})----------------								
Control	17	12b‡	27b	37	23b	53b‡	50	33	45b
MTE§	26	29a	47a	57	39a	70b	60	38	56a
BTE	21	24a	38ab	49	34ab	79a	56	45	60a
TTE	18	30a	36ab	35	30ab	73a	64	39	58a

† WAT, weeks after the initial treatment.

‡ Means followed by same letter within the same column are not significantly different at the 0.05 probability level using Fisher's LSD test.
§ MTE, BTE, and TTE represent monthly TE application at 0.048 kg ai ha^{-1}, bimonthly TE application at 0.096 kg ai ha^{-1} (BTE), and trimonthly TE application at 0.19 kg ai ha^{-1}, respectively.

Appendix E

1996 National Turfgrass Evaluation Program (NTEP) Zoysiagrass trial at TAES-Dallas

Abstract. To evaluate the performance of commercial and experimental cultivars of zoysiagrass, twenty-eight zoysiagrasses, including nineteen cultivars from NTEP program and nine selections from Texas A&M Univ.-Dallas, were established at TAES-Dallas center for evaluation in July 1996. DALZ9601, Emerald, HT-210, Cavalier, DALZ9602, Zeon, and Z-18 had the finest leaf texture, Victoria and DeAnza had medium leaf texture, and the most coarse leaf-textured entry was Miyako. DALZ9601, along with Zeon and Cavalier had high turf quality among the fine textured entries. J-14, El-Toro, Jamur, and palisades exhibited high turf quality among the course textured entries. Cavalier, DALZ9601, Zeon, Emerald, Meyer, and Palisades had darker green color than other entries. The most rapid establishment was observed for DALZ9604, TAES 4365. El-Toro, Jamur, Miyako, and DALZ9606. Among the seeded entries, J-36 and J-37 were the first to germinate. Green up and color retention data showed that Emerald, DALZ9601, Cavalier, and Zeon had a longer growing season than the others.

Materials and Methods. Nineteen selections, including 8 seeded and 11 vegetatively propagated were provided by USDA-NTEP. In addition, three recently released new vegetative cultivars and six experimental lines from Texas A&M Univ.-Dallas breeding program were included for evaluation. All entries were established in native blackland prairie soil on 1.83 x 1.83 m plots on July 29, 1996. The experiment was a randomized complete block design with three replications. The seeding rate for the seeded entries was 1 lb/1000 ft^2. Zoysiagrass seeds were placed on top of the ground and covered with transparent polyethylene for 3 weeks to accelerate the germination. The planting ratio for the vegetative entries was 1:32 plug:plot area. The experiment was watered as needed to prevent water stress, and was maintained at a 5.0 cm mowing height. Three 49 kg N/ha applications of NH_4NO_3 (34-0-0) were applied, for a total fertilizer level of 147 kg N/ha per year.

Turf establish rate was collected as the percentage of plot area covered with turf. Monthly color was rated on a 1 to 9 scale where 9 = darkest green and 1=brown. Leaf texture was also rated as a 1 to 9 scale where 9 = finest leaf texture.

Results

Establishment Rate. Among vegetative entries, much more rapid establishments were noted for DALZ9604 and TAES 4365, which covered 68% and 58% of the plot area within 70 days (Table E1). El-Toro, Jamur, Miyako, and DALZ9606 also exhibited a relatively fast establishment rate. Cavalier and Meyer had the lowest establishment rate. On Jan. 10, 1997, Meyer and Cavalier only covered over 25% of the plots area. Among the seeded entries, J-36 and J-37 were the first to germinate, and they had the highest seedling vigor and fastest establishment rate. Chinese Common had a relatively fast establishment rate. On August 1997, approximately 1 year after planting, all the plots except for Z-18, Korean Common, and DALZ9602 were fully established. The poor coverage of Z-18 and DALZ9602 was due to the severe winterkill. Korean Common exhibited a poor germination rate for unknown reason.

Turf quality. Data collected to date indicated that Zeon and DALZ9601 had high turf quality among the fine textured entries. El-Toro, Jamur, and Palisades had best turf quality among course textured entries. Victoria had the best quality among the medium textured entries (Table E2).

Texture. DALZ9601, Emerald, HT-210, Cavalier, DALZ9602, Zeon, and Z-18 had the finest leaf texture, Victoria and DeAnza had medium leaf texture, and the most coarse leaf-textured entry was Miyako.

Genetic Color, Fall Color retention, and Spring Green up. Cavalier, DALZ9601, Zeon, Emerald, Meyer, and Palisades had darker green color than other entries. DALZ9602, DALZ9603, DALZ9604, DALZ9607, DeAnza, and all seeded entries had lighter green color than others. From Oct 4 to Nov. 14, Meyer and Chinese Common had the fastest decline in leaf color while Emerald, Cavalier, DALZ9601, HT-210. Miyako, Palisades, DALZ9602, DALZ9604, DALZ9607, and Zeon exhibited superior fall color retention. The earliest spring green up was observed for Emerald, Cavalier, DALZ9601, Zeon, and Palisades. Generally, vegetative entries retained green cover longer into the winter than seeded entries (Table 2). Rated on April 6, except Z-18, DALZ9602, HT-210, DALZ9604, DALZ9605, DeAnza, DALZ9603, and DALZ9607, all entries exhibited > 50% turf area covered with green tissue (Table E3). However, Z-18 had only < 1% and DALZ9602, HT-210, DALZ9604, DALZ9605, and DeAnza had only < 40% turf covered with green tissue, suggesting that some degree of winter injury had occurred due to their limited winter hardiness.

Table E1. Turf establishment, indicated by the percentage of the plot covered with turf, during 1996 and 1997 for 1996 NTEP zoysiagrass trial.

Entry	10/4/96	11/14/96	3/12/97	4/18/97	5/15/97	6/20/97	7/23/97	8/19/97	mean
DALZ9604	68.3a	76.7a	73.3a	22.7	50.0	87.7a	93.3a	98.0a	71.3
Miyako	51.7	53.3	58.3	50.0a	71.7a	90.0a	91.7a	97.7a	70.5
J-37	53.3	40.0	60.0	53.3a	60.0a	94.3a	95.3a	97.0a	69.2
J-14	50.0	45.0	49.3	56.7a	64.0a	91.0a	93.0a	98.0a	68.4
DALZ9603	58.3a	48.5	63.3a	31.0	56.7	92.0a	95.3a	98.0a	67.9
DALZ9606	46.7	48.3	61.7a	46.7a	56.7	91.0a	94.7a	97.0a	67.8
J-36	51.7	43.3	50.0	51.7a	56.7	85.0a	94.3a	98.0a	66.3
JaMur	48.3	41.7	53.3	43.3	61.0a	86.7a	93.3a	98.0a	65.7
El-Toro	51.7	46.7	53.3	43.3	48.3	82.7a	89.7a	98.0a	64.2
Palisade	36.7	41.0	41.0	43.3	55.0	92.7a	93.3a	98.0a	62.6
Emerald	31.7	35.7	39.3	51.7a	60.0a	89.7a	93.3a	97.0a	62.3
Chinese Common	43.3	31.7	45.0	43.3	53.3	83.3a	92.7a	98.0a	61.3
Zeon	27.3	42.3	41.0	46.7a	46.7	86.0a	94.0a	98.0a	60.3
Crowne	38.3	38.3	40.0	39.3	47.0	81.7a	91.0a	98.0a	59.2
DALZ9601	24.0	33.3	35.7	37.7	36.7	75.0	92.7a	98.0a	54.1
Victoria	35.7	39.0	35.0	31.7	36.7	65.0	86.0a	97.3a	53.3
Zen-400	25.0	26.7	31.7	33.3	41.7	78.3a	91.0a	97.3a	53.1
DeAnza	34.0	36.7	35.0	21.3	31.0	70.0	84.3a	97.3a	51.2
Zenith	35.0	36.0	31.7	31.7	30.0	62.7	85.3a	96.0a	51.0
DALZ9607	33.3	40.0	36.7	24.3	30.0	63.3	79.3	91.7a	49.8
DALZ9605	33.3	41.7	41.7	21.7	26.7	53.3	72.7	94.7a	48.2
Cavalier	20.0	25.0	22.3	27.7	31.0	63.3	84.3a	98.0a	46.5
Meyer	20.0	25.0	22.7	27.7	28.7	60.0	83.3a	97.0a	45.5
HT-210	23.3	31.7	31.0	16.7	26.0	48.3	83.3a	96.0a	44.5
Zen-500	22.3	25.0	24.3	22.7	25.0	53.3	79.3	88.3	42.5
DALZ9602	25.0	35.0	35.0	7.7	10.0	16.7	28.3	66.7	28.0
Korean Common	1.5	2.0	2.0	4.0	4.5	7.5	22.5	40.0	11.4
Z-18	11.3	19.3	19.0	0.0	0.3	0.7	1.0	3.3	7.4

[1] Established on July 31, 1996.

[2] Turf ground coverage was rated as the % of the plot area which is covered by buffalograss.

Table E2. Turf quality of the 1996 NTEP zoysiagrass trial at TAES-Dallas in 1997.

Entry	4/18	6/20	7/23	8/19	9/19	10/9	11/19	Mean
Zeon	4.5a	8.2a	7.4a	7.5a	8.2a	7.0a	5.9a	6.9
DALZ9601	4.0	8.0a	7.1	7.3a	8.3a	7.2a	5.9a	6.8
Cavalier	3.7	7.7a	6.9	7.4a	7.9	7.1a	5.6a	6.6
J-14	4.8a	7.4	7.2	7.4a	7.1	6.9a	5.2a	6.6
El-Toro	4.3a	7.3	6.9	7.3a	7.3	7.1a	5.0a	6.5
JaMur	4.3a	7.3	6.9	7.4a	7.3	7.2a	5.0a	6.5
Palisades	4.2a	7.4	6.8	7.5a	7.3	7.3a	5.2a	6.5
Victoria	3.4	7.6a	7.2	7.4a	7.7a	6.9a	5.3a	6.5
DALZ9606	3.8	7.2	7.1	7.6a	6.9	6.9a	5.3a	6.4
Crowne	4.2a	7.0	7.0	7.6a	7.3	6.9a	4.7	6.4
DALZ9604	3.0	6.6	6.9	7.4a	7.4	6.9a	5.9a	6.3
J-36	4.7a	6.5	7.0	7.2a	6.8	7.0a	5.2a	6.3
J-37	4.7a	6.8	7.4a	6.8	6.6	6.8a	5.0a	6.3
Zenith	3.5	6.9	6.9	7.3a	7.3	7.0a	5.1a	6.3
Zen-400	3.8	6.9	6.8	7.2a	7.0	6.9a	5.1a	6.2
DALZ9603	3.7	6.7	6.1	7.4a	6.6	7.0a	5.6a	6.1
Chinese Common	4.2a	6.2	6.8	7.2a	6.9	6.4	4.7	6.1
DeAnza	2.8	6.7	6.3	7.5a	7.3	7.2a	5.2a	6.1
Miyako	4.3a	6.2	6.2	7.2a	7.1	7.1a	5.0a	6.1
HT-210	2.2	7.3	7.0	7.1a	7.6	4.7	4.8	5.8
Meyer	3.2	6.5	7.3	7.3a	6.5	6.2	3.8	5.8
DALZ9605	2.7	7.0	5.0	7.0	6.7	6.5	5.1a	5.7
DALZ9607	3.2	6.9	5.8	7.1a	6.5	6.0	4.2	5.7
Zen-500	2.8	6.0	6.2	6.8	6.6	6.4	4.9a	5.7
DALZ9602	1.2	6.0	4.0	6.4	4.0	3.7	3.7	4.2
Korean Common	.	.	.	.	.	2	2	3.7
Z-18	.	.	.	.	.	.	.	1.4
LSD(0.05)	0.8	0.9	0.95	0.5	0.6	1.6	1.1	

[1] Turf quality was rated on a scale of 1 to 9, where 9 was the best, and 5 was the minimum acceptable.

Table E3. Genetic color, fall color retention, and spring green up of the 1996 NTEP zoysiagrass trial at TAES-Dallas.

Entry	Genetic color	Fall color retention 11/14/96	12/1/96	1/10/97	Spring green-up 2/10/97	3/10/97	%Green tissue[2]	TPI[3]
Vegetative Entries								
Cavalier	8.1a	6.0a	6.2a	1.7	2.1a	4.4a	73.3a	6
Crowne	7.2a	5.2	5.9	1.4	1.5	3.8	61.7	1
DALZ9601	8.1a	5.7a	6.1a	1.7	2.7a	4.4a	75.0a	6
DeAnza	5.9	4.8	5.3	1.3	1.2	2.4	35.0	0
El-Toro	6.7	4.9	4.8	1.3	1.4	3.9	56.7	0
Emerald	7.7a	5.6a	6.1a	2.3a	2.7a	4.8a	76.7a	7
HT-210	6.7	5.9a	6.7a	1.1	1.3	2.4	26.7	2
J-14	6.3	5.0	4.5	1.7	1.2	3.3	73.3a	1
JaMur	6.8	5.0	4.8	1.3	1.4	4.1	60.0	0
Meyer	7.5a	4.2	3.7	1.2	1.4	2.8	81.7a	2
Miyako	6.6	5.1	6.2a	1.5	1.6	3.9	56.7	1
Palisade	7.5a	5.9a	6.1a	1.4	1.7	4.3a	68.3	4
DALZ9602	5.5	5.7a	6.5a	1.0	1.2	1.9	11.7	2
DALZ9603	5.8	5.6a	5.8	1.1	1.2	3.0	45.0	1
DALZ9604	5.8	5.7a	6.6a	1.1	1.1	2.8	28.3	2
DALZ9605	6.5	5.4	5.8	1.0	1.1	2.8	33.3	0
DALZ9606	6.0	4.8	5.1	1.3	1.4	4.2	60.0	0
DALZ9607	5.8	5.6a	6.6a	1.1	1.1	2.7	48.3	2
Victoria	7.2a	5.5	5.8	1.6	1.6	3.4	50.0	1
Zeon	8.0a	5.6a	6.2a	1.7	2.7a	4.4a	73.3a	6
Seeded Entries								
Chinese Common	5.6	3.8	2.0	1.2	1.2	3.0	78.3a	1
J-36	5.5	4.7	4.5	1.6	1.5	4.1	83.3a	1
J-37	5.7	4.5	4.0	1.5	1.4	4.0	81.7a	1
Z-18	4.8	4.4	4.7	1.0	1.0	1.0	0.7	0
Zen-400	5.5	4.2	3.0	1.1	1.2	2.5	81.7a	1
Zen-500	6.2	4.4	3.7	1.6	1.6	3.2	68.3	0
Zenith	6.5	4.5	4.2	1.5	1.5	3.1	70.0	0

[1] Color quality was rated on a scale of 1 to 9, where 9 was the darkest green color, and 5 was the minimum acceptable greencolor.
[2] % green tissue was rated on April 6, 1997 as the percentage of turf covered with green color.
[3] TPI = turf performance index, which is the number of times an entry occurred in the top statistical group.