1996

ANNUAL PROGRESS REPORT

BREEDING AND DEVELOPMENT OF ZOYSIAGRASS

Submitted by:

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Executive Summary

Principal Investigator: Dr. M.C. Engelke
Co-Investigators: Dr. Ikuko Yamamoto
Dr. Yaling Qian

Research Period: 1 November 1995 through 1 November 1996

After the review process of Plant Improvement Review Committee, four high quality turf-type zoysiagrass cultivars were officially released in 1996. 'Diamond,' formerly identified as DALZ8502, is a very fine texture, dense, shade tolerant *Zoysia matrella*, suitable for golf course tee boxes, greens surrounds, putting greens, and athletic fields. 'Cavalier,' formerly known as DALZ8507, is a fine-texture *Z. matrella*, suitable for golf course fairways, athletic fields, and home lawns. Cavalier's overall turfgrass performance was evaluated as number one in the National Turfgrass Evaluation Programs over a 3-year period. 'Crowne,' formerly identifed as DALZ8512, and 'Palisades,' former DALZ8514, are medium-coarse texture *Z. japonica's* and suitable for use on golf course roughs, sports fields, home lawns, or as utility turf. Crowne is noted for excellent competition against weeds, and low water use needs. Palisades is also noted for low water use, and also has a more rapid harvest cycle than other zoysiagrasses.

All cultivars are vegetatively propagated by either stolons and/or rhizomes. The rate of establishment and harvest cycle differes considerably among them. Diamond reproduces primarily by a deep, dense rhizome system which requires approximately 15 months for the first harvest, with subsequent harvest in Dallas, Texas approximately every 6 months. Cavalier is primarily stoloniferous and requires 10 - 12 months for establishment, with a 12 month harvest cycle. Crowne's and Palisades both reproduce extensively with stolons and rhizomes. Crowne's harvest cycle will approach three crops in 24 months, whereas, Palisades will provide two harvest in 12 months in environments similar to north Texas. Approximately 1100 m^2 of breeder fields and 7000 to 8600 m^2 of foundation fields are ready for harvest for Cavalier, Crowne and Palisades. Diamond is available only as breeder stock as a foundation field is not available.

The zoysiagrass breeding program has expanded its personnel base with the addition of Dr. Yaling Qian, Ph. D. (Kansas State Univ., 1996) as an Assistant Research Scientist. Dr. Qian's primary research in on stress physiology and management of zoysiagrasses.

1996 RESEARCH REPORT
BREEDING AND DEVELOPMENT OF ZOYSIAGRASS

M. C. Engelke, Y. Qian, and I. Yamamoto

I. Introduction

The zoysiagrass breeding and development program is in its 12th year of funding through the United States Golf Association. Considerable genetic variability does exist among *Zoysia* spp. and after many years of selections, evaluations, and extensive examinations, we released four zoysiagrass cultivars. A fifth will be submitted for release in 1997 This report summarizes the project activities for the period of 1 Nov. 1995 to 1 Nov. 1996 and addresses the introductions of four of the new zoysiagrass cultivars.

II. Technical Support Personnel

Dr. Ikuko Yamamoto (Assistant Research Scientist) has served the Turfgrass Breeding Program since February 1995. Dr. Yamamoto's responsibilities focus on breeding and development of zoysiagrasses by conventional methods and molecular genetic techniques. The primary objective of her research is interacting with Drs J. A. Reinert and P. F. Colbaugh in evaluation and introduction of disease and/or insect resistance to susceptible DALZ lines. Approximately 40% of her time is devoted to the zoysiagrass project.

Dr. Yaling Qian (Assistant Research Scientist) joined the Turfgrass Breeding Program in February 1996 from Kansas State University (Appendix A).

Dr. Qian's primary responsibility is to examine physiological stress effects on zoysiagrasses. Specifically, her research focuses on root development and carboydrate reserve status of 'Diamond' zoysiagrass under low light conditions, and on water requirements of advanced and near release selections. Approximately 80% of her time is devoted to the zoysiagrass project.

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 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; hens, 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.

Development of Insect Resistant Cultivars

Application of Biotechnology in Zoysiagrass Breeding

The incidence of disease and/or insect infestation has often complicated turfgrass management. The primary cultural practice for pest control centers on the timely, and voluminous, use of pesticides. Over the past few years, however, considerable emphasis has been placed on alternative forms of pest management such as the breeding of pest resistant cultivars. More recently, successful biotechnology applications in the turfgrass area suggest that we can efficiently introduce pest resistance into turfgrass cultivars by combining cell biology and molecular genetic techniques with conventional breeding methods.
At TAES - Dallas, we have developed vegetatively propagated zoysiagrass cultivars through the conventional breeding methods. A vegetative cultivars is released after years of selections based on morphological and physiological characteristics. Although the developed cultivar possesses several agronomically desirable characteristics, some disadvantages may also exist. Introduction of a few new genes by genetic engineering should be an efficient way to improve existing cultivars. To apply the biotechnology, the development of an efficient and reproducible tissue or cell culture system is essential. Plant regeneration via callus and protoplast cultures was reported in zoysiagrasses using mature caryopses (embryos) as explants. However, since zoysiagrass seeds, generally produced by cross-pollination, are genetically heterogeneous, plants regenerated from a seed-derived callus are genetically different from each other, and the parental lines. It is unknown whether the explant possesses agronomically or physiologically desirable genes. To overcome the problem, we are currently developing a tissue culture system utilizing a vegetative tissue (nodal segment) of elite clones as an explant.

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 can transfer the insect-resistant gene(s) from resistant lines to susceptible lines by conventional recurrent selection techniques; however, the advanced molecular genetic techniques will accomplish the transfer within a much shorter time period. Although this project is still in its early stage of development, a part of this study was presented in a Turfgrass Biotechnology Workshop, East Lansing, MI, in August 1996 and will be presented in the ASA annual meeting, Indianapolis, IN, in November 1996. Determination of the mode of inheritance and identification of the resistant gene(s) are the next significant aspects in this project.

F1 Progeny

Twenty-six F1 progeny produced by five different crosses are under propagation for the screening tests for insect/mite resistance. The crosses were made between: DALZ8501 (♀) x Crowne (♂); Crowne x DALZ8501; Crowne x Diamond; DALZ8501 x Diamond; and Diamond x DALZ8501. When *Z. japonica* was used as mother plants and crossed with *Z. matrella*, the F1 progeny tended to possess *Z. japonica* type morphology. Since some of the F1 progeny possess agronomically superior characteristics, 6 progeny (1 from a cross between DALZ8501 x Crowne; 3 from Crowne x DALZ8501; 2 from Crowne x Diamond) are under evaluation in the 1996 NTEP trial at TAES - Dallas. Three progeny from DALZ8501 x Diamond are being examined under field conditions using Diamond as standard. Due to low pollen viability of DALZ8501 (34%), seed production was limited when DALZ8501 was used as a pollen plant. The pollen viability of other genotypes were 94% for Diamond and 80% for Crowne. New sets of crosses will be made between all possible combinations, including Cavalier and DALZ8516.

IV. Field Evaluation and Production Trials

National Turfgrass Evaluation Program (NTEP)

Summary of 1991 NTEP trials

The 1991 NTEP trial was completed in Feb. 1996. The summaries of 1991 NTEP trials over all location were presented in Appendix B (Tables B1 and B2). Texas A&M entry DALZ8507 (Cavalier) performed at the top among 10 fine-texture turf (*Z. matrella*) while DALZ8512 (Crowne) had performed best among 10 coarse-texture zoysiagrass (*Z.japonica*) over the 5 year period..

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 release cultivars (Cavalier, Crowne and Palisades).

Data collected to date is presented in Appendix C (Tables C1 and C2). Among the vegetative entries, two zoysia hybrids, DALZ9604 and DALZ9603 had highest establishment rate. Seventy days after planting the turf coverage were 68% and 58% respectively whereas the ground cover for Meyer was only 20%. Cavalier and Palisades continuely exhibited good genetic color and quality.

Zoysia matrella trials
Five zoysia matrella, Diamond, Royal97, DALZ9608, DALZ9609, and DALZ9610 were plug planted in field plots for evaluation under close mowing. Two month after planting, new Experimental lines DALZ9608, 9609, and 9610 had faster turf coverage than Diamond.

Shade Tolerance Evaluation of 1991 NTEP Trials
The study was initiated in 1992 and completed in 1995. Shade tolerances of 24 zoysiagrasses were evaluated for a prolonged period under dense oak trees. According to the results from 1995, 8 of 10 top-ranked entries were DALZ lines. Diamond and DALZ8516 were the best, followed by DALZ8508, DALZ8510, and Royal97. Among the top 10 entries, Diamond and DALZ8516 seem to be particularly superior to low light intensity conditions since the differences in the accumulative TPI between the top two entries and the following increased year by year.

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

The preliminary study under the natural shade under trees indicated that Diamond was the most shade tolerant cultivar among *zoysia spp*. Combining with other characteristic (such as fine texture, high density, tolerant to low mowing height, and good recuperative ability from rhizomes), shade tolerance character makes Diamond one of the most potential cultivars to be used for dome-turf. A series of studies were conducted in 1996 under greenhouse and field conditions to determine the extent of shade level to which Diamond zoysiagrass can be rooted and established, and to examine the optimum and maximum shade levels Diamond can sustain. In addition to the examination of turf performance and root growth under shade, shading effects on energy reserve status and other physiological parameters were also measured. Under relatively high shade conditions, Diamond developed adequate root system within a short period. Turf can produce acceptable quality up to 73% shade for 3 months. Color quality and chlorophyll content of diamond under 47% to 73% shade were superior to that under full sun. Unlike other grasses, Diamond produced more than twice higher clipping yields under shade than under full sun. However, the energy reserves decreased as the shade level increase. Further detailed results are presented in Appendix D. In 1997, we will test different management approaches to maintain Diamond under targeted shade levels. We believe adaquate management will help grass to reduce the stress under low light intensity.

Diamond Putting Greens

Winter covering effects on spring green-up
A Diamond green at TAES-Dallas was covered throughout the winter when ambient temperatures dropped below 5°C. Winter damage happened for uncovered area due to a severe cold and dry winter of 1995-96. In contrast, under the cover, Diamond remained green throughout the winter and

was maintained in excellent condition. To prevent freezing injury, ensure early spring green-up, or be able to supply plant materials during winter, the covering treatment is practical.

Sod Regrowth Potential for Oriental Zoysiagrass Collection

One of the major limitation of zoysiagrass is that zoysia generally is slow to establish and lack recuperative potential. Zoysiagrass which possess rapid establishment and recuperative abilities would greatly improve availability of sod, and increase their use on high trafficked turf area. Total 731oriental zoysiagrass accessions have been maintained in replicated field since 1984. In June 1996, these zoysiagrass plots were harvested with a sod cutter. After harvesting, plots were irrigatied, fertilized, and allowed to regrowth to determine the sod regrowth potential of oriental zoysiagrass collection and identify germtypes which possess good regrowth potential from rhizomes. Regrowth from rhizomes was determined 14, 21 and 80 days after harvesting by visually rating the shoot emergency and percent turf cover. The relative fast regrowth germplasms are TAES1569, TAES1529, TAES1512, TAES1509, TAES2097, TAES2104, TAES2119, TAES2121, and TAES2099. These germplams will be used for further zoysiagrass development programs.

Linear Gradient Irrigation System

The study to compare drought resistance of nine zoysiagrasses and three other species using the Linear Gradient Irrigation System (LGIS) has been terminated after 5 years of testing. The relative drought resistance and turf quality watered at optimum and deficit irrigation levels were presented in Appendix E. The area will be excavated and fumigated in the spring 1997. Plots with new zoysiagrass experimental line from the project may be established.

Polycross Nurseries

Two polycross nurseries are maintained and examined for rate of spread, texture, density, green cover, and seed production. These characteristics are evaluated under normal environmental conditions so that cultivars with desirable combinations of traits can be identified. The nurseries are maintained with minimum irrigation to prevent wilting, and fertilized at 24 kg N ha^{-1}, twice per year. The nurseries are not regularly mowed. Several new lines will be selected in 1997.

III. Characteristics of New Cultivars and Sod Production and Availability

Diamond (APPENDIX F)

Diamond (DALZ8502) is a fine textured highly rhizomatous, vegetatively propagated *Z. matrella* noted specifically for its excellent tolerance to low light and high salt conditions, and rapid recuperative ability. Diamond is suitable for use as a warm-season turfgrass for putting greens and tee boxes on golf courses especially in the coastal regions of the southern United States where shade and salinity are a problem.

Agronomic merits of Diamond:
1) Excellent salt tolerance
2) Excellent shade tolerance
3) Highly rhizomatous
4) Excellent sod strength
5) Low water requirements
6) Early spring green up
7) Good genetic color
8) Tawny mole cricket resistance
9) Excellent fall color retention
10) Fine leaf texture
11) High shoot density
12) *Rhizoctonia* blight resistance
13) Fall armyworm resistance

Agronomic limitations of Diamond:
1) Lacks winter hardiness
2) Tropical and sub-tropical climates
3) Susceptible to the tropical sod webworm
4) Susceptible to zoysiagrass mite
5) Tendency to thatch and scalp
6) Will not tolerate overseeding
7) Slow initial establishment from sprigs

Cavalier (APPENDIX G)

Cavalier (DALZ8507) is a fine-textured, long-leaf, vegetatively propagated *Z. matrella* noted specifically for uniformity in appearance and distinct summer presentation. It is genetically stable, basically self-infertile and vegetatively propagated through weak rhizome and strong stolon growth. Cavalier has good shade tolerance, salt tolerance and reasonably good recuperative ability under sports play. Finer textured cultivars such as Cavalier often lack winter-hardiness to survive in the mid-western states. As a *Z. matrella*, however, Cavalier has demonstrated excellent winter hardiness through evaluation with regional and national trials, and is quite suitable for uses as golf course fairways, tees and more specifically home lawns throughout the mid-west to mid-Atlantic states and throughout the south. The production cycle is on a par with 'Meyer,' however its water use, disease and insect resistance and general turf quality is highly superior to Meyer. Optimum mowing height will range between 1-5 cm.

Agronomic merits of Cavalier:
1) Cold hardy
2) Shade tolerant
3) Salt tolerant
4) Insect resistance
   - Tropical sod webworm
   - Fall armyworm
   - Tawny mole cricket
5) Disease resistance
   - *Pythium* blight
   - *Rhizoctonia* blight
6) High visual quality
7) Fine leaf texture
8) Spreads by stolons
9) Good genetic color

Agronomic limitations of Cavalier:
1) Requires sharp reel mower
2) Slow rate of establishment
3) Slow rate of recovery
4) Vegetative propagation required
5) Potential tendency of thatch
6) Susceptible to zoysiagrass mite

Crowne (APPENDIX H)

Crowne (DALZ8512) is a coarse-textured, vegetatively propagated clone of *Z. japonica* which is noted specifically for competitive ability against weeds, tolerance to drought conditions and low water use, excellent cold hardiness, and rapid recuperative ability. It is intermediate in salt tolerance. Crowne is suitable for use as warm-season turfgrass for golf course roughs, home lawns, industrial parks, and highway right-of-ways throughout the central mid-western states. Optimum mowing height will range from 5.0 to 7.5 cm; however, it can be mowed as close as 1.5 cm.

Agronomic merits of Crowne:
1) Medium-coarse texture
2) High visual quality
3) Rapid establishment and regrowth
4) Good fall color retention
5) Shade tolerant
6) Salt tolerant
7) Cold hardy
8) Heat tolerant
9) Variable mowing height (1.0 to 7.5 cm)

Agronomic limitations of Crowne:
1) Susceptible to *Rhizoctonia*
2) Tendency to scalp

Palisades (APPENDIX I)

Palisades (DALZ8514) is a medium-coarse textured vegetatively propagated clone of *Z. japonica* which is noted specifically for its tolerance to low light conditions (shade), low water use, excellent cold hardiness, and rapid recuperative ability. It is intermediate in salt tolerance. Palisades is suitable for use as a warm-season turfgrass for golf course fairways, and roughs throughout the transition zone, home lawns, sports fields, industrial parks, and highway medians. Optimum mowing height ranges from 1.0 to 5.0 cm. On tees and fairways, mowing heights of 8 mm is possible with acceptable results.

Agronomic merits of Palisades:
1) Medium-coarse texture
2) High visual quality
3) Rapid establishment and regrowth
4) Good fall color retention
5) Shade tolerant
6) Salt tolerant
7) Cold hardy
8) Heat tolerant
9) Variable mowing height (1.0 to 5.0 cm)

Agronomic limitations of Palisades:
1) Susceptible to fall armyworm

Sod Production and Availability

All cultivars are vegetatively propagated zoysiagrasses which are commercialized by the production, marketing, and sale of sprigs, plugs, or sod. The initial establishment of Diamond from sprigs or stolons is relatively slow, and it will take as long as 15 months. Cavalier may require up to 12 months for full coverage, harvestable sod, while it will be 7 to 12 months for Crowne and 7 to 10 months for Palisades. During this time period, the turf must be maintained at a reasonable height of cut: 1.0-1.25 cm for Diamond; 1.25-2.5 cm for others. A slicing aerifier used during the initial establishment period will encourage additional tiller production and accelerated growth. Fertility must be balanced and may require as much as 200-300 kg N ha^{-1} during the first year. Production of subsequent crops will require between 150-200 kg N ha^{-1} per year. Once established, sod should be harvested to a depth of 6-8 mm below the crown. Cavalier is weakly rhizomatous, therefore an advantage may be gained by leaving a ribbon during harvest. In contrast, it is not necessary to leave ribbon for Diamond, Crowne, and Palisades since they are highly rhizomatous. Cycle time between harvestable crops ranges from 4-6 months active growing season for Diamond, 12 months for Cavalier and 8-12 months for Crowne, and 6 to 12 months for Palisades depending on the location.

The breeder field for each cultivar is approximately 1100 m^2 . About 450 m^2 of Diamond, 700 m^2 of Cavalier, 800 m^2 each of Crowne and Palisades are available for immediate harvest. The remaining area will be available for harvest by mid June. The foundation grade production fields are 7000 m^2 for Cavalier, 8600 m^2 for Crowne and Palisades, and they are ready for harvest. Planting rate of these cultivars should approach 412 m^2 ha^{-1} when spread as plugs or mechanically as sprigs.

APPENDICES

Appendix A

VITA

Yaling Qian

EDUCATION

Ph.D., Horticulture. Kansas State University. December 1995.
    Dissertation Title: Water use and drought resistance of warm-season turfgrasses in Kansas.
M.S., Agronomy. Nanjing Agricultural University, China. July 1988.
    Thesis title: Physiological and anatomical characteristics of the cucumber root system under Fe-deficiency.
B.S., Biology. Hangzhou Normal College, China. 1981.

WORK EXPERIENCE

Graduate Research Assistant. Horticulture Department, Kansas State Univ. Jan., 1993-Present.
Instructor. Biology Department, Hangzhou Normal College. China. Sept., 1987 - Dec., 1992.
    Courses lectured: Botany, Botany Lab
Graduate Teaching Assistant. Nanjing Agricultural University, China. Sept., 1985 - July, 1987.
Instructor. Biology Department, Hangzhou Normal College. China. July, 1981 - Sept., 1985
    Courses Lectured:
    Plant Physiology, Plant Physiology Lab.

AWARDS:

Watson Fellowship from the Golf Course Superintendants Association of American. 1995.
Outstanding Teaching Award from Hangzhou Normal College, China. 1992.

PUBLICATIONS

Fry, J., P. Dernoeden, W. Upham and Y. Qian. 1995. Safety and efficacy of halosulfuron-methyl for yellow nutsedge top kill in cool-season turf. HortScience. 30:285-288.

Qian, Y.L. and J.D. Fry. 1996. Zoysiagrass rooting and plant water status as affected by irrigation frequency. HortScience. 31:

Qian, Y., J. Fry, S. Wiest and W. Upham. 1996. Estimation of turfgrass evapotranspiration using atmometers and an empirical model. Crop Sci. (In Press)

Qian, Y. 1990. Location of proton-excretion induced by Fe-stress in roots of intact cucumber. J. of Hangzhou Normal Univ. 3:66-68.

Qian, Y. 1989. The effect of Fe-deficiency on chloroplast structure in cucumber. J. of Hangzhou Normal College. 6:75-78.

LABORATORY EXPERIENCE
Measurement of soil-plant-water relation parameters
PCR, gene cloning, DNA transformation, microprojectile bombardment
Light and electron-microscopy techniques
Tissue culture
Routine techniques and instrumentation in plant physiology and biochemistry

FIELD EXPERIENCE
Turf management
Pesticide and fertilizer application
Design and layout of field experiments
Data acquisition techniques
Environmental parameters measurement

COMPUTER PROFICIENCY
Wordperfect, SAS, Harvard Graphics, Sigma Plot, Spreadsheets (Quattro Pro, Microsoft Excel), Unix, Main Frame.

MEMBER
American Society of Agronomy and Crop Science Society of America.

Appendix B

Summary of the 1991 Zoysiagrass NTEP

Table B1. Accumulative turf performance index (TPI) of turf quality for the 1991 NTEP national zoysiagrass trial at 20 - 23 locations each year.

Entry	1992 Max=20	1993 Max=22	1994 Max=23	1995 Max=20	Total Max=85	Rank (1-24)
	---------------------------------Accumulative TPI [1]---------------------------------					
Zoysia matrella						
Cavalier	12	16	16	17	61	1
Marquee(2033)	10	12	17	16	55	2.5
Emerald	9	17	16	13	55	2.5
DALZ8508	11	14	15	11	51	4
Royal97	10	13	14	11	48	6
QT 2004	9	13	12	13	47	8
OMNI(2013)	6	13	15	12	46	10
Diamond	3	7	8	6	24	17
DALZ 8701	4	3	4	1	12	20
DALZ 8501	4	2	3	2	11	23.5
Z. japonica						
Crowne	11	13	13	11	48	6
Sunburst	10	12	12	14	48	6
TC 5018	11	10	15	9	45	9
EL Toro	11	9	12	8	40	11
Palisades	11	9	11	8	39	12
Meyer	5	9	13	10	37	13
CD 259-13	6	5	11	9	31	14
Belair	4	8	11	6	29	15
DALZ 8516	3	6	9	11	29	16
QT 2047	4	6	5	4	19	20
Seeded Zoysiagrass						
TGS-W10	1	7	9	6	23	18
TGS-B10	3	5	7	6	21	19
JZ-1	1	3	4	5	13	21
Korean Com	0	3	6	2	11	23.5

[1]TPI is the turf performance index, which is the number of times an entry occurred in the top statistical group.

Table B2. Accumulative turf performance index (TPI) of all observations for the 1991 NTEP national zoysiagrass trial at 20 - 23 locations each year.

Entry	1992 Max=115	1993 Max=131	1994 Max=147	1995 Max=116	Total Max=509	Rank (1-24)
	Accumulative TPI [1]					
Zoysia matrella						
Cavalier	59	82	101	81	323	1
Emerald	47	87	97	74	305	2
Marquee (2033)	49	79	95	77	300	3
DALZ8508	50	79	88	68	285	4
Royal97	49	74	86	66	275	5
QT 2004	52	73	80	68	273	7
Omni (2013)	49	71	85	65	270	8
Diamond	32	60	71	63	226	14
DALZ 8501	26	39	39	33	137	23
DALZ 8701	23	42	44	25	134	24
Z. japonica						
Sunburst	59	69	82	64	274	6
Crowne	67	62	79	57	265	9
TC 5018	57	61	83	53	254	10
EL Toro	65	68	69	48	250	11
Palisades	60	62	69	51	242	12
DALZ 8516	22	57	77	73	229	13
CD 259-13	42	51	63	59	215	15
Meyer	29	54	71	50	204	16
Belair	22	57	66	52	197	17
QT 2047	47	45	45	40	177	18.5
Seeded Zoysiagrass						
TGS-W10	22	47	58	50	177	18.5
TGS-B10	30	39	56	45	170	20
Korean Com	29	40	50	44	163	21
JZ-1	27	38	50	47	162	22

[1]TPI is the turf performance index, which is the number of times an entry occurred in the top statistical group.

Appendix C

1996 Zoysiagrass NTEP Trials - TAES-Dallas

Table C1. Stolon number and percent turf ground cover for zoysiagrasses of the 1996 NTEP planted on 30 July, 1996 at Texas A&M Research Center - Dallas.

Entry	Aug 16	Sep 10	Oct 4
	Stolon ---no.---	-----Percent turf cover-------	
DALZ9604	63 a	52 a	68a
DALZ9603	41 a	45	58a
EL Toro	22	42	53
Miyako	12	40	52
J-14	22	38	50
Jamur	26	36	48
DALZ9606	20	40	47
Crowne	2	29	38
Palisades	1	25	37
Victoria	26	33	36
DeAnza	5	27	34
DALZ9607	9	29	33
DALZ9605	17	27	33
Emerald	7	30	31
Zeon	5	25	27
DALZ9602	4	25	25
DALZ9601	4	24	24
HT-210	4	24	23
Cavalier	0	19	20
Meyer	1	22	20
	Seeded Entry		
J-37	0	40	53
J-36	0	38	52
Chinese Common	0	33	43
Zenith	0	22	35
Zen-400	0	19	25
Zen-500	0	15	22
Z-18	0	11	11
Korean Common	0	1	2
LSD[1]	6.5	9.8	12.0

[1]LSD is the Least significant difference between entry means based on the protected LSD test ($P < 0.05$)

Table C2. Genetic color and leaf texture for zoysiagrasses of the 1996 NTEP planted on 30 July, 1996[1] at Texas A&M Research Center - Dallas.

Entry	Color	Texture
Vegetative Entry		
Cavalier	8.1a	8.1 a
Crowne	7.2a	5.8
DALZ9601	8.1a	8.1 a
DALZ9602	5.5	8.2 a
DALZ9603	5.7	6.1
DALZ9604	5.7	6.2
DALZ9605	6.5	6.0
DALZ9606	6.0	6.3
DALZ9607	5.7	5.9
DeAnza	5.9	6.3
EL Toro	6.8	5.2
Emerald	7.8a	8.8 a
HT-210	6.7	8.8 a
J-14	6.3	5.5
JaMur	6.8	5.7
Meyer	7.5a	6.4
Miyako	6.6	5.0
Palisades	7.6a	6.5
Victoria	7.2a	7.2
Zeon	8.0a	8.0 a
Seeded Entry		
Chinese Common	5.6	6.1
J-36	5.5	5.2
J-37	5.7	5.7
Z-18	4.8	8.0 a
Zen-400	5.6	5.9
Zen-500	6.2	6.1
Zenith	6.5	6.3
LSD[2]	0.9	0.7

[1] Leaf color and texture were rated on scales of 1 to 9 with 9 represented the darkest color and finest texture.
[2] LSD is the Least significant difference between entry means based on the protected LSD test ($P < 0.05$)

Appendix D

Evaluation Drought Resistance of Zoysiagrasses Under Linear Gradient Irrigation System - TAES-Dallas

Table D1. Wilt line of nine zoysiagrassed and four species under linear gradient irrigation system during prolong drought period in 1996[1].

Grass	6/17/96	7/15/96
	------------------Wilt line------------------------	
BUFFALOGRASS		
Prairie	10.5a	8.5a
BERMUDAGRASS		
Baby	9.0a	8.2a
Tifway	8.5	8.8a
ST. AUGUSTINEGRASS		
Nortam	7.7	8.2a
ZOYSIAGRASS		
Crowne	7.7	8.2a
El Toro	7.5	7.4a
Palisades	7.2	7.3a
Diamond	7.0	6.8
Cavalier	7.0	6.5
DALZ8510	6.3	6.5
Emerald	6.0	6.5
DALZ8501	5.7	6.3
Meyer	5.2	5.2
BLUEGRASS		
Texas X Kentucky Hybrid	5.2	5.0
LSD[2]	1.68	1.6

[1] Wilt line is the distance (m) between the central trench and the position where the turf start showing drought stress. The higher numbers is the less water grass needed to prevent wilt.
[2] LSD is the Least significant difference between entry means based on the protected LSD test ($P < 0.05$)

Table D2. Turf quality of 13 turfgrasses watered at optimum (Ep) and deficit irrigation (Ep) level.

	Irrigation Level	
Grass	Optimum	deficit
	------------turf quality[1]-----------	
ZOSYIAGRASS		
Cavalier	8.3a	5.0
DALZ8510	8.0a	5.0
Diamond	7.0a	6.0a
DALZ8501	6.5	4.5
Emerald	6.5	4.3
Crowne	6.5	6.8a
Meyer	6.3	2.0
Palisades	6.0	5.0
El Toro	6.0	5.8a
BERMUDAGRASS		
Baby	5.5	4.5
Tifway	5.0	4.3
Tifgreen	4.8	5.0
BUFFALOGRASS		
Prairie	4.8	6.3a
ST. AUGUSTINEGRASS		
Nortam	3.8	4.7
BLUEGRASS		
Texas X Kentucky	3.5	2.3
LSD[2]	1.5	1.4

[1] Turf quality ratings 1 to 9; where 5 is the minimum acceptable level of turf quality and 9 is the best.

[2] LSD is the Least significant difference between entry means based on the protected LSD test ($P < 0.05$).

Appendix E

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

INTRODUCTION

Turf managers often report that shade is one of the major problems in growing quality turfgrass. Few turfgrasses are suitable for sports turf under low light intensity. It is generally considered that zoysiagrasses have intermediate shade tolerance. However, greater variation of shade tolerance was found within zoysia genus. In a preliminary 3-year study, Diamond zoysiagrass (tested as DALZ8502) ranked at the top for its turf performance among 25 commercial and experimental varieties under dense oak trees. The characteristics of Diamond, including fine texture, good wear tolerance, good recuperative ability from rhizomes, make it a promising turfgrass for the playing surface of sport fields and possibly for use in dome stadiums. Additional information is needed on the influences of low light intensity on rooting characteristics and establishment, and how established turf responds to low light intensities.

OBJECTIVES

1) To determine rooting characteristics of Diamond zoysiagrass under low light intensities during sod establishment;

2) To evaluate turf performance, growth habit and energy reserves of Diamond zoysiagrass under low light intensities.

MATERIALS AND METHODS

In The Greenhouse:

Study was conducted from 14 March to 2 May and repeated from 3 May to 14 June, 1996. Diamond was sodded on a wooden bench filled with fine sand for 6 weeks. Root zone temperature was adjusted at 26 to 28 C by circulating controlled-temperature water through pipe in the soil. Clear acrylic plastic root-observation tubes was designed to measure root growth *in situ*. Immediately after sodding shade treatments (63%, 81%, 90%, and 95% shade) were imposed, with the normal greenhouse condition (30% shade) as control.

Turf was mowed weekly at a 2-cm height. Turf quality, color quality, and turf density were visually assessed weekly on a scale of 1 to 9 (best) and a rating of less than 6 was considered unacceptable. Maximum root extension was determined by measuring the length of the deepest root visible at the soil/root observation tube interface. Root mass was determined on day 42 when the experiment ended.

In The Field

Diamond zoysiagrass was established in 1992 on Houston clay soil. Irrigation was performed to prevent drought. Four shade treatments (full sun and 47%, 73%, 86% polypropylene shade cloth) were imposed in a completely randomized design with four replications on July 1, 1996. Grass was mowed at 2-cm weekly. Parameters assessed weekly were turf quality, color quality, turf density, shoot vertical growth, clipping water content, and clipping dry weight.

To quantify energy reserve status, total nonstructural and water soluble carbohydrates were determined for under-ground tissue (rhizome + root) using Nelson's colorimetric enzyme digestion method. The difference between TNC and soluble carbohydrate content indicated the starch content. Chlorophyll content was determined by modification of the technique of Arnon.

Analysis

ANOVA was performed and mean differences of shade treatments were separated using a protected LSD test. Data were also subject to regression analysis to determine significant linear or quadratic effect of shade level on each measured parameters.

RESULTS AND DISCUSSION

Root Growth

Diamond exposed up to 81% shade could root readily during sod establishment, indicated by high MRE (Table 1). In study I, MRE under 63% and 81% shades were 4 and 3 times higher than that of control. The difficulty of rooting for control was likely due to the moisture stress. In study II, measurements within the first 3 weeks indicated that 63 and 81% shade rooted faster than control. Then after, MRE was speed up for control. Both studies showed that MRE was inhibited by 90 and 95% shading. Root mass, which was only determined at the end of study, decreased by 100% with the degree of shade increased from 81% to 90% in study I, and linearly declined with increasing degree of shade in study II.

Turf Performance

The turf performances for the greenhouse study were presented in table 2. Turf produced acceptable quality with up to 81% shade during 6 weeks study period.

In the field, turf under 47% shade persistently produced good turf quality (Fig. 1). With shade level increasing further, turf quality decreased, and the decrease magnified with time. Compared to full sun, 73% and 87% shade treatments deceased turf quality by 18% and 54%. But only turf quality under 86% shade was unacceptable at the end of study. Similar to turf quality, 47 and 73% shading produced enhanced color qualities compared to control (Table 3). The enhanced color could be contributed to the higher leaf chlorophyll content (Table 4). The response of turf and color qualities to shade were best fitted to quadratic models. In contrast, turf density was linearly correlated with shade level. Loss of acceptable density was noted for 87% shade treatment .

Shoot Growth and Carbohydrate Reserves

For the duration of this study, shade greatly increased the yield of clippings. Cumulative total clipping dry weight were 195, 256, and 253 kg/m^2 for 47%, 73%, and 87% shades, which were 1.3x, 2.0x and 2.0x greater than that of control (Fig. 2). The rapid growth under shade may have resulted from the hormone level changes under shade.

No difference in the soluble carbohydrate content was detected among shade levels (Fig. 3). However, TNC of rhizome+root was responded with sensitivity to light intensity. The measured TNC contents at the end of study were 85, 61, 29, and 15 mg g^{-1} for 0, 47%, 73%, and 87% shades, respectively. The linear model best fitted the relation between TNC and shade level. At 47% shade, TNC was reduced 22% relative to full sun within the initial 3 weeks, but stable at that level as study continues. Eleven weeks under 87% shade resulted in a complete depletion of reserved starch of under-ground tissues. The low TNC contents under shade may have been resulted from 1)the decreased photosynthetic capability as a result of low light intensity, and 2)the comparatively higher shoot growth, which resulted in more clipping removal by regular mowing. With TNC reserves implicated in regrowth and persistence of perennial grasses, results suggested that high level of shade may fail to maintain long term stand persistence, and stress and wear tolerances would likely be lessened.

However, our results demonstrate that Diamond zoysiagrass has sufficient shade tolerant to warrant consideration for further evaluation of different management approaches to approach acceptable turf quality under 70-80% shade level, and further tests on the persistence under more naturalized sports turf setting.

Table 1. Effect of shade levels on maximum root extension (MRE) and root mass of Diamond zoysiagrass in the greenhouse.

% Shade	Study I MRE by week 1	Study I MRE by week 3	Study I MRE by week 6	Study I Root mass	Study II MRE by week 1	Study II MRE by week 3	Study II MRE by week 6	Study II Root mass
	-----cm-----			--mg--	-----cm-----			---mg---
30%	0.8ns	2.2c	3.8b	110a	1.9	8.6ab	20.2a	510a
63%	1.6	15.9a	22.3a	160a	2.0	11.4a	16.7ab	290b
81%	0.7	11.3ab	16.6a	120a	2.4	10.7a	13.5b	190c
90%	1.0	7.2bc	6.1b	60b	0.3	3.7b	10.0c	80d
95%	0.8	2.9c	2.0b	40b	_	_	_	_
Shade effect ‡								
Linear	ns	ns	ns	*	ns	ns	***	***
Quadratic	ns	***	***	**	ns	**	ns	ns

† Means followed by same letter within the same column are not significantly different.

‡ NS, *, ** and *** indicate non-significant or significant linear or quadratic regression at $P < 0.05$, 0.01 and 0.001 level.

Table 2. Effect of shade levels on turf quality, color quality, and shoot density of Diamond zoysiagrass 6 weeks after treatment in the greenhouse.

% Shade	Quality (1-9) Study I	Quality (1-9) Study II	Color (1-9) Study I	Color (1-9) Study II	Density (1-9) Study I	Density (1-9) Study II
30%	6.3c†	8.4a	6.1c	8.2a	7.4b	8.5a
63%	8.5a	8.1a	8.4a	8.2a	8.4a	8.0a
81%	7.0b	6.9b	7.5b	7.0b	7.0b	7.0b
90%	6.1c	5.6c	6.3c	5.6c	6.1c	6.0b
95%	5.1d	_	5.5c	_	5.1d	_
Shade effect ‡						
Linear	ns	***	ns	***	***	***
Quadratic	***	***	***	***	***	*

† Means followed by same letter within the same column are not significantly different.

‡ NS, *, and *** indicate non-significant or significant linear or quadratic regression at $P = 0.05$, 0.01 and 0.001 level.

Table 3. Effect of shade levels on turf color and density of Diamond zoysiagrass in the field in 1996.

% Shade	Color (1-9)				Density (1-9)			
	July	Aug.	Sep.	Oct.	July	Aug.	Sept.	Oct.
0	7.4b	7.9b	8.0b	7.7b	9.0a	8.9	9.0	8.9
47%	8.2a	8.6a	8.6a	8.5a	8.9a	8.6	8.5	8.5
73%	8.3a	8.4a	8.2ab	8.2a	8.8ab	8.2	7.6	7.0
87%	8.2a	7.4b	6.1c	5.1c	8.7b	7.3	5.9	4.9
Shade effect								
Linear	ns	ns	ns	*	*	***	***	***
Quadratic	*	**	**	*	ns	**	***	***

† Means followed by same letter within the same column are not significantly different.

‡ NS, *, ** and *** indicate non-significant or significant linear or quadratic regression at $P < 0.05$, 0.01 and 0.001 level.

Table 4. Effect of shade levels on clipping water content, tiller number, and leaf chlorophyll content of Diamond zoysiagrass grown in the field in 1996.

% Shade	Tiller number† (no. cm^{-2})	Clipping water content‡	Leaf chlorophyll content§ (mg g^{-1})
0	6.8 a‡	60%b	1.87 b
47%	5.9 b	61%ab	2.45 a
73%	4.9 c	63%a	2.58 a
87%	3.5 d	63%a	2.09 ab
Shade effect#			
Linear	***	**	*
Quadratic	*	***	***

† Tiller numbers were counted 14 weeks after the shade treatments.

‡ Means of 14 weekly measurements.

§ Means of 7 biweekly measurements.

NS, *, ** and *** indicate non-significant or significant linear or quadratic regression at $P < 0.05$, 0.01 and 0.001 level.