FINAL RESEARCH PROGRESS REPORT

of

PHYSIOLOGICAL BASIS FOR SELECTION OF BENTGRASSES WITH SUPERIOR DROUGHT RESISTANCE

Submitted by:

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Executive Summary

Principle Investigator:	Dr. Richard H. White
Graduate Research Assistants:	Mr. Gene Taylor, Mr. Scott Abernathy, and Mr. John Jordan
Research Period:	1 August 1994 through 1 November 1997

Twenty-eight maternal clones of creeping bentgrass were evaluated for tolerance to moisture deficit tolerance. Using a greenhouse based screening procedure, clones were identified with high, intermediate, and low resistance to water stress. Ranking in greenhouse based procedures were relative to previous performance in field based parent/progeny trials. These results provide support for the relevance of this greenhouse based screening procedure. Further evaluations of the water relations characteristics of specific clones indicated that superior performance was associated with more negative osmotic potential and low cell wall elasticity. The heritability of these traits has not been confirmed.

Performance and water balance of nine creeping bentgrass cultivars was evaluated under irrigation intervals of 1-day, 2-day, and 4-day. Irrigation interval had less influence on turf quality than expected. However, irrigation interval had a significant effect on leaf turgor potential of A4, Crenshaw, L93, Mariner, and Penncross. Frequent irrigation had a negative impact on plant water status and caused a decrease in turf quality due to a decrease in density and an increase in algae. Cultivars, such as L93 and Crenshaw, maintained positive water balance and good turf quality with infrequent irrigation. Differences in turgor maintenance capability of creeping bentgrasses under putting green conditions were demonstrated as well as the relationship between irrigation frequency and plant water status. Less frequent irrigation allowed a favorable water balance in specific cultivars without sacrificing putting green quality.

Inter-seeding research indicated that this process can be used to successfully establish a new bentgrass into an existing Penncross bentgrass golf green. Although the percentage change in the population could be considered low, population shifts of about 5 to 30% were observed following a single inter-seeding in conjunction with minimal cultivation followed by topdressing. Dramatic changes in turf quality or performance were not observed following inter-seeding. Based on controlled blending experiments, weakly adapted cultivars reduce putting green quality of blends with even strongly adapted cultivars. Although evidence for disease suppression was not clearly delineated, judicious blending can provide a strong putting surface with careful cultivar selection. Care should be used in selection of a cultivar for use in inter-seeding. Based on blending studies, a cultivar that provides superior quality as a single variety may not provide an improvement in putting green quality when blended through the inter-seeding process with an existing poorer performing cultivar.

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PHYSIOLOGICAL BASIS FOR SELECTION OF BENTGRASSES WITH SUPERIOR DROUGHT RESISTANCE

Richard H. White

INTRODUCTION

This program is a cooperative research project funded jointly by the Texas Agricultural Experiment Station (TAES) and the United States Golf Association (USGA). This project was initiated in August 1994. Annual progress reports are submitted 1 November each year and semi-annual progress reports are submitted in 1 May. This report constitutes the final progress report for the project and highlights activities between 1 August 1994 and 1 November 1997.

PROFESSIONAL AND TECHNICAL SUPPORT

Mr. Gene Taylor joined the project in August 1994. Gene is a Ph. D. candidate and Graduate Research Assistant funded by this USGA grant. Gene holds a B.S. degree from East Carolina University and an M. S. degree from North Carolina State University. Dr. Milt Engelke is co-chair of Gene's graduate committee. Mr. Taylor is preparing his Dissertation Research Project to address mechanisms of summer stress tolerance in creeping bentgrass with emphasis on water balance. Gene is supported by USGA grant funds.

Mr. Scott Abernathy joined the project in August 1996. Scott received his B. S. in Biomedical Sciences in December 1995. Following graduation Scott worked in Dallas, Texas at BentTree Country Club for 9 months. He returned to the Soil and Crop Sciences Department at Texas A&M University to pursue a M. S. degree in Agronomy in August 1996. Scott will provide support for the bentgrass blending and bentgrass inter-seeding portions of this project. Scott is funded through the Texas Turfgrass Association's Potts Fellowship Program.

Mr. John Jordan will join the project during May 1997. John received his B. S. degree from Iowa State. John's emphasis will be directed toward water management and relationships of field performance to greenhouse screening procedures for water deficit tolerance. John is funded through grant funds not provided by the USGA.

OBJECTIVES:

1. **Develop a rapid, economical, physiologically based drought resistance screening procedure for greenhouse use that is relevant to field performance of bentgrass germplasm.**

A Competitive Soil Moisture Extraction Technique (CSMET) that simulates drought was used to assess maternal clones and parent progeny relationships for a creeping bentgrass population obtain from Dr. M. C. Engelke. This technique previously provided a reliable assessment tool for tall fescue and zoysiagrass and related well to water requirement and drought resistance of zoysiagrass genotypes. The primary focus of the current work was to identify creeping bentgrasses that tolerate moisture deficit, the primary mechanisms of drought tolerance, and the heritability of these traits.

This study proceeded in three phases. The first phase was designed to determine, using the CSMET, if significant differences in the ability to tolerate low soil water potentials existed between a group of 28 maternal bentgrass clones; the second phase was to determine if observed levels of high, medium and low water stress tolerance is passed on to progeny plants from a select group of maternal plants; third, determine major physiological and morphological characteristics which influence water deficit stress tolerance in the creeping bentgrass plants.

Results: Phase one of this study was completed during the fall 1995. Maternal clones having high, intermediate, and low resistance to water stress were identified for further testing. Maternal clone 2833 is representative of high, 9999 low, and 3106 and 3153 intermediate water stress tolerance groups (Figures 1 and 2). These data are in agreement with previous field performance evaluations of these clones at the TAMU-REC at Dallas. Thus, these data provide support for the relevance of the CSMET procedure as a fairly rapid screening tool.

Further evaluations of water relations characteristics were assessed for the maternal clones considered to have high, intermediate, and low resistance to water stress as identified in earlier tests. Preliminary assessments indicated that turgor maintenance accounted for the superior performance of specific clones such as 2833. Basal osmotic potential and osmotic adjustment appeared to contribute to turgor maintenance in superior clones based on data from CSMET analysis of maternal clones. Independent experiments were conducted to determine water potential at zero turgor (Ψ_0), osmotic potential at full turgor ($\Psi\pi_{100}$), relative water content at zero turgor (RWC_0), apoplastic water fraction (β), bulk modulus of tissue elasticity (ε), and turgid weight:dry weight ratios for clones, including 2833 and 2845 considered to have high, 3106 and 3153 considered intermediate, and 3250 and 9999 considered to have low resistance to water stress as identified in earlier tests. Water relations characteristics were determined before and after moisture stress.

In contrast to tall fescue and zoysiagrass genotypes, water relations characteristics of creeping bentgrass were similar before and after exposure to moisture stress. These results indicate that pre-stress measurements of water relations characteristics may be used to assess physiological drought tolerance attributes of creeping bentgrass. Therefore, fewer time restrictions in screening germplasm would occur because of a lack of a requirement for exposure to stress conditions prior to evaluation.

Water relations characteristics of creeping bentgrass were distinctly different from those of tall fescue and zoysiagrass. For example, Ψ_0 for the creeping bentgrass clones was less than 1 MPa (Table 1), whereas Ψ_0 for zoysiagrass and tall fescue ranges from 1.5 to 2.5. Other characters, such as RWC_0, β, and ε were also much less than values determined for tall fescue and zoysiagrass.

Clone 3153 lost turgor at the highest leaf water potential (Table 1). All other clones had similar Ψ_0. In general, clone 2833 had the most negative and clone 9999 the most positive $\Psi\pi_{100}$ which supports earlier suggestions that low basal osmotic potential may account for turgor maintenance in superior creeping bentgrass clones. However, ε increased as $\Psi\pi_{100}$. ε is an indicator of cell wall rigidity. A higher ε means increased cell wall rigidity a factor that contributes to increased turgor pressure. The relationship between ε and $\Psi\pi_{100}$ probably accounts for the relative similarity in Ψ_0 among clones. However, ε and $\Psi\pi_{100}$ appear to be useful indicators for selection of creeping bentgrass clones with superior tolerance of moisture deficit. Zoysiagrasses that are drought resistant and a low water requirement have a greater ε and more negative $\Psi\pi_{100}$ than zoysiagrasses that are more susceptible to drought and have a greater water requirement.

Parent/progeny tests were established during January 1996 based on tests of maternal clones. A stress cycle was being imposed for the first parent/progeny test when a suspected fairy ring fungus caused plant death prior to completion of this study. Disease problemis continued during 1996 and the initial plantings were abandoned. Parent progeny tests were reestablished during 1997 but a similar problem as in the initial tests reoccurred. The problem has been identified as a root infesting mealybug. Appropriate controls were applied and the parent/progeny tests were reestablished in 1997 and are progressing but behind schedule. The results of this portion of the project are not available but will be delivered as an adendum to this report.

2. Determine the relationship between mechanisms of drought tolerance to the performance, drought resistance, and *in situ* water requirements of commercial bentgrass germplasm under field conditions.

An experimental green was constructed during 1996 to accomplish this objective. The green was constructed to USGA-Green Section specifications. The study area included 10 independently controlled irrigation blocks that were 15 by 15 feet. Nine creeping bentgrass cultivars including A4, Crenshaw, L93, Mariner, Penncross, Putter, Seaside, Southshore, and SR1020 were established in 5 by 5 foot plots in each irrigation block. Plots received uniform fertilization and were maintained at a 0.125 inch mowing height. Irrigation was uniformly applied until July 1997 when irrigation treatments were imposed. Irrigation treatments consisted of frequencies of 1-day, 2-days, and 4-days. Irrigation treatments received the same quantity of water based on historical evapotranspiration data and was 0.33, 0.67, and 1.34 inches at each application for the 1-day, 2-day, and 4-day treatments.

Turf quality and algae occurrence were determined weekly during application of irrigation treatments from 28 July through 1 September. Leaf water and osmotic potential were measured weekly at 0600 and 1400 hours and turgor potential calculated from leaf and osmotic potentials. Maximum daily air temperature during the period averaged 98° F and soil temperature at a 4 inch depth averaged 95° F. Class A Pan Evaporation averaged 0.31 inches with a maximum of 0.48

inches during the period.

Results: Performance of cultivars differed substantially (Table 2). In general, L93, Southshore, and SR1020 had good turf quality, Crenshaw, Putter, and A4 were intermediate, and Mariner and Penncross least turf quality. Turf quality of Seaside was poor. Irrigation treatments affected turf quality on one of seven observation dates. Differences in turf quality were observed among irrigation treatments on 4 September only. Irrigation at 4-day frequency produced superior quality compared to the 1-day treatment and was similar to the 2-day treatment. Abundant algae occurrence in the 1-day irrigation treatment contributed to lower quality but less turf density was also observed for the 1-day compared to the 4-day irrigation treatment. Some cultivars, such as L93, Southshore, and SR1020 remained relatively strong regardless of irrigation treatment.

Although irrigation treatment had less influence on turf quality than expected, irrigation treatment had a significant effect on leaf turgor potential of A4, Crenshaw, L93, Mariner, and Penncross (Table 3). Average turgor potential of A4 and Mariner decreased as irrigation interval increased. Turgor potential of Crenshaw, L93, and Penncross increased as irrigation interval increased from 1-day to 2-day. Turgor potential of Crenshaw, L93, and Penncross declined as irrigation interval increased from 2-day to 4-day.

These data indicate that A4 and Mariner are more sensitive to moisture deficit and likely require or are more tolerant of frequent irrigation. In general, irrigation at a 2-day interval was near optimum to maintain creeping bentgrass at a more positive water status. Frequent irrigation (1-day interval), generally, had a negative impact on plant water status and caused a decrease in turf quality due to a decrease in density (data not shown) and increased algae occurrence. Cultivars, such as L93 and Crenshaw, were capable of maintaining a positive water balance and good turf quality with infrequent (4-day interval) irrigation.

The results of this study indicate differences in turgor maintenance capability of creeping bentgrasses under putting green conditions and indicate a relationship between irrigation frequency and plant water status. This study also demonstrates a relationship between turgor maintenance at different irrigation regimes and turf quality.

3. **Objectives: Assess management systems for the incorporation of diverse bentgrass germplasm into existing bentgrass stands for rapid and efficient improvement of putting green stress resistance and functional quality.**

Turfgrass blends and mixtures are frequently used when planting turfgrass stands to increase the genetic diversity and thus pest and abiotic stress resistance of turf. However, this has not been used extensively on bentgrass putting greens. Rather, reliance on the diversity of bentgrass populations created by polycross or synthetic breeding technologies has been the norm. Limited efforts have been made to explore the use of bentgrass blends on putting greens. This may, in part, be due to difficulties some turfgrass managers have reported with overseeding existing stands of creeping bentgrass. However, technologies exist that should make this practice routine in the future. Routine seeding of putting surfaces with new germplasm should 1) increase the desirable plant to weed seed propagule ratio, 2) increase the genetic biotic and abiotic stress resistance within the new bentgrass population with subsequent reductions of management inputs required, and 3) improve the aesthetic and functional qualities of the putting surface.

Inter-seeding Studies: Test locations were identified and were inter-seeded one time during 1995. Although several Penncross golf greens were located and planted during 1995, two locations have received primary emphasis. The locations include the Texas A&M University Research and Extension Center at Dallas (TAMU-REC at Dallas) and the Dallas Country Club in Dallas, Texas. The experimental design used in all locations was a multiple-strip-split plot design. Treatments were seeding, mechanical disruption, and chemical suppression. Main plots were seeding treatments consisting of seeding or no seed application. Sub-plots were chemical suppression treatments consisting of none, cimectacarb (Primo), and glyphosate (Roundup). Sub-sub plots were mechanical disruption treatments consisting of none, vertical mowing, star-tine aerification, and core aerification. Chemical and mechanical treatments were systematically arranged in row and column strips to include all possible combinations of chemical with mechanical treatments. Chemical treatments were applied about 72 hr prior to mechanical treatment aerification. Mechanical treatments were applied followed by seed treatments and the area uniformly topdressed. Experimental areas were maintained as a putting green throughout the study period. Daily mowing was applied continuously and immediately after seeding with 1 pound of Crenshaw creeping bentgrass per 1000 square feet. Irrigation was applied as needed to prevent water stress. Random counts within each plot were taken about 4 weeks after planting to determine seedling emergence. Bimonthly visual assessments were taken to determine treatment effects on turf quality. Data were analyzed by appropriate statistical models to determine treatment effects.

Electrophorectic identification of isozyme banding patterns has been used to determine shifts in bentgrass populations. This technology proposed by Dr. Yamamoto, Post-doctoral Fellow working under the direction of Dr. M. C. Engelke, has been applied through close collaboration with Dr. Engelke's research group. This technology allows the determination of the percentage of a bentgrass turf populated by the germplasm used for interseeding compared with the percentage of the stand populated by the original or existing bentgrass. In this technique, the green's composition is estimated by comparing the isoenzyme banding patterns from the interseeded green with those of standard blends (proportional blends produced under laboratory conditions).

Results: Seedling counts indicated greater plant density in the seeded than no seed treatment at the TAMU-REC at Dallas and the Dallas Country Club (Table 4). Vertical mowing was superior to other mechanical treatments in aiding initial seedling establishment at the TAMU-REC at Dallas location but mechanical treatments were similar at the Dallas Country Club. Absolute plant density was greater for no mechanical treatment at both locations. Topdressing following inter-seeding may be a reasonably good way to provide good germination without other means of mechanical incorporation.

Isozyme analysis allows for the genetic identification of Crenshaw and Penncross as well as some other creeping bentgrass genotypes. Because of unique band markers possessed by Crenshaw, a determination of the percentage Crenshaw and Penncross can be made for a blend of these two cultivars. When samples with unknown populations of Crenshaw and Penncross are compared with standard blends, the isozyme analysis technique can determine the percentage (±5%) of each cultivar in the blend. The technique is invaluable to the assessment of the success of inter-seeding programs and to this research project.

Isozyme analysis was conducted 6 months after establishing the inter-seeding study at the TAMU-REC at Dallas and the Dallas Country Club. Across all treatments, the single inter-seeding of Crenshaw into the existing Penncross putting green at the TAMU-REC at Dallas caused an overall shift to about 25% Crenshaw in the bentgrass population 6 months after inter-seeding (Table 5). The percentage increased to 35% at about 14 months after inter-seeding (Table 6). However, Crenshaw percentages ranged from about 7 to 33 at 6 months after inter-seeding for the no chemical treatment. At about 14 months after inter-seeding, the percentage of Crenshaw ranged from about 8 to 16 for the no chemical treatment.

Severe growth suppression of the existing Penncross by glyphosate allowed more rapid conversion to Crenshaw. Glyphosate in combination with all mechanical treatments except core tine cultivation resulted in 50% or more Crenshaw in the population 6 months after inter-seeding and as much as 95% at about 14 months after inter-seeding. Suppression of existing bentgrass is too aggressive to be of much practical importance on most golf course putting greens. Turf quality evaluations indicate that the inter-seeded cultivar and incompletely glyphosate killed existing cultivar provide recovery that is too slow for this to be pragmatic.

Seedling emergence (Table 1) at the Dallas Country Club location 4 weeks after inter-seeding indicated, based on plant density counts, successful emergence of Crenshaw in an existing Penncross bentgrass putting green and was superior to emergence observed in spring 1995 at the TAMU-REC at Dallas location. Mechanical treatments had minimal effect on seedling emergence. Isozyme analysis of samples collected from the Dallas Country Club location 6 months after inter-seeding indicate that, overall, Crenshaw contributed less than 10% of the plant population. Water management during the extremely dry fall and winter of 1995 and 1996 probably contributed to very low percentages of Crenshaw in the population at the Dallas Country Club location.

Based on these data, the percentage population change that one could expect following a single seeding operation would range from about 5 up to 30% at 6 to 12 months after inter-seeding. More rapid population changes may be achieved by multiple inter-seedings.

The results of our inter-seeding research indicate that this process can be used to successfully establish a new bentgrass into an existing Penncross bentgrass golf green (Tables 4 and 5). Although the percentage change in the population could be considered low, we have observed population shifts of about 5 to 30% by a single inter-seeding in conjunction with minimal cultivation followed by topdressing. Samples collected during spring 1997 from TAMU-REC at

Dallas will allow a determination of persistence and change in inter-seeded populations.

Although seedling emergence was excellent at the Dallas Country Club test site, isozyme analysis indicated low percentages (10% or less) of the inter-seeded cultivar and would be considered unsuccessful, probably as a result of water management problems. Analyses of samples collected by Dr. Yamamoto from in-play golf greens at Dallas Country Club, provide an indication that inter-seeding can be successful. Populations of 70 to 75% Penncross and 25 to 30% inter-seeded grass were detected 6-months after inter-seeding.

We have not observed dramatic changes in turf quality or performance following inter-seeding. My current recommendations are that the golf course superintendent should address soil and environmental deficiencies, such as poor air movement, poor drainage, and mowing and irrigation practices, first and then inter-seeded. Based on these studies, current recommendations for inter-seeding should include a moderate vertical mowing, followed by seeding, and topdressing. Golf course superintendents need to be aware that they may never achieve a complete change in the population nor a rapid improvement in overall greens performance.

Blending Studies: A new 25,000 square foot experimental green was constructed in September and October 1996. A bentgrass blending study was planted on November 12, 1996. Five bentgrasses, selected for performance based on National Turfgrass Evaluation Program trials and disease resistance, were used. The five cultivars included Penncross, L-93, A-4, Crenshaw, and Mariner, and were planted to 6 foot by 6 foot plots in all possible combinations of single, two-way, and three-way blends. A completely random design with three replications was used. Planned comparisons among single, two-way, and three-way blends, and for comparison among cultivars were used to assess differences in turf quality and disease reaction. Naturally occurring disease was minimal during 1997. The experimental area was inoculated twice during fall 1997 with brown patch and dollar spot. Infected area was measured and visually assessed for disease injury.

Results: Turf quality for 1997 was greatest for Crenshaw, least for A4, Mariner, and Penncross, and L93 was intermediate (Table 7). Differences in turf quality were most notable during May through September. Blending affected turf quality on only 1 of 10 observation dates. On 17 October 1997, single varieties had lower turf quality than two-way blends. The effects of blends on turf quality may become more evident with time.

Individual cultivars had either positive, negative or no affect on overall turf quality (Table 9). Including Crenshaw as a component in blends improved putting green quality. A similar response was observed for L93. These cultivars had the greatest quality when planted as single varieties and made a positive contribution when used in blends. In contrast, Penncross and Mariner had a negative effect on putting green quality when included as a component in blends. A4 had no overall effect on putting green quality.

The relationship of specific cultivars for inter-seeding Penncross greens were assessed by comparing the individual cultivars Crenshaw, L93, and Penncross (Table 10). In general, blending Crenshaw with L93, two strong cultivars, did not improve putting green quality above that observed for Crenshaw and L93 planted as single varieties. A 50:50 blend of Penncross and Crenshaw did not improve quality above that of Penncross alone. However, a 50:50 blend of Penncross and L93 improved quality above that of Penncross alone. A three-way blend of equal proportions of Penncross, L93, and Crenshaw produced high turf quality similar to that of Crenshaw planted as a single variety.

Disease development during December 1996 and January 1997 did not demonstrate differences among single, two-way, and three-way blends, although the turfgrass stand was extremely young. Inoculation of the experimental area in fall 1997 with brown patch and dollar spot indicate differences among individual cultivars in susceptibility to these diseases (data not shown). However, blending did not provide substantial, consistent suppression of these two diseases.

These data indicate that cultivars should be carefully chosen to use in blends. Weakly adapted cultivars reduce putting green quality. Although evidence for disease suppression was not clearly delineated, judicious blending can provide a strong putting surface. The results of this study also indicate that care should be used in selection of a cultivar for use in inter-seeding. A cultivar that provides superior quality as a single variety may not provide an improvement in putting green quality when blended through the inter-seeding process with an existing poorer performing cultivar.

Table 1. Water potential at zero turgor (Ψ_0), osmotic potential at full turgor ($\Psi\pi_{100}$), relative water content at zero turgor (RWC_0), apoplastic water fraction (β), bulk modulus of tissue elasticity (ε), and turgid weight:dry weight ratios (TW:DW) for six maternal creeping bentgrass clones.

Clone	Ψ_0	$\Psi\pi_{100}$	RWC_0	β	ε	TW:DW
	-MPa	-MPa	$g\ g^{-1}$	$g\ g^{-1}$	MPa	$g\ g^{-1}$
2833	0.83 b†	2.39 a	0.46	0.058 ab	1.35 a	6.32
2845	0.84 b	2.24 ab	0.48	0.078 a	1.42 a	8.01
3106	0.75 b	2.06 ab	0.43	0.003 b	0.91 b	7.71
3153	0.95 a	2.40 a	0.44	0.016 ab	1.14 ab	6.67
3250	0.81 b	1.97 b	0.49	0.049 ab	1.16 ab	8.45
9999	0.82 b	1.95 b	0.50	0.050 ab	1.19 ab	6.81

†Means within columns followed by the same lower case letter are not different based on the Waller Duncan *k*-ratio *T* test where *k*=100. NS, not significant.

Table 2. Turf quality of creeping bentgrass cultivars during 1997 under three irrigation frequencies at the Texas A&M University Turfgrass Field Laboratory, College Station, TX.

Cultivar	Turf quality†								
	21 July	28 July	4 Aug	11 Aug	18 Aug	19 Aug	22 Aug	4 Sept	Mean
				1-Day irrigation					
A4	4.3	4.3	4.5	4.8	4.5	4.0	4.7	4.0	4.4
Crenshaw	5.3	5.0	4.3	5.0	4.7	4.0	4.7	5.0	4.8
L93	5.0	5.5	4.8	5.0	4.3	4.6	5.3	5.0	4.9
Mariner	4.2	3.8	4.2	4.2	3.7	3.3	4.2	4.0	4.0
Penncross	3.7	3.7	3.5	3.7	3.2	3.3	3.3	3.0	3.4
Putter	4.3	4.7	4.7	4.7	4.2	4.3	4.7	4.3	4.5
Seaside	2.7	2.3	2.7	2.5	2.3	1.0	1.7	1.0	2.0
Southshore	4.7	4.8	5.0	4.8	4.7	4.7	4.7	5.0	4.8
SR1020	4.7	4.7	5.0	5.2	4.7	5.7	5.7	5.3	5.1
Irrigation Mean	4.3	4.3	4.3	4.4	4.0	3.9	4.3	4.1	4.2
				2-Day irrigation					
A4	4.3	4.8	4.5	4.5	4.2	4.0	5.0	4.3	4.5
Crenshaw	5.3	5.5	4.8	4.8	4.5	5.0	5.7	6.3	5.2
L93	5.3	5.3	5.3	5.0	4.7	5.0	5.3	6.0	5.2
Mariner	4.2	4.3	4.0	4.5	4.0	3.3	4.2	3.7	4.0
Penncross	3.8	3.7	3.3	3.5	3.5	3.0	3.3	3.3	3.4
Putter	4.0	4.3	4.3	4.3	4.0	4.0	3.7	5.0	4.2
Seaside	3.0	2.7	2.8	2.8	2.5	1.3	2.3	1.3	2.3
Southshore	5.0	5.2	5.2	5.0	4.5	4.7	5.7	6.0	5.2
SR1020	4.8	5.2	4.8	4.7	4.7	4.0	4.7	5.3	4.8
Mean	4.4	4.6	4.3	4.3	4.1	3.8	4.4	4.6	4.3
				4-Day irrigation					
A4	4.3	4.5	4.3	4.0	4.2	3.6	2.7	4.7	4.0
Crenshaw	5.3	4.6	4.3	4.6	4.2	4.3	5.2	5.3	4.7
L93	5.8	5.3	5.0	5.0	4.8	5.3	3.7	6.0	5.1
Mariner	4.2	4.2	4.3	4.5	4.0	3.7	4.3	4.7	4.2
Penncross	4.2	3.8	3.5	3.5	3.2	3.3	3.0	3.7	3.5
Putter	4.3	4.2	4.8	4.5	4.0	4.3	3.7	6.0	4.5
Seaside	3.0	2.7	2.8	2.3	2.3	1.3	1.7	2.0	2.3
Southshore	5.3	5.0	5.5	5.0	4.3	5.0	4.3	7.3	5.2
SR1020	4.8	4.8	5.2	5.2	4.2	5.3	5.0	7.7	5.3
Mean	4.6	4.3	4.4	4.3	3.9	4.0	3.7	5.3	4.3
MSD_I§	NS	NS	NS	NS	NS	NS	NS	1.0	NS
MSD_C¶	0.9	0.8	0.7	0.7	0.5	1.1	1.5	1.3	0.7

† Turf quality visually evaluated on a 1 to 9 scale where 9 most dense, uniform, and smooth, and darkest green.
§Minimum significant difference for comparison of irrigation treatment means within dates and cultivars based on the Waller Duncan *k*-ratio *T* test where *k*=100. NS, not significant.
¶Minimum significant difference for comparison of cultivar means within dates and irrigation treatments based on the Waller Duncan *k*-ratio *T* test where *k*=100. NS, not significant.

Table 3. Mean turgor potential of five creeping bentgrass cultivars at three frequencies of irrigation during August 1997 at the Texas A&M University Turfgrass Field Laboratory, College Station, TX.

Cultivar	Turgor potential irrigation treatments		
	1-Day	2-Day	4-Day
	MPa	MPa	MPa
A4	0.99	0.87	0.22
Crenshaw	0.76	1.33	0.48
L93	0.85	1.11	0.42
Mariner	1.36	1.16	0.83
Penncross	0.50	1.63	0.46
Mean	0.89	1.22	0.48
LSD_C†	0.42	NS	0.31
LSD_T§		0.17	

Source of variation	Pr>F
Treatment (T)	0.0001
Cultivar (C)	0.01
T by C	0.002

†LSD_C, Least Significant Difference for comparison of cultivar means within irrigation treatments.

§LSD_T, Least Significant Difference for comparison of irrigation treatment means within cultivars.

Table 4. Seedling emergence 4 weeks after inter-seeding at the Texas A&M University Research and Extension Center at Dallas, Texas in April and the Dallas Country Club in October 1995.

Seeding treatment	Mechanical treatment	May[†] 1995	Nov 1995
		------------- plants m^{-2}	--------------
No seed	Core tine	237 c	581 c
No seed	Star tine	161 c	560 c
No seed	Verticut	194 c	484 c
No seed	None	194 c	312 c
Seeded	Core tine	538 b	1378 ab
Seeded	Star tine	624 b	2110 a
Seeded	Verticut	1894 a	1238 ab
Seeded	None	926 b	2282 a

[†]Means within a column followed by the same lower case letter are not different at the 0.05% level of probability. Plant density was determined only for the glyphosate treatment.

Table 5. Percentage of Crenshaw creeping bentgrass identified by isozyme analysis 6 and 14 months after inter-seeding into an existing Penncross putting green at the Texas A&M University Research and Extension Center at Dallas, Texas.

Seeding treatment	Percentage Crenshaw glyphosate†	cimectacarb	none	Mean
	------------------ 6 months ------------------			
No seed	3	3	5	4
Seeded	51*	11	14*	26*
	------------------ 14 months ------------------			
No seed	3	3	3	3
Seeded	83*	10	11	35*

†Chemical treatments were applied 7 days before mechanical and seeding treatments. Glyphosate did not cause complete kill of the existing Penncross.

*Significantly different within a sampling date and chemical treatment at the 0.05 level of probability.

Table 6. Percentage of Crenshaw creeping bentgrass identified by isozyme analysis at 6 and 14 months after inter-seeding into an existing Penncross putting green at the Texas A&M University Research and Extension Center at Dallas, Texas.

Mechanical treatment	Percentage Crenshaw† glyphosate	cimectacarb	none	Mean
	---------- 6 months ----------			
Core tine	12	8	7	9
Star tine	53	10	7	23
Verticut	70	12	10	31
None	70	15	33	39
Mean	51	11	14	26
$LSD_{0.05M}$§	29	NS	NS	25
	---------- 14 months ----------			
Core tine	61	10	10	27
Star tine	89	8	8	35
Verticut	85	11	16	37
None	95	10	11	39
Mean	83	10	11	35
$LSD_{0.05M}$	24	NS	NS	NS

†Chemical treatments were applied about 7 days before mechanical and seeding treatment. Glyphosate did not cause complete kill of the existing Penncross.

§ $LSD_{0.05M}$, Least significant difference for comparison of mechanical treatment means within dates; NS, not significantly different at the 0.05 level of probability.

Table 7. Turf quality of five creeping bentgrass cultivars used in a blending study at the Texas A&M University Turfgrass Field Laboratory in College Station, Texas. Cultivars were planted 12 November 1996.

	1997 Turf quality†										
Cultivar	26 Feb	3 Mar	26 Mar	7 May	29 May	17 June	28 July	22 Aug	4 Sept	17 Oct	Mean
Crenshaw	4.7	5.0	6.3	6.7	8.0	7.0	6.0	6.0	4.0	5.0	5.9
L93	4.3	5.0	6.3	6.8	7.3	6.3	5.0	5.7	2.7	4.0	5.3
A4	4.0	4.3	5.3	5.7	4.7	4.7	3.3	4.3	2.0	5.0	4.3
Mariner	4.3	4.7	5.7	6.4	3.7	4.0	4.7	3.0	2.0	4.3	4.3
Penncross	4.3	5.3	6.0	6.1	4.3	3.7	3.0	3.3	1.7	4.3	4.2
MSD§	NS	NS	NS	NS	1.5	1.2	2.0	1.8	1.6	NS	1.0

†Turf quality visually evaluated on a 1 to 9 scale where 9 most dense, uniform, and smooth, and darkest green.

§Minimum significant difference for comparison of turf quality means within dates based on the Waller Duncan *k*-ratio *T* test where *k*=100. NS, not significant.

Table 8. Mean turf quality of five creeping bentgrass cultivars planted as single varieties and two-way and three-way blends at the Texas A&M University Turfgrass Field Laboratory in College Station, Texas. Cultivars were planted 12 November 1996.

	1997 Turf quality†										
Blend	26 Feb	3 Mar	26 Mar	7 May	29 May	17 June	28 July	22 Aug	4 Sept	17 Oct	Mean
Single varieties	4.3	4.9	5.9	6.4	5.6	5.1	4.4	4.5	2.5	4.5	4.8
Two-way blends	4.3	4.6	6.0	6.3	6.0	5.5	4.3	4.6	2.5	5.3	4.9
Three-way blends	4.2	4.7	6.0	6.5	5.8	5.3	4.4	4.8	2.6	5.1	4.9
Contrast	Probability > F										
Single vs. others	0.76	0.43	0.78	0.91	0.41	0.43	0.84	0.42	0.70	0.03	0.49
Single vs. two-way	0.91	0.39	0.84	0.74	0.33	0.30	0.81	0.65	0.78	0.02	0.50
Single vs. three-way	0.66	0.57	0.75	0.60	0.60	0.68	0.90	0.31	0.68	0.10	0.55

†Turf quality visually evaluated on a 1 to 9 scale where 9 most dense, uniform, and smooth, and darkest green.

Table 9. Contribution of five creeping bentgrass cultivars to turf quality when planted as single varieties and two-way and three-way blends at the Texas A&M University Turfgrass Field Laboratory in College Station, Texas. Cultivars were planted 12 November 1996.

Blend	1997 Turf quality[†] 26 Feb	3 Mar	26 Mar	7 May	29 May	17 June	28 July	22 Aug	4 Sept	17 Oct	Mean
Crenshaw +	4.4	4.7	6.1	6.5	6.4	5.7	4.7	5.3	2.9	5.2	5.2
Crenshaw -	4.2	4.6	5.9	6.3	5.5	5.0	4.1	4.2	2.2	4.9	4.7
L93 +	4.4	4.8	6.2	6.6	6.6	5.7	4.6	5.1	2.8	5.2	5.2
L93 -	4.2	4.6	5.9	6.2	5.3	5.0	4.1	4.3	2.4	4.9	4.7
A4 +	4.0	4.4	5.9	6.4	5.8	5.3	4.1	4.5	2.4	5.0	4.8
A4 -	4.5	4.9	6.1	6.4	5.9	5.3	4.5	4.8	2.6	5.0	5.0
Mariner +	4.2	4.5	5.9	6.3	5.2	5.0	4.4	4.4	2.3	5.2	4.7
Mariner -	4.4	4.8	6.1	6.4	6.4	5.6	4.4	4.9	2.7	4.9	5.0
Penncross +	4.3	4.8	6.0	6.2	5.3	4.9	4.0	4.3	2.3	4.8	4.7
Penncross -	4.2	4.6	6.0	6.5	6.3	5.6	4.6	5.0	2.7	5.2	5.1
Contrast	Probability > F										
Crenshaw + vs. Crenshaw -	0.50	0.85	0.50	0.16	0.0003	0.0017	0.0100	0.0001	0.0001	0.15	0.0003
L93 + vs. L93-	0.64	0.59	0.29	0.03	0.0001	0.0067	0.0200	0.0003	0.0140	0.15	0.0004
A4 + vs. A4 -	0.08	0.13	0.65	0.88	0.8800	0.8500	0.0400	0.6400	0.3470	0.75	0.2390
Mariner + vs. Mariner -	0.34	0.40	0.52	0.72	0.0001	0.0200	0.9800	0.0730	0.0627	0.15	0.0560
Penncross + vs Penncross -	0.95	0.71	0.76	0.30	0.0009	0.0026	0.0020	0.0300	0.0310	0.42	0.0185

[†]Turf quality visually evaluated on a 1 to 9 scale where 9 most dense, uniform, and smooth, and darkest green.

Table 10. Mean turf quality of Crenshaw, L93, and Penncross creeping bentgrass cultivars planted as single varieties and two-way and three-way blends at the Texas A&M University Turfgrass Field Laboratory in College Station, Texas. Cultivars were planted 12 November 1996.

	1997 Turf quality†										
Blend	26 Feb	3 Mar	26 Mar	7 May	29 May	17 June	28 July	22 Aug	4 Sept	17 Oct	Mean
Crenshaw	4.7	5.0	6.3	6.7	8.0 a	7.0 a	6.0 a	6.0 a	4.0 a	5.0	5.9 a
L93	4.3	5.0	6.3	6.8	7.3 a	6.3 a	5.0 ab	5.7 a	2.7 bc	4.0	5.3 ab
Penncross	4.3	5.3	6.0	6.1	4.3 b	3.7 d	3.0 c	3.3 b	1.7 c	4.3	4.2 c
Crenshaw + L93	5.3	6.0	6.7	6.7	7.3 a	6.7 a	5.3 ab	5.7 a	3.0 ab	6.0	5.9 a
Penncross + L93	5.3	5.7	6.7	6.7	7.0 a	5.3 c	4.0 bc	5.0 a	2.7 bc	5.3	5.4 ab
Penncross + Crenshaw	4.0	3.7	5.3	6.1	5.3 b	6.0 b	4.3 bc	4.7 ab	2.3 bc	4.7	4.6 bc
Penn. + Cren. + L93	5.0	5.7	6.7	6.7	7.0 a	5.3 c	5.0 ab	6.0 a	3.0 ab	5.0	5.5 a

†Turf quality visually evaluated on a 1 to 9 scale where 9 most dense, uniform, and smooth, and darkest green.

§Means within columns followed by the same lower case letter are not different based on the Waller Duncan *k*-ratio *T* test where *k*=100. NS, not significant.

Figures

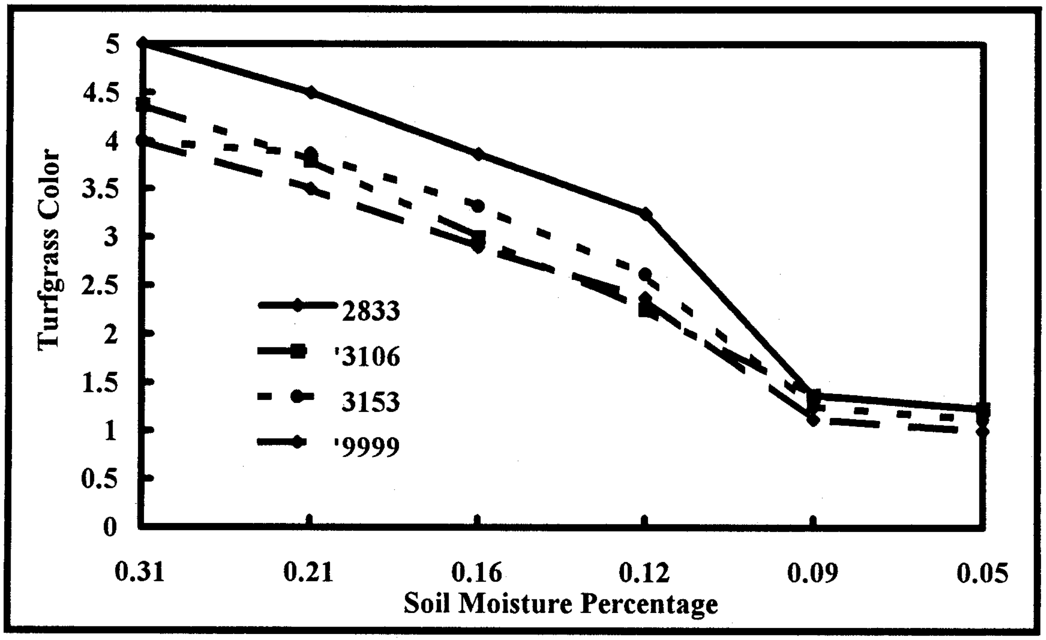

Figure 1. Turfgrass color response of selected maternal clones during soil drying. A total of 28 maternal clones were examined. The clones presented here represent those with high, intermediate and low drought tolerance.

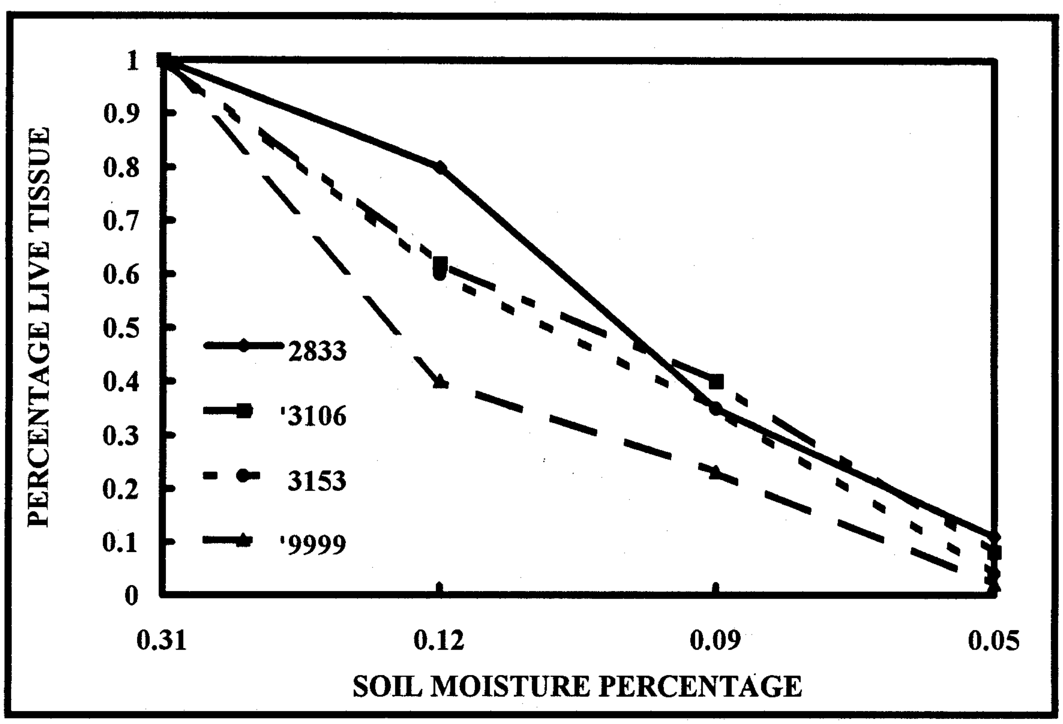

Figure 2. Percentage live tissue of selected maternal clones during soil drying. A total of 28 maternal clones were examined. The clones presented here represent those with high, intermediate and low drought tolerance.