



ANNUAL BLUEGRASS  
*Poa annua* L.



CREEPING BENTGRASS  
*Agrostis palustris* Huds.



BERMUDAGRASS  
*Cynodon* L. spp.



BUFFALOGRASS  
*Buchloe dactyloides* (Nutt.) Engelm.



ZOYSIAGRASS  
*Zoysia japonica* Steud.

# 1983-1992 TURFGRASS RESEARCH SUMMARY



*Cover illustrations by Steven M. Batten*



# **1983-1992 TURFGRASS RESEARCH SUMMARY**

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**IN COOPERATION WITH:**

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**TO: THE READERS OF THE SUMMARY REPORT OF THE 1983-1992 TURFGRASS RESEARCH PROGRAM**

How quickly time goes by! It was 1982 when the USGA Green Section and the Golf Course Superintendents Association of America (GCSAA) got together to plan a major new thrust into turfgrass research for the benefit of the game of golf. A decade later, the carefully planned 10-year Turfgrass Research Program has taken its place in golf history.

Foremost among the objectives of the program was to develop new grasses for golf that use less water and help lower maintenance costs. Another objective was to encourage a new generation of young scientists to become leaders in turfgrass research. By any measure, the program has been a success.

During a decade of turfgrass research, more than \$5 million was spent to fund more than 40 different projects. The benefits of this work are described throughout this report, but a few highlights are worth noting. First of all, our knowledge about water use rates of the various turfgrasses and how these grasses react to moisture stress has been greatly expanded. Secondly, the turfgrass breeding programs designed to introduce new grasses that require less water and pesticide use have been firmly established and are producing the next generation of grasses for golf. And third, investigations of various cultural practices have helped forward our understanding of how these practices can contribute to our goal of better golf turf with fewer inputs.

In the following pages you will read about the successes of the sponsored projects, the theses and other publications that have been generated, and the nearly 50 graduate and post-doctoral students who have benefitted directly from grants from the Turfgrass Research Program. A less obvious benefit, yet perhaps one of the most important of all, is that the program helped fund a decade of growth in turfgrass science programs at universities throughout the country, even at a time when other agricultural disciplines fell victim to budget

USGA

cuts and downsizing. Many outstanding scientists from other fields were drawn to the study of turfgrass science, a situation that surely will pay big dividends for golf in the years ahead.

I am pleased to report that the USGA Executive Committee has agreed to extend the Turfgrass Research Program for five additional years, and the GCSAA has committed its support and cooperation as well. The theme of the 1993-1997 Turfgrass Research Program is called simply "Conserving Natural Resources" and will build on the progress made during the historic 10-year program just completed.

Finally, the USGA and the game of golf is indebted to the 32 individuals who gave so generously of their time while serving on the USGA Turfgrass Research Committee, and particularly to Dr. James Watson and Dr. Paul Rieke, the only committee members to serve for the entire 10-year period. Thanks, too, to the many individuals, organizations, and golf courses that contributed funds to help carry out this vital work for the benefit of golf.

With appreciation,

A handwritten signature in cursive script that reads "Jim Snow". The signature is written in dark ink and includes a long horizontal flourish extending to the right.

James T. Snow  
National Director, Green Section

# 1983-1992 Turfgrass Research Summary

## Table of Contents

<b>List of Tables</b> .....	iv
<b>List of Figures</b> .....	iv
<b>1992 Turfgrass Research Committee</b> .....	v
 <b>I. Executive Summary</b> .....	 1
 <b>II. The Impact of Golf and Why Turfgrass Research is Needed</b> .....	 5
Golfers and Golf Courses .....	5
Economic Impact of Golf .....	5
Golf and the Environment .....	8
The USGA Decides to Become More Involved in Turfgrass Research .....	9
Fund Raising .....	10
 <b>III. The Turfgrass Research Program 1983 - 1992</b> .....	 14
Turfgrass Information File .....	14
Plant Stress Mechanisms .....	15
Cultural Practices .....	17
Cultivar Evaluation .....	18
Management .....	18
Pathology .....	19
Soil Compaction .....	21
Salt Screening .....	23
Water Use .....	24
Entomology .....	24
Mycorrhizae .....	25
Turfgrass Breeding .....	26
General - Cool Season Species .....	26
Bentgrass .....	26
Bermudagrass .....	28
Native Grasses .....	30
Annual Bluegrass .....	32
Zoysiagrass .....	32
 <b>IV. Appendix</b> .....	 34
Appendix A: 1983-1992 Turfgrass Research Budget Summary .....	35
Appendix B: List of Graduate Students .....	36
Appendix C: List of Theses .....	37
Appendix D: List of Publications .....	39

## List of Tables

Table 1.	Increase in the number of golfers and rounds played in the United States from 1958 to 1990 .....	5
Table 2.	Increase in the total number of golf facilities in the United States from 1946 to 1990 .....	5
Table 3.	Distribution of golf courses, number of rounds played and golfers by State in 1990 .....	6
Table 4.	Range and median dimensions of turfgrass on golf courses in the United States .....	6
Table 5.	Estimate of turfgrass acreage by golf courses by State .....	7
Table 6.	Annual expenditures: Core vs. Occasional Golfers .....	8
Table 7.	Golf course maintenance costs by regions .....	8
Table 8.	Research Committee Members .....	9
Table 9.	The Honor Roll - List of donors to the USGA/GCSAA Turfgrass Research Program .....	11
Table 10.	Summary of Mean Rates of Turfgrass Evapotranspiration .....	17
Table 11.	Turfgrass Morphological, Anatomical and Physical Characteristics Contributing to Drought Resistance .....	17
Table 12.	Relative Resistance of Turfgrass Grown in Region of Climatic Adaption and Preferred Cultural Regime .....	18
Table 13.	Types of plant morphology which affect the resistance to evapotranspiration .....	18
Table 14.	Relative salt resistance of several turfgrass species used in the United States .....	24
Table 15.	Summary of USGA/GCSAA Turfgrass Breeding Programs .....	30

## List of Figures

Figure 1.	Increase in golf course maintenance cost from 1971 to 1991 .....	8
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## **I. Executive Summary**

The Turfgrass Research Program sponsored by the United States Golf Association, in cooperation with the Golf Course Superintendents Association of America, had three primary goals. First, develop minimal maintenance turfgrasses for golf courses through a fifty percent reduction in water use and maintenance costs. Second, develop the Turfgrass Information File, a large collection of publications on Turfgrass Science and Culture, and make the information within this data base available to the public through written, telephone, or computer inquiries. Third, develop young leaders in Turfgrass Science through direct involvement and financial support of higher education in the United States.

This research program and its stated objectives have proven to be prophetic as environmental consciousness has increased, the information and computer age is reaching full stride and, more than ever before, universities need direction and financial support from the private sector in order to prepare our young scientists for the challenges of the next century.

The research program started at a funding level of \$250,000 in 1983, and has now become the most focused, well planned research mission in Turfgrass Science since the historical days of the Green Section's efforts in the 1920's, 30's and 40's. An annual budget of nearly three quarters of a million dollars is currently distributed among 20 research projects located in fourteen states.

The USGA Turfgrass Research Committee has been instrumental in making this program work. The USGA has successfully implemented many important research projects and kept university indirect costs down to 16 percent, or less in some cases. At least one on-site monitoring visit to each university is made each year to evaluate the research progress first hand, and tell the USGA story to university administration.

The following pages discuss some of the interesting statistics about golfers and golf course trends, why turfgrass research was needed for golf courses, results of the major research projects supported over the last ten years, and includes appendices listing graduate students, dissertations, and various scientific and technical publications.

Overall, through the efforts of the individual turfgrass scientists and their support staff, many significant accomplishments were made. Water management, and our knowledge about how much water golf turf species use, has greatly improved.

New bentgrasses, bermudagrasses and buffalograsses already have been released to sod and seed producers and are making their way on to golf courses. Royalties, which will help continue the support of turfgrass research efforts, are starting to be received by the USGA Foundation. The Turfgrass Information File, or TGIF, was completed and shows promise to become a self sustaining service at the Michigan State University Library. Over thirty M.S. and Ph.D. graduate students have received degrees through the direct support of the USGA. Over two hundred scientific or technical articles have been published, and twenty-nine of the thirty-six projects were completed.

The future direction of the Turfgrass Research Program will include support of several existing turfgrass breeding programs, with more projects concentrating in the biotechnology and genetic engineering sciences. Alternative pest management and cultural practices, which help to reduce maintenance costs, will require additional attention and financial support. The research program also will continue to develop young leaders in the biological sciences and engineering.

### **Turfgrass Information File**

The amount of information on turfgrass science and management was growing faster than researchers, golf course superintendents and many others could possibly keep pace with. Even the university libraries across the country could not adequately maintain a complete record of all the important turfgrass literature. The Turfgrass Information File at Michigan State University Library is the most well organized and complete collection on turfgrass science and management in the world. This collection is available to anyone interested by calling, writing, or accessing directly by computer.

### **Plant Stress Mechanisms**

For years, plant physiologists and plant breeders worked independently on improving the ability of turfgrasses to tolerate environmental stresses. The initial research on plant stress mechanisms documented what was known about these mechanisms and suggested ways to select and improve turfgrasses for golf courses that would require less water. These studies set the pace for

more cooperation between plant breeders and physiologists to direct concurrent research which developed selection techniques for other plant stresses such as tolerance to heat and cold, salinity, or poor quality water.

### Cultural Practices

Sixteen studies were conducted on a wide range of new ideas to improve specific management practices related to disease and insect problems, soil compaction, salt tolerance and water usage. Research was conducted to improve or introduce new cultural practices specific for golf course turf and the quality of playing surfaces on golf courses. A summary of the major findings include:

#### Management

- Improved greenhouse techniques were developed for making nutritional comparisons among new turfgrasses.
- Clipping removal from creeping bentgrass/*Poa annua* fairways was found to favor bentgrass competitiveness.
- Plant growth regulators reduced *Poa annua* on fairways when applied at label rates after several years of use.
- Heat shock proteins play a role in the ability of *Poa annua* to sustain high temperatures.

#### Soil Compaction

- Hollow tine cultivation ranked equal to or higher than solid tine cultivation; however, both methods reduced soil compaction.
- Among the five cultivation techniques examined (hollow tine, Verti-Drain, Verti-Slicer, Aeravator, and Hydro-Ject), the Verti-Drain was most effective in making improvements deeper in the soil profile, while hollow tine coring was best at improving soil surface conditions.
- In studies combining cultivation techniques, results indicated a vigorous cultivation program (Verti-Drain + Core Aerification) greatly improved turfgrass water use efficiency by enhancing water uptake from deeper zones within a fine-textured soil profile prone to surface compaction.
- The Yeager-Twose Turf Conditioner (a subsurface aerification unit) appeared to be well suited for achieving both physical and chemical modification of fine textured soils,

especially when lime is needed.

### Salt Screening

- Salt tolerance screening methods were developed to evaluate and rank buffalograss, zoysiagrass and bentgrass selections from USGA/GCSAA sponsored breeding programs.
- Promising zoysiagrass and bentgrass selections with good salt tolerance were identified, while buffalograss selections were very sensitive to salt.
- A tissue culture method was developed for screening mature turfgrass plants exposed to increasing levels of salt.

### Water Use

- For a well watered irrigation regime common to tees and high quality fairways in the Southwest, Tifway bermudagrass used the least water compared to Meyer zoysiagrass and common centipedegrass.
- At moderate moisture irrigation, typical of fairways in the south, water use rates were 39 and 11 percent greater than Tifway bermudagrass during August for Meyer zoysiagrass and centipedegrass, respectively.
- Under severe moisture stress, such as for rough areas, Meyer zoysiagrass was severely wilted and centipedegrass used 43 percent more water than Tifway bermudagrass.
- Research results for the entire season were compiled to base irrigation scheduling on atmospheric, soil or plant based criteria rather than guessing.
- Mycorrhizal fungi associated with bentgrass and *Poa annua* were isolated from old putting greens and sand dune soils to evaluate their effect on the establishment and maintenance of greens.

### Pathology

- Screening techniques were developed for resistance to *Pythium* blight and root rot, brown patch, dollar spot, spring dead spot, summer patch, and necrotic ring spot pathogens.
- The inheritance for resistance to *Pythium* blight in bentgrass appeared to be a predictable and stable characteristic.
- A total of 12 percent of a large progeny population appeared to have resistance to

#### *Pythium* root rot.

- The bentgrass and zoysiagrass entries in the National Turfgrass Evaluation Program were screened for *Rhizoctonia* and *Pythium* blight disease resistance.
- Seed lots of 42 bentgrasses from Pennsylvania State University were screened for resistance to summer patch and necrotic ring spot.
- Fungicides and fertilizer treatments to control spring dead spot on bermudagrass were evaluated at four locations in the southern United States.
- A monoclonal antibody test was successfully developed for rapidly diagnosing the presence of necrotic ring spot and spring dead spot pathogens in turf.
- Tissue culture screening techniques were developed which simultaneously grows creeping bentgrass and *Rhizoctonia* brown patch to select disease resistant lines.

#### Entomology

- Thirty new fungal endophytes which may impart insect resistance were isolated from turfgrasses.
- More than 700 collections were screened and 14 fungal endophyte-infected species of *Poa* and *Agrostis* were found.
- DNA probes were developed to help rapidly identify the presence of a particular endophyte species within turfgrasses.
- Scouting methods for southern mole crickets were developed to monitor population changes and reduce annual pesticide applications.
- Biologically active materials, pheromones, were isolated from mole crickets to either attract or repel crickets under golf course conditions.

#### Turfgrass Breeding

The turf breeding projects were directed toward developing new varieties which require less water, are more tolerant to heat, cold, or salinity stresses, or improved disease or insect resistance. Plant breeding is a slow process which involves developing effective screening techniques, testing thousands of progeny with the screening procedures to find the best ones, and using the best materials as parents for a new variety or the start

of a new cycle of screening. In the last ten years, many new grasses have made their way on to golf courses or into national testing programs. Highlights of accomplishments include:

- New creeping bentgrasses, developed with full or partial support by the USGA include: 'Pennlinks', 'Providence', 'SYN-1 88', 'SYN-3 88', and 'SYN-4 88'.
- Colonial bentgrass breeding efforts were supported in New Zealand, and BR-1518 was entered in the National Turfgrass Evaluation Trials.
- New seed propagated bermudagrasses include NuMex 'Sahara', which was released in 1988, and two cold hardy experimentals from Oklahoma State University which were entered into the National Turfgrass Evaluation Trials in 1992.
- New vegetatively propagated bermudagrasses include 'Tifton 10' for roughs and fairways, several hybrid (*Cynodon dactylon* x *C. transvaalensis*) 'Midiron' and 'Tifway' mutants for fairways, and promising African (*C. transvaalensis*) selections for putting greens.
- The University of Nebraska released the first turf-type buffalograss, 'NE 84-609', while several other vegetatively and seed propagated varieties were entered into the National Turfgrass Evaluation Trials in 1991.
- New alkaligrass, blue grama, and fairway crested wheatgrass varieties were developed and are nearing release from Colorado State University.
- Curly mesquitegrass, native to the Arizona desert, was evaluated as a potential fine turf for hot, dry climates.
- Three annual bluegrasses (*Poa annua* var *reptans*) and two *P. supina* seeded varieties were selected for seed production and turf performance trials.
- Nine new vegetatively propagated zoysiagrasses, with medium to fine texture and lower maintenance requirements, were entered into the National Turfgrass Evaluation Trials in 1991.
- New screening techniques were developed for heat and cold hardiness, resistance to salinity, root length, tolerance to low clipping height, mowing, winter color retention, leaf texture, seed production, and drought tolerance.



## II. The Impact of Golf and Why Turfgrass Research Is Needed

Golf is played on grass. As the game of golf has grown, so has the knowledge on how to produce, establish, and maintain the turfgrasses used for golf course playing surfaces. The growth in the number of golfers and the number of rounds played has required construction of more golf courses able to withstand an increased number of rounds. At the same time, golf courses have experienced increased maintenance costs and tougher government regulation with regard to water use and environmental issues.

The interaction of the increase in the game's popularity with higher maintenance costs and government regulation created several problems needing solutions. Turfgrass research was needed to solve these problems; however, significant funding for this research was not available to the university researchers able to address these problems. The following sections document the increased popularity of golf, its economic impact, environmental issues golf courses face, and why the USGA got involved in turfgrass research.

### Golfers and Golf Courses

The popularity of golf has increased steadily in the United States since 1946. In the short span from 1985 to 1990, the number of golfers increased from 17 to 25 million (Table 1). In this same period, the number of rounds of golf played annually increased by 17.6 percent. Between 1968 and 1990, the number of golf facilities increased from 9,600 to 12,800 (Table 2) and the National Golf Foundation estimates that over 12 percent of the population in the United States over the age of 12 plays golf (Table 3).

Most golf courses and the golfers using these facilities are concentrated in the major urban centers of the United States. The expansion of golf in regions with densely populated urban areas has increased concern about land use, water

**Table 1. Increase in the number of golfers and rounds played in the United States from 1958 to 1990.**

Total number	Year				
	1958	1963	1968	1985	1990
----- in millions -----					
Golfers	4.0	7.3	11.3	17.5	25.0
Rounds	---	---	194	415	488

From: Nutter and Watson (1969) and National Golf Foundation (1989, 1991).

resources, and environmental quality. The concentration of golf courses in areas requiring extensive water resources and expensive management practices has led to the need for increased funding of research to develop methods that reduce the resources needed to manage golf course facilities.

According to National Golf Foundation estimates, there are over 13,951 golf courses in the United States. Assuming an average size of 124 to 180 acres per facility, there are from 1.7 to 2.5 million acres of land dedicated to golf facilities. This estimate includes all areas of golf facilities, such as clubhouse and parking lots, that are not covered with turfgrass. The actual managed turfgrass acreage on golf courses is less than the total area of the facility reported by the National Golf Foundation.

The average dimensions of greens, surrounds,

**Table 2. Increase in the total number of golf facilities in the United States from 1946 to 1990.**

Item	Year				
	1946	1958	1963	1968	1990
----- in thousands -----					
Number of facilities	4.8	5.7	7.5	9.6	12.8
Estimated acreage	---	---	300	417	533*

From: Nutter and Watson (1969), Heuber (1984), National Golf Foundation (1991) and \*Estimate from Table 5.

tees, fairways, and rough vary among regulation, executive, and Par-3 golf courses. Golf course acreage in the United States (Table 5) was estimated on the basis of median turfgrass area dimensions (Table 4) and estimates of the number of golf holes by state (Table 3). Approximately 1.3 million acres of land are managed for golf course turfgrass in the United States.

The construction and maintenance intensity of golf course turfgrass areas decreases in the following order: putting greens, tees, surrounds, fairways, and roughs. The total annual amount used and number of applications for fertilizers and pesticides decreases from the greens to the rough. The portion of the golf course receiving the intensive management of green and tee areas is relatively small (6%) compared to the total acreage of turfgrass on the golf course.

### Economic Impact of Golf

**Table 3. Distribution of golf courses, number of rounds played and golfers by State in 1990.**

State	Courses	Annual Total		% Total Population
		Rounds	Golfers <sup>a</sup>	
		----- in thousands -----		
AL	211	5,254	264	7.9
AZ	236	8,736	416	13.7
AR	151	4,404	109	5.6
CA	853	56,556	2,842	11.8
CO	187	7,567	409	14.5
CT	168	7,823	354	12.8
DE	28	832	52	9.3
DC	10	459	23	4.0
FL	1,011	44,518	1,374	12.3
GA	324	11,577	510	9.5
ID	82	1,963	130	17.0
IL	606	22,950	1,530	16.0
IN	387	13,355	639	13.8
IA	367	8,235	394	17.4
KS	243	5,270	288	13.8
KY	228	8,280	345	11.1
LA	148	5,105	201	5.6
ME	121	2,038	109	10.8
MD	146	7,134	392	10.0
MA	329	12,960	720	14.3
MI	749	22,532	1,273	16.9
MN	394	11,123	727	21.2
MS	145	3,047	110	5.3
MO	280	8,283	499	11.7
MT	75	1,047	88	13.6
NE	173	3,899	194	15.0
NV	55	2,348	118	13.0
NH	99	1,629	90	9.5
NJ	263	11,680	730	11.0
NM	82	3,779	171	13.6
NY	781	25,631	1,643	10.9
NC	474	12,119	609	11.0
ND	103	1,634	99	19.3
OH	704	25,713	1,375	18.7
OK	172	6,528	257	9.6
OR	159	4,452	291	15.3
PA	643	18,850	1,071	10.8
RI	48	1,962	93	10.9
SC	316	9,222	290	10.0
SD	110	2,349	77	13.0
TN	234	7,482	358	8.5
TX	756	32,036	1,497	10.5
UT	94	3,257	267	21.0
VT	60	720	55	11.6
VA	256	8,348	469	9.4
WA	240	6,834	510	13.4
WV	109	3,213	135	8.8
WI	417	11,766	769	19.3
WY	49	1,668	67	17.4
Total	13,876	488,167	25,033	12.7 <sup>a</sup>

From: National Golf Foundation (1991); <sup>a</sup>Age > 12; <sup>b</sup>Average.

The economic impact of the game of golf is difficult to estimate; however, more attention is being paid to the impact of "golfing dollars" as more regions of the United States become highly urbanized or develop as tourist destinations. The National Golf Foundation recently estimated that there are approximately 12 million "Core Golfers", 14 million "Occasional Golfers" and 2 million "Junior Golfers" in the United States. A core

**Table 4. Range and median dimensions of turfgrass areas on golf courses in the United States.**

Area	Range <sup>a</sup>	Median dimension		
		Regulation	Executive <sup>b</sup>	Par-3 <sup>b</sup>
		----- acres -----		
Greens	0.027 - 0.618 0.124 - 0.195 <sup>d</sup>	0.128 <sup>c</sup>	0.111	0.086
Surrounds	0.163 - 0.272	0.205 <sup>c</sup>	0.148	0.148
Tee	0.025 - 0.166	0.049 <sup>c</sup>	0.049	0.049
Fairways	1.656 - 3.29 <sup>c</sup>	2.800 <sup>c</sup>	1.977	1.648
Rough	2.197 - 4.942	3.568 <sup>c</sup>	2.224	2.224

<sup>a</sup> Beard (1982)

<sup>b</sup> Estimates only

<sup>c</sup> National Golf Foundation (1985)

<sup>d</sup> Most popular range

<sup>e</sup> Range for 18-hole courses only

<sup>f</sup> Total dimension includes non-turfgrass facilities

golfer is defined as someone who is at least 18 years of age and plays eight or more rounds of golf per year. An occasional golfer is someone of the same age who plays fewer than eight rounds annually.

The average annual expenditure of core golfers for golf equipment and facility fees is \$3,246 compared to \$1,087 for occasional golfers (Table 6). These estimated annual expenditures for core and occasional golfers translate to an economic impact over \$54 billion across the United States. The amount spent on green and guest fees at public and private courses, respectively, would comprise over \$6.6 billion of the total amount spent by core and occasional golfers. The National Golf Foundation also estimated that during 1985 to 1990, the cost of an 18-hole weekday round of golf at a public facility increased 42 percent compared to a 23 percent growth in the Consumer Price Index experienced in the United States.

The maintenance of golf courses continues to make a major economic impact and has experienced rapid increases during the last twenty years. During the 1970's, the cost of energy rose substantially and caused an inflationary increase in the cost of living. The cost of maintaining golf courses was not immune to increasing energy costs which resulted in higher prices for the fuel, fertilizers and pesticides manufactured by the petroleum and chemical industries (Figure 1). The increased cost of living led to higher labor costs, which put additional strain on golf course

**Table 5. Estimate of turfgrass acreage by golf courses by State<sup>a</sup>.**

State	Total Holes <sup>b</sup>			Estimated Acreage of Turfgrass in hectares <sup>c</sup>					
	Reg.	Exec.	Par-3	Green	Surrounds	Tee	Fairway	Rough	Total
	number			acres					
AL	2,943	54	54	389	619	151	8,435	10,741	20,335
AK	90	9	0	13	20	5	270	341	649
AZ	3,006	621	117	466	726	185	9,836	12,367	23,580
AR	1,962	27	27	257	410	100	5,591	7,121	13,479
CA	10,710	1,341	891	1,602	2,528	639	34,104	43,178	82,051
CO	2,475	126	135	344	546	135	7,401	9,412	17,838
CT	2,412	63	81	324	516	126	7,011	8,926	16,903
DE	432	18	18	59	94	23	1,275	1,621	3,072
DC	126	27	0	19	30	8	406	510	973
FL	13,851	2,016	747	2,068	3,249	821	43,994	55,567	105,699
GA	4,626	63	90	609	971	236	13,224	16,846	31,886
HI	1,026	27	36	138	220	54	2,985	3,801	7,198
ID	1,035	36	45	141	225	55	3,043	3,873	7,337
IL	8,019	387	288	1,098	1,745	430	23,690	30,114	57,077
IN	5,148	189	360	714	1,137	281	15,380	19,590	37,102
IA	3,843	117	99	515	820	201	11,154	14,193	26,883
KS	2,736	81	45	364	581	141	7,894	10,043	19,023
KY	2,826	99	135	386	615	151	8,330	10,604	20,086
LA	2,043	9	18	265	423	102	5,742	8,634	15,166
ME	1,332	36	81	182	292	72	3,934	5,013	9,493
MD	2,169	90	54	293	467	114	6,339	8,059	15,272
MA	4,293	126	342	595	949	235	12,832	16,359	30,970
MI	10,098	522	396	1,390	2,207	544	29,955	38,072	72,168
MN	4,212	450	351	622	983	248	13,260	16,810	31,923
MS	1,881	0	54	246	393	96	5,355	6,832	12,922
MO	3,456	63	117	461	736	180	9,993	12,732	24,102
MT	864	0	45	115	183	45	2,493	3,183	6,019
NE	1,710	144	117	246	390	97	5,265	6,682	12,680
NV	801	45	9	109	173	42	2,346	2,978	5,648
NH	1,089	45	126	156	250	62	3,345	4,266	8,079
NJ	3,834	162	171	525	835	206	11,336	14,421	27,323
NM	1,053	27	36	141	225	55	3,061	3,897	7,379
NY	10,170	576	468	1,411	2,241	554	30,382	38,610	73,198
NC	7,326	144	189	974	1,552	379	21,106	26,881	50,892
ND	981	45	27	133	213	52	2,880	3,661	6,939
OH	9,702	567	405	1,345	2,135	528	28,950	36,780	69,738
OK	2,268	27	27	297	474	115	6,448	8,213	15,547
OR	1,764	234	99	261	410	104	5,564	7,035	13,374
PA	8,910	315	477	1,221	1,945	479	26,354	33,553	63,552
RI	675	0	27	89	143	35	1,934	2,469	4,670
SC	4,833	63	171	643	1,025	250	13,937	17,765	33,620
SD	1,089	36	18	146	232	57	3,150	4,006	7,591
TN	3,312	36	54	434	692	168	9,433	12,018	22,745
TX	10,350	162	297	1,374	2,192	534	29,786	37,951	71,837
UT	1,152	54	81	161	257	64	3,465	4,411	8,358
VT	765	27	18	103	163	40	2,225	2,830	5,361
VA	3,807	72	99	506	806	197	10,964	13,964	26,437
WA	2,871	198	234	411	652	163	8,815	11,205	21,246
WV	1,341	45	99	186	297	73	4,006	5,105	9,667
WI	5,121	252	288	711	1,129	280	15,310	19,473	36,903
WY	630	9	0	82	131	32	1,782	2,268	4,295
Total	183,168	9,882	8,163	25,340	40,247	9,944	545,770	694,984	1,316,285

<sup>a</sup> Estimates of acreage based on the median dimensions of turfgrass areas on golf courses (Table 4) and the distribution of the types of golf course holes by state (Table 3).

<sup>b</sup> The distribution of golf course holes (Table 3) is available from estimates of the number of regulation (Reg.), executive (Exec.), and Par-3 holes (National Golf Foundation 1991)

**Table 6. Annual expenditures: Core vs. Occasional Golfers.**

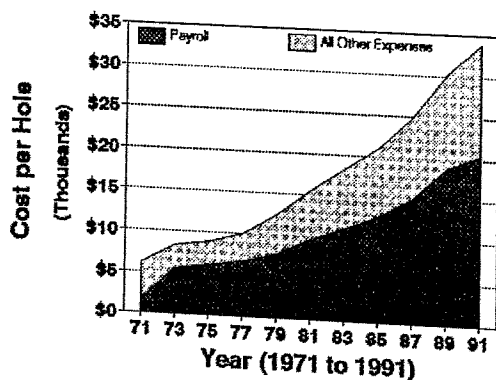
Item	Average Expenditure*	
	Core	Occasional
Clubs		
Woods	\$141.10	\$101.05
Irons	225.22	124.77
Putters	46.20	41.34
Other Equipment		
Bags	68.77	60.46
Balls	67.25	36.62
Gloves	30.84	12.09
Pull Carts	46.00	42.55
Shoes	60.83	50.27
Umbrellas	23.60	17.07
Fees		
Green Fees/Public Courses	243.17	97.52
Guest Fees/Private Courses	130.17	54.16
Cart Rental	206.69	57.06
Pull Cart Rental	22.42	8.53
Caddy Fees	228.45	27.54
Initiation Fees	908.26	51.78
Annual Dues	797.59	304.20
Totals	\$3,246.56	\$1,087.01

\*National Golf Association Report (1992) of expenditures made by core and occasional golfers in 1989.

maintenance budgets.

In 1992, average payroll climbed to \$15,888 per hole while payroll taxes and benefits increased to \$3,610 per hole. Rising personnel costs, which totaled 63 cents of every maintenance dollar, pushed the nationwide maintenance cost per golf hole to \$30,870. This increase continues a 20-year trend during which maintenance costs have risen 500 percent.

An estimate of the economic impact of golf



**Figure 1. Increase in golf course maintenance costs from 1971 to 1991.**

course maintenance for the United States is \$6.2 billion. This figure is the total number of regulation, executive, and par-3 golf holes (201,213) and the average maintenance cost per hole (\$30,870). Even though this figure approximates the amount spent on golf course maintenance, it closely corresponds with the estimated \$6.6 billion spent annually by core and occasional golfers on green and guest fees. A 1982 estimate of turfgrass maintenance costs on golf courses, prepared by the University of California, suggested an annual expense of \$1.5 billion as compared to a 1985 NGF/GCSAA estimate of \$1.7 billion.

**Table 7. Golf course maintenance costs by region.**

Item	East	South	Mid-west	West	Average
Payroll	14,959	15,291	12,303	18,781	15,888
Taxes Benefits	3,123	2,919	2,544	5,396	3,610
Supplies	5,761	6,097	5,423	6,043	5,904
Repairs	2,351	2,872	1,742	3,303	2,695
Other	1,797	3,142	1,518	4,422	2,733
Total	27,991	30,321	23,529	37,945	30,870

Source: Pannell Kerr Forster (1992)

## Golf and the Environment

The establishment and culture of turfgrasses used on golf courses has become a well accepted practice in the United States. In addition to the enjoyment golf courses provide, they also serve as important soil and water conservation features in both urban and rural areas. The maintenance of quality turfgrass at the levels currently demanded by the public, however, requires intensive management of water, nutrients, and pests. As a result, potential environmental effects of these practices have become a public concern.

The major environmental concern from the 1930's through the 1950's involved soil and water conservation on agricultural land. The use of forage grasses and maintenance of turfgrass was one of the major soil and water conservation practices developed by the United States Department of Agriculture Soil Conservation Service to reduce soil erosion. In many urban areas, golf courses and other large turfgrass areas were incorporated into storm water management plans to stabilize the soil in areas prone to flooding.

By the 1960's, the primary environmental issue



focused on the pollution of water resources due to contamination by soil, nutrients, and chlorinated organic pesticides. Agricultural, forestry and urban areas were identified as potential sources of chemical and sediment losses. Eutrophication of surface water, sedimentation of streams and lakes, introduction of persistent pesticides in the global food chain, and identification of high levels of nitrates in drinking water became important environmental issues.

In the 1970's, the focus of environmental research shifted from the identification of pollution problems to the development of management practices to mitigate nonpoint pollution from agricultural and urban areas. In addition to concerns about water quality, the increased use of water resources by agriculture, industry, and municipalities has led to shortages in many areas. In arid regions of the United States and in regions with periodic drought conditions, allocation of water for turfgrass irrigation has been a controversial policy issue.

Although consumption of water for turfgrass is relatively small compared to agricultural and industrial use, irrigation of golf facilities is highly visible and has been considered a luxury use by certain sectors of the public. The development of cultural practices to conserve water used in the management of golf courses, even in humid regions, became a critical research need during this period and was not being adequately addressed.

### **The USGA Decides to Become More Involved in Turfgrass Research**

The original concept of the need for a national turfgrass research program to address the escalating maintenance costs and water use of golf courses was developed by A. M. Radko of the USGA Green Section and Dr. James B. Beard of Texas A&M University. The primary purpose of the program was to develop minimal maintenance turfgrasses to meet the future needs of golf. Emphasis was placed on the development of water conserving, salt-tolerant, cold and heat-tolerant, disease and insect resistant grasses having low nutritional requirements.

Never before had such an intensive and extensive turfgrass research program been undertaken. In January 1982, William Bengeyfield, national director of the Green Section, chaired the newly formed Turfgrass Research Committee to help guide the USGA's multi-million dollar

turfgrass research program for a span of ten years or more (Table 8). "We believe this will develop into one of our most important undertakings," said Harry W. Easterly, Jr., who, in 1982, was the Senior Executive Director of the USGA. "In time, the research program developed by this Committee could lead to major breakthroughs in all phases of turfgrass maintenance ..." The Committee's entire purpose was to establish a sound program, closely follow its progress, and achieve the proposed objectives.

The Committee has successfully brought a greater sense of direction, cost effectiveness, and concentration to vital areas of turfgrass research

**Table 8. Research Committee Members**

Raymond Anderson 1990 - 1992	Howard Kaerwer 1987 - 1992
George M. Bard 1983 - 1989	Dr. Michael P. Kenna 1988 - 1992
William H. Bengeyfield 1983 - 1989	Dean Knuth 1990 - 1992
Dr. Bruce Branham 1991	Ann Leslie 1990 - 1992
Thomas Burton 1987 - 1992	Dr. Charles F. Mancino 1986 - 1987
Dr. Nick Christians 1989 - 1990	James B. Moncrief 1983 - 1986
Dr. Karl Danneberger 1985	Charles Passios 1991 - 1992
Ron Dodson 1990 - 1992	Dr. Charles Peacock 1992
Marion B. Farmer 1986	James G. Prusa 1983 - 1986
Gerald Faubel 1985 - 1989	Dr. Paul E. Rieke 1983- 1992
David B. Fay 1988 - 1992	William R. Roberts 1989 - 1990
Dr. Marvin H. Ferguson 1983-1984	Charles W. Smith 1983 - 1989
Dr. Victor Gibeault 1985 - 1992	James T. Snow 1990 - 1992
Frank Hannigan 1985 - 1987	F. Morgan Taylor 1987 - 1989
Dr. Peter Hayes 1988 - 1992	Jaime Ortiz-Patino 1991 -1992
Rees Jones 1990 - 1992	Dr. James R. Watson 1983 - 1992

for golf. The Committee successfully established specific agreements, reduced indirect costs to 16 percent, monitored expenditures, set expectations, ensured proper progress and was accountable to those providing funds.

In the spring of 1982, turfgrass researchers throughout the nation were invited to express their views and interests in research needs. Gradually, a long range plan evolved from the Committee's work, objectives were established and guidelines were carefully drawn. The Committee also initiated plans for developing a computerized reference source for published turfgrass literature, and for improving germplasm for future turfgrass breeding projects. The computerized reference source has become the Turfgrass Information File, or TGIF, located at Michigan State University. The effort to support germplasm development led to successful expeditions to Asia, South Africa, and the United Kingdom, and to cooperative research in New Zealand.

### **Fund Raising**

The USGA Fund-Raising Campaign, inaugurated in 1983 to raise funds for research, moved into full swing through the efforts of B. P. "Bobby" Russell, Chairman of the USGA Capital Campaign, and Donald L. Spencer, USGA Foundation and Membership. After reading the article, "The Search for Better Grasses" by the late Dr. Victor B. Youngner, Bobby Russell wrote a letter to Harry Easterly and suggested a simple plan that could raise significant funding for turfgrass research. The idea was to have all golfers at USGA Member Clubs contribute \$1 a year for each year of the ten-year USGA Turfgrass Research Program. Baltusrol Golf Club, where Bobby Russell is a member, passed a resolution endorsing the concept and committed \$1,000 per year for the Turfgrass Research Program.

Golf course superintendents, green committee chairman and the boards of directors for clubs across the United States were asked to solicit their clubs to contribute to the USGA Turfgrass Research program following the example of Bobby Russell and Baltusrol Golf Club. A special plea was directed toward golf course superintendents to help "get the ball rolling."

The Golf Course Superintendents Association of America, through Research Committee member Jim Prusa, then Assistant Executive Director of GCSAA, helped the fund raising effort and initiated a spirit of cooperation between the USGA

and GCSAA to accelerate the turfgrass research efforts. The cooperative effort was based on the premise that for any business, including the maintenance of golf courses, to be successful, individuals and organizations must believe in something larger than themselves. A common bond grew between the GCSAA and USGA Green Section and it was agreed to work together to support a national turfgrass program.

Over the last ten years, the "Honor Roll" of donors to the USGA Capital Campaign has listed many contributions made through the direct efforts of the club's golf course superintendent. The response of USGA Member Club officials, the GCSAA and, most important, individual golfers and golf course superintendents, demonstrated the widespread support of a national turfgrass research program to provide minimal maintenance turfgrasses. Because of the support from these organizations and individuals, the USGA/GCSAA Turfgrass Research Program has been successful.

**Table 9. The Honor Roll - List of Donors to the USGA/GCSAA Turfgrass Research Program**

**Memorial Turfgrass Donors**

Robert L. Baker, In Memory of O. Sproule Baker & Family  
The Ohio Valley Senior Golf Assn., In Memory of J. Earle Nelson  
Alexander M. Radko, In Memory of Dr. Marvin H. Ferguson  
Charles Rainwater, Jr., Brown Rainwater, and Crawford Rainwater, For the Charles V. Rainwater Memorial Endowment  
Russell Scarpelli, In Memory of James W. Kirwan  
The Toro Company, In Memory of Dr. Marvin H. Ferguson  
Dr. James R. Watson, In Memory of Dr. Marvin H. Ferguson

**Foundation Turfgrass Donors**

American Express Foundation  
Frank E. & Seba B. Payne Foundation, Chicago, IL  
The William Penn Foundation

**Corporation Turfgrass Donors**

Arthur Hills & Associates  
Asahi Broadcasting Corp., Japan  
Bentgrass Research, Inc., TX  
Boulders Carefree Partners, AZ  
City of Tucson Parks & Recreation Department, AZ  
Draft Company  
Ford Motor Company  
Garden Services, Inc., GA  
General Cinema Theaters  
Hilton Head Company, Inc., SC  
Ico, Inc., TX  
John Knorr Associates, PA  
Lofts Seed, Inc., NJ  
Mobil Oil Corp., NY  
Piney Coking Coal Land Company  
Princeville Development Corp., HI  
Royal Lawns of Monmouth, NJ  
Satsuma Landscape & Maintenance  
Sentry Services, Inc.  
Toro Company, MN  
Xerox Corp., CT

**Association Turfgrass Donors**

Alabama Golf Assn., AL  
Alabama Seniors Golf Assn.  
California Golf Writers Assn.  
Connecticut State Golf Assn., CT  
Club Managers Assn., SC  
Golf Course Supt. of America  
GCSA of Oregon  
GCSA of New Jersey, NJ  
GCSA of South Dakota  
Hoosier Turfgrass Assn., IN  
Houston Golf Assn.  
Indian Hills Senior Men's Golf Assn.  
Maine State Golf Assn., ME  
Minnesota Golf Course Supt. Assn.  
National Golf Fund, Inc., FL  
Southern Golf Assn., AL  
Western NY GCSA, NY  
West Virginia Golf Supt.  
Wy-Mont Golf Course Supt. Assn., MT

**Clubs in Which Individuals Have Made Donations**

Abenauqi Country Club, NH  
Alpine Country Club, NJ

Golf Club of Avon, CT  
Birmam Wood Golf Club, CA  
Black Hall Club, CT  
Blind Brook Club, NY  
Brae Burn Country Club, MA  
Brentwood Country Club, CA  
Canoe Brook Country Club, NJ  
Carmel Valley Golf and Country Club, CA  
Cohasset Golf Club, MA  
Concord Country Club, MA  
Creek Club, The, NY  
Dallas Athletic Club, TX  
Dallas Country Club, TX  
Deal Golf & Country Club, NJ  
Diablo Country Club, CA  
Echo Lake Country Club, NJ  
Essex Country Club, MA  
Fairmount Country Club, NJ  
Fairview Country Club, CT  
Country Club of Farmington, The, CT  
Gaston Country Club, NC  
Glen Ridge Country Club, NJ  
Grandfather Golf & Country Club, NC  
Greenwich Country Club, CT  
Hartford Golf Club, CT  
Huntingdon Valley Country Club, PA  
Inglewood Country Club, WA  
Kent Country Club, MI  
Kittansett Club, The, MA  
Knollwood Club, IL  
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Los Angeles Country Club, The, CA  
Manasquan River Golf Club, NJ  
Manufacturers Golf & Country Club, PA  
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Navesink Country Club, NJ  
New Orleans Country Club, LA  
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Oak Park Country Club, IL  
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Pine Valley Golf Club, NJ  
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Prairie Dunes Country Club, KS  
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Riverton Country Club, NJ  
Salem Country Club, MA  
Silverado Country Club, CA  
Spokane Country Club, WA  
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Woodhill Country Club, MN  
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Bloomington Country Club, IL  
Bob O'Link Golf Club, IL  
Bodega Harbour Golf Club, CA  
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Brandermill Men's Golf Assn., VA  
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Brook Hollow Golf Club, TX  
Brookhaven Country Club, TX  
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California Golf Club of San Francisco, CA  
Calumet Country Club, IL  
Candlewood Country Club, CA  
Canterbury Golf Club, OH  
Canton Public Golf Course, CT  
Cary Country Club, IL  
Castle Pines Golf Club, CO  
Cedar Ridge Country Club, OK  
Centerton Golf Club, NJ  
Chagrin Valley Country Club, OH  
Champaign Country Club, IL  
Champions Golf Club, TX  
Charlotte Country Club, NC  
Chartiers Country Club, PA  
Cherokee Town & Country Club, GA  
Cherry Hills Country Club, MO  
Cherry Hills Country Club, CO  
Cheyenne Country Club, WY  
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Chikaming Country Club, MI  
Churchill Valley Country Club, PA  
Claremont Country Club, CA  
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Columbia Country Club, MD  
Columbus Country Club, OH  
Concordia Golf Club  
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Cordova Junior Golf, CA  
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The Country Club, UT  
Cove Cay Country Club, FL  
Cress Creek Country Club, IL  
Crestmont Country Club, NJ  
Crestwicke Country Club, IL  
Crystal Lake Country Club, IL  
Crystal Downs Country Club, MI  
Cypress Point Club, CA  
Del-Paso Country Club, CA  
Desert Forest Golf Club, AZ  
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Hercules Country Club, DE  
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Hinadale Golf Club, IL  
Hole-In-The-Wall Golf Club, FL  
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Hollywood Golf Club, NJ  
Honors Course, Inc., The, TN  
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Illini Country Club, IL  
Imperial Golf Club  
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Indian Hills Country Club, GA  
Indian Hills Men's Golf Assn., GA  
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Industry Hills Rec. & Conf. Center, CA  
Innis Arden Golf Club, CT  
Jackson, Country Club of, MI  
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Kissing Camels Golf Club, CO  
Kitsap Golf & Country Club, WA  
Knickerbocker Country Club, NJ  
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- La Jolla Country Club, CA  
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 Petersburg, Country Club of, VA  
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 Phoenix Country Club, CA  
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 Pine Tree Golf Club, FL  
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 Riverhill Country Club, TX  
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 Rochester, Country Club of, NY  
 Rochester Golf & Country Club, MN  
 Rock Spring Club, NJ  
 Royal Poinciana Golf Club, FL  
 Ruth Lake Country Club, IL  
 Rutland Country Club, VT  
 Sahalee Country Club, WA  
 Saint Charles's Golf Course, MO  
 Saint David's Golf Club, PA  
 Salinas Golf & Country Club, CA  
 Salisbury Country Club, VA  
 San Francisco Golf Club, CA  
 San Gabriel Country Club, CA  
 San Joaquin Country Club, CA  
 San Jose Country Club, CA  
 San Mateo Men's Golf Club, CA  
 San Vicente Inn & Golf Club, CA  
 Santa Ana Country Club, CA  
 Santa Maria Country Club, CA  
 Santa Rosa Golf & Country Club, CA  
 Saucon Valley Country Club, PA  
 Scarsdale Golf Club, NY  
 Scioto Country Club, OH  
 Sea Island Golf Club, GA  
 Seacrest Country Club, CA  
 Seattle Golf Club, WA  
 Sedgefield Country Club, NC  
 Seminole Golf Club, FL  
 Sequoia Country Club, CA  
 Shannopin Country Club, PA  
 Sharon Heights Golf & CC, CA  
 Shawnee Golf & Country Club, OK  
 Shoal Creek Country Club, AL  
 Shorehaven Golf Club, The  
 Silver Spring Country Club, CT  
 Singletree Golf Club, CO  
 Skokie Country Club, IL  
 Sleepy Hollow Country Club, NY  
 Snee Farm Country Club, SC  
 Somerset Country Club, MN  
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 South Hills Country Club, PA  
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 Southview Country Club, MN  
 Spartanburg Country Club  
 Spring Valley Country Club, SC  
 Springs Club, Inc., CA  
 Spyglass Hill Golf Club, CA  
 St. Clair Country Club, IL  
 St. Clair Country Club, PA  
 St. Cloud Country Club, MN  
 Starmount Forest Country Club, NC  
 Stockdale Country Club, CA  
 Stonehenge Golf & Country Club, VA  
 Stono River Golf Club, SC  
 Stonycroft Hills Club, MI  
 Suburban Golf Club, NJ  
 Summit Hills Country Club, Inc., KY  
 Sundale Country Club, CA  
 Sunningdale Country Club, NY  
 Sunnyside Country Club, PA  
 Sunnyside Country Club, CA  
 Sunrise Country Club, CA  
 Sylva Country Club  
 Tacoma Country & Golf Club, WA  
 Tanglewood Golf Club  
 Tatnuck Country Club, MA  
 Thunderbird Country Club, CA  
 Town & Country Club of St. Paul, MN  
 Towson Golf & Country Club, MD  
 Trails Golf Club, The, OK  
 Trenton Country Club, NJ  
 Tumble Brook Country Club, CT  
 Tuscarora Golf Club, Inc., NY  
 Twin Lakes Golf & Country Club, WA  
 Useless Bay Golf & Country Club, WA  
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 Virginia Country Club, CA  
 Vista Valley Country Club, CA  
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 Wakonda Club, IA  
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 Waverley Country Club, OR  
 Waynesborough Country Club, PA  
 Wayzata Country Club, MN  
 Westmoreland Country Club, PA  
 Weston Golf Club, MA  
 Westview Country Club, IL  
 Westwood Country Club, OH  
 Wheatley Hills Golf Club, NY  
 Wianno Club, Inc., MA  
 Wigwam Country Club, AZ  
 Wild Dunes Golf Club, SC  
 Wilderness Country Club, FL  
 Wildwood Golf & Country Club, NJ  
 Williamette Valley Country Club, OR  
 Willow Oaks Country Club, VA  
 Winchester Country Club, MA  
 Winged Foot Golf Club, Inc., NY  
 Wolferts Roost Country Club, NY  
 Woodbridge Country Club, CT  
 Woodcrest Club  
 Woodland Country Club, IN  
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### III. The Turfgrass Research Program 1983 - 1992

The concept of supporting turfgrass research was not new, since the USGA has been involved in turfgrass research since 1921. The USGA, in cooperation with the GCSAA, decided to support a greatly expanded turfgrass research effort to solve important several problems facing golf courses. The primary purpose of the Turfgrass Research Program was to develop minimal maintenance turfgrasses to meet the future needs of golf through a fifty percent reduction in water use and maintenance costs. Other goals included developing the Turfgrass Information File and encouraging young scientists to become leaders in turfgrass research.

In January 1982, William Bengeyfield, then national director of the Green Section, led the newly formed USGA/GCSAA Turfgrass Research Committee to help direct a plan of action for the next ten years. The plan directed funds toward the development of the Turfgrass Information File, a better understanding of plant stress mechanisms, evaluating cultural practices which improved the ability of golf course turf to tolerate stress, and accelerating plant breeding efforts to develop turfgrasses with better resistance to climatic stress and pest problems. Following is a summary of the specific USGA/GCSAA research objectives for these four areas of interest and the results from the research projects funded during the last ten years.

#### **Turfgrass Information File**

The purpose of this project was to provide efficient and effective access to all published and processed materials reporting the results of research affecting turfgrasses and their management. Access to this information would be provided to the research community, golf course superintendents, cooperative extension services, and commercial concerns.

A sizable and rapidly growing body of literature directly related to turfgrass science and culture was widely dispersed, not only in this country, but throughout the world. This created a major problem for researchers, extension specialists and professional turfgrass managers seeking past research data, conclusions and information. In all too many instances, experiments were repeated simply because there was no available single source or record of earlier work.

In 1982, authoritative estimates indicated that approximately 28,000 references existed in this

#### **Statement of Intent**

*It is the intent of the United States Golf Association (USGA), in cooperation with Golf Course Superintendents Association of American (GCSAA), through the USGA Foundation, to collect and disseminate substantial funding for the support of research to improve turfgrasses which reduce water use and maintenance costs, and further, to encourage young scientists to become leaders in turfgrass research.*

*It is anticipated that funds for this purpose will be derived in major part from contributions to the USGA Foundation. Additional funds may be derived in the future from royalties attributed to marketable discoveries. The USGA presently intends to return any income received from royalties to the support of turfgrass research. Institutions which accept these research grants will be asked to engage in a free exchange of information with other investigators.*

*Historically, the sport of golf has maintained a leadership role in the development of improved turfgrasses through the activities of the USGA Green Section. While those developments have helped to provide better playing areas for golf, they have had a far-reaching impact on turfgrass improvement for other uses. Home lawns, parks, school grounds, highway rights of way and all other turfgrass uses have been improved by developments which were pioneered by the USGA.*

*The USGA expects to support research at numerous institutions. In some cases, several will be involved with the development of grasses and maintenance practices where the research may interact and overlap.*

*In view of this Statement of Intent, it is expected that recipients of grants will embrace the spirit of cooperation which the USGA and GCSAA is attempting to promote and that they will engage in a free exchange of information with other investigators.*

field. Approximately 30 percent of them were in scientific and technical journals or reports. However, the remainder were in semi-scientific or popular publications. In his *Turfgrass Bibliography From 1672 to 1972*, Dr. James B. Beard cited over 16,000 entries. No other known turfgrass index or bibliographic source existed when the USGA/GCSAA Research Program began in 1983.

The Michigan State University (MSU) Library was assigned the task to design and develop the

bibliographic computer data base to provide access to all published turfgrass information. The principal reason for locating TGIF at MSU Library was the existence of the O.J. Noer Memorial Turfgrass collection, including books, journals, research reports, and conference proceedings. Through the cooperative efforts of the USGA, GCSAA, Noer Foundation, and MSU Library, the Turfgrass Information Center (TIC) was created to 1) develop and maintain the collection of literature on turfgrass science and culture, 2) provide access to the bibliographic data of this collection, and 3) deliver documents or copies from the collection to researchers, practitioners, and other appropriate users.

Over 25,000 published materials have been abstracted, recorded, and logged into the data base. Anyone interested in a subject search can either call the center, mail a request, or log on by computer.

If mailing a request, it is important to be specific about the subject. All that is needed is a paragraph or two describing the desired information, and a list of terms, including synonyms, relevant to the request. The ease-of-use for on-line computer searches of the database has been greatly improved since the database went on-line in 1988. Those interested in searching the data base via computer should contact TIC to receive the necessary technical details and registration forms.

Requests, questions or comments concerning TGIF should be addressed to:

Turfgrass Information Center  
W-212 Library  
Michigan State University  
East Lansing, MI 48824-1048  
Phone requests:  
(517) 353-7209 (800) 446-TGIF

### **Plant Stress Mechanisms**

The purpose of these studies was to identify and quantify basic stress mechanisms for utilization in

long-range breeding programs. This important step would help lead to the efficient development of minimal maintenance and water conserving golf course turfgrasses. Documenting this information established an essential foundation for future turfgrass breeding and improvement work.

The response mechanisms for stress caused by drought, heat, cold, poor water quality and salinity were investigated. Many of the stress response mechanisms were already known; however, the mechanisms were neither summarized well in the turfgrass literature nor fully investigated through well documented scientific research. To develop efficient screening methods for turf breeding programs, better and more complete information about all of these stress problems was considered essential in the development of new stress tolerant turfgrasses.

This research work was done independently by turf physiologists, or as a cooperative effort between turf breeders and physiologists. With this knowledge, breeders have been able to develop rapid screening techniques, identify desirable germplasm, and make appropriate crosses to produce stress tolerant grasses.

*Texas A&M University - Dr. James Beard*

### *Water Use and Drought Resistance*

The morphological, anatomical, and physiological characteristics of turfgrasses interact and provide the mechanisms which regulate water use and resistance to prolonged periods of drought. Determining which of these mechanisms are the most important for every major turfgrass species was a monumental task. Dr. Beard initiated a research program to compile and delineate the comparative water use rates among the 19 major turfgrass species used throughout the United States, and determine the drought resistance mechanisms which enable some cultivars within a species to perform better than others (Table 10).

Water use rate is the total amount of water required for turfgrass growth plus the quantity transpired from the grass plant and evaporated from associated soil surfaces. It is typically measured as evapotranspiration (ET), and expressed as ET in millimeters per day.

The comparative water use rates of turfgrass species are distinctly different from their relative drought resistances. For example, tall fescue is one of the more drought resistant cool-season turfgrasses, but it has a very high water use rate. If the goal is to reduce water use rates of irrigated

**Table 10. Summary of Mean Rates of Turfgrass Evapotranspiration.**

Turfgrass species <sup>a,b</sup>		Mean Summer ET rate, mm d <sup>-1</sup>	Rel. rank <sup>c</sup>
Cool Season	Warm Season		
	Buffalograss	5-7	Very low
	Bermuda hybrids <sup>d</sup>	6-7	Low
	Centipedegrass	6-9	
	Bermudagrass <sup>d</sup>	6-9	
	Zoysiagrass <sup>d</sup>	5-8	
Hard fescue		7-8.5	Med.
Chewings fescue		7-8.5	
Red fescue		7-8.5	
	Bahiagrass	6-8.5	
	Seashore paspalum	6-8.5	
	St. Augustine	6-9	
Perennial rye		6.6-11	High
	Carpetgrass	8.8-10	
	Kikuyugrass	8.5-10	
Tall fescue		7.2-13	
Creeping bent		5-10	
Annual		>10	
bluegrass		4->10	
Kentucky bluegrass		>10	
Italian rye			

<sup>a</sup>Mean rate of water use averaged over 28 years of previous research and values determined by Beard (1989) and co-workers.

<sup>b</sup>Based on the most widely used cultivars of each species.

<sup>c</sup>Based on ranking by Beard (1989).

<sup>d</sup>Variable among cultivars within species.

turfgrasses, then those species that require the lowest possible supplemental irrigation would be the best selections.

The documented differences among species reported was substantial for ET comparisons under non-limiting soil moisture conditions (Table 10). Warm-season species, as a group, had lower ET rates than cool-season species. The range of ET rates for the warm-season turfgrasses was 5 to 9 mm per day as compared to 5 to 13 mm per day for cool-season species. The high-density, low growing turfgrasses, such as buffalograss, hybrid bermudagrass, and centipedegrass exhibited the lowest water use rates. For cool-season species, the fine-leaved fescues ranked medium, while Kentucky bluegrass, annual bluegrass, and creeping bentgrass exhibited high water use rates.

Drought resistance is a term that encompasses a range of mechanisms which allow plants to withstand periods of drought. The two major categories of drought resistance are avoidance and

**Table 11. Turfgrass Morphological, Anatomical and Physical Characteristics Contributing to Drought Resistance.**

Term	Definition
Drought Resistance	Various mechanisms exist that a turfgrass plant may have to withstand periods of drought. Two major types are drought resistance and avoidance.
1. Drought Avoidance	Ability of a plant to avoid tissue damage in a drought period by postponement of dehydration. The plant is able to maintain adequate tissue water content and thus avoid or postpone the stress. <ul style="list-style-type: none"> <li>• Deep, extensive root system</li> <li>• High root length density</li> <li>• High root hair density</li> <li>• Good root viability</li> <li>• Rolling, folding leaves</li> <li>• Thick cuticle on the leaves</li> <li>• Hairy leaf surfaces</li> <li>• Reduced leaf area through smaller leaves</li> <li>• Reduced leaf area through death of lower leaves or tillers</li> <li>• Slow leaf extension rates after mowing</li> <li>• Leaf densities and orientations contributing to high canopy resistances</li> <li>• Stomatal closure</li> <li>• Stomatal density</li> <li>• Stomata that are located so as to reduce transpiration</li> <li>• Smaller conducting tissue</li> <li>• Smaller mesophyll cells in leaves</li> <li>• Possible proline or betaine accumulation</li> </ul>
2. Drought Tolerance	Ability of a turfgrass to tolerate a drought period. Two potential mechanisms are by escape and hardiness.
a) Escape	The plant has a life cycle such that it lives through the drought in a dormant state or as seed.
b) Hardiness	The plant develops a greater hardiness to low tissue water deficits. This process normally involves a greater drought tolerance of protoplasm and protoplasmic membranes from alterations in their properties, and binding of water to protoplasmic constituents. Osmotic adjustments to maintain adequate tissue water content may also be involved during long term or short duration moisture stress periods.

tolerance (Table 11). The drought resistances of 11 warm-season turfgrass species was compared for a drought stress period of 48 days without irrigation. After this period, irrigation was reinstated and the ability of plants to recover after



**Table 12. Relative Resistance of Turfgrass Grown in Region of Climatic Adaption and Preferred Cultural Regime.**

Turfgrass species <sup>a,b</sup>		Relative ranking
Cool Season	Warm Season	
	Bermuda <sup>b</sup>	Superior
	Bermuda hybrids <sup>b</sup>	
	Buffalograss	Excellent
	Seashore paspalum <sup>b</sup>	
	Zoysiagrass	
	Bahiagrass	
Fairway wheatgrass	St. Augustine <sup>b</sup>	Good
	Centipedegrass	
	Carpetgrass	
Tall fescue		Moderate
Perennial ryegrass <sup>b</sup>		Fair
Kentucky bluegrass <sup>b</sup>		
Creeping bentgrass <sup>b</sup>		
Hard fescue		
Chewings fescue		
Red fescue		
Colonial bentgrass		Poor
Annual bluegrass		
Rough bluegrass		Very poor

From Beard 1989

<sup>a</sup>Based on the most used cultivars of each species.

<sup>b</sup>Variable among cultivars within species.

the stress was evaluated (Table 12). Significant differences in leaf firing and shoot recovery were observed during and after the period of induced drought. In general, those species that turned yellow or brown earlier tend to have poorer post-drought stress shoot recovery or, in other words, poor drought resistance.

Additional stress mechanism studies on these warm-season species revealed that specific types of plant morphology affect the resistance to evapotranspiration and the surface area from which it occurs. The major factors discovered were low leaf area and high canopy resistance (Table 13). These characteristics, in addition to leaf-firing and shoot recovery, provide important clues and can be used as guidelines when selecting cultivars

**Table 13. Types of plant morphology which affect the resistance to evapotranspiration.**

High Canopy Resistance to ET	Low Leaf Blade Area for ET
High shoot density	Slow vertical leaf extension rate
High leaf number	
More horizontal leaf orientation	Narrow leaf

possessing low water use rates and drought resistance. Furthermore, turfgrass breeders can use these same characteristics to make field selections that will most likely produce grasses which use less water and survive extended periods of drought.

### Cultural Practices

A series of research projects with the aim of substantial reduction in water use and maintenance costs were funded to study turf management problems on a local and regional basis. This was necessary because of unique climatic, soil and stress conditions. The objectives of these studies focused on the following:

- Range of adaptation and stress tolerance of new grasses resulting from the breeding projects
- Evaluation of direct and interacting effects of two or more cultural practices
- Management of native and low maintenance grasses
- Development of cultural programs which substantially reduce weedy species in golf turf
- Development of cultural practices which allow efficient turf management under conditions of poor quality soils or severe air pollution, or which permit the use of effluent or other marginal quality waters
- New research techniques that reduce pesticide and other chemical usage

These projects were conducted by qualified turfgrass researchers at locations representing a range of environmental conditions.

The results of these studies have led to the development of maintenance programs that conserve substantial quantities of water, reduce fertilizer needs and decrease mowing frequency; all without impairment of functional quality or aesthetic appeal.

## Cultivar Evaluation

Several turfgrass researchers received funding to cooperate with USGA/GCSAA supported breeding projects. The purpose of these studies was to evaluate the adaptation and performance of the experimental varieties as they became available from the various turf breeding programs. As one can imagine, results from these studies produced interesting surprises and some disappointments. The data collected from these turfgrass evaluation trials were used by many of the breeders in their selection decisions and release documentation.

## Management

*University of Nebraska - Dr. Robert C. Shearman*

### *Cultural Practice Interactions on Golf Course Turf*

Several research projects were initiated and completed which evaluated the direct and interacting effects of two or more cultural practices (i.e., watering, fertilizing, cultivating, and mowing). A greenhouse hydroponic technique for making relative nutritional comparisons and screening turfgrass selections was developed. Irrigation and potassium treatments were combined to determine the effects of Kentucky bluegrass fairway turf exposed to traffic.

In addition, fairway management studies determined the effects of irrigation frequency, clipping removal or return, nitrogen nutrition, and traffic on 'Pennncross' creeping bentgrass competition with annual bluegrass and fairway quality. Fairway playing conditions improved with reduced irrigation, clipping removal, reduced nitrogen, and lower traffic. Annual bluegrass encroachment increased with nitrogen rate.

The effects of vertical mowing frequency and mowing height on putting green speed, rooting, and stress resistance also were determined. Vertical mowing had no effect on ball roll, color, canopy reflectance, or root production. As expected, ball roll decreased 0.2 to 0.4 m (8 to 16 inches) when mowing heights were raised from 3.2 mm (0.125 or 1/8 inches) to 4.8 mm (0.189 or 3/16 inches). Canopy temperatures also decreased when mowing heights were raised. Color, quality, vegetation index, and root production all increased significantly when mowing heights were raised 1.6 mm (1/16 inches).

*Michigan State University - Dr. Bruce E. Branham*

### *The Effect of Seven Management Factors and Their Interaction on the Competitive Ability of Annual Bluegrass and Bentgrass*

Research was conducted for a three year period on the competition between annual bluegrass and creeping bentgrass under fairway conditions. Five management factors were investigated, including irrigation (100 percent of open pan evaporation three times per week, 75 percent of open pan evaporation applied daily, and irrigation at severe wilt); clippings removed or returned; nitrogen fertility (2 lbs. nitrogen per 1000 square feet annually or 6 lbs. nitrogen per 1000 square feet annually); plant growth regulator treatment (Embark at 1/8 lbs. product per acre, Cutless at 1.0 lbs. product per acre and a control); and overseeding with 'Pennncross' creeping bentgrass or no overseeding.

Results showed that only clipping treatments, plant growth regulators, and the initial annual bluegrass population had a significant effect over all three years. Nitrogen fertility was significant in only one of the three years. The plant growth regulator treatment was not significant in any one year, but was significant when data were analyzed over all three years.

Over the three years of the study, clipping-removed plots had 12 percent more creeping bentgrass than clipping-returned plots when averaged over all treatments. Clipping-removed plots were found to contain 60 percent less viable annual bluegrass seed than clipping-returned plots, possibly a reason for the increase in creeping bentgrass. Thus, returning clippings is a passive form of annual bluegrass overseeding.

A very interesting interaction between nitrogen fertility and plant growth regulator treatment occurred when the data was combined over three years. At low nitrogen fertility (2 lbs. nitrogen per 1000 square feet annually), there was no difference in annual bluegrass populations whether treated with Embark, Cutless, or no plant growth regulator. However, under high nitrogen fertility (6 lbs. nitrogen per 1000 square feet annually), plots treated with Embark had significantly more annual bluegrass than plots treated with Cutless or not treated. Thus, it appeared from this study that Embark actually favored annual bluegrass under high nitrogen conditions, while under no conditions was Cutless found to favor either annual bluegrass or creeping bentgrass when compared to plots receiving no plant growth regulator.

**Ohio State University - Dr. Karl Danneberger**

***Mechanisms for Heat Tolerance in Annual Bluegrass***

A number of factors govern heat tolerance in turfgrass plants. This research specifically evaluated what role heat shock proteins play in high temperature tolerance of annual bluegrass and other turfgrass species. Results demonstrated the difference observed at the whole plant level was also present at the cell level.

Heat shock proteins are produced during periods of high temperature stress. Normal protein synthesis shuts down at high temperatures, while heat shock proteins are beginning to synthesize. Their occurrence is ubiquitous in nature, but their role in heat tolerance is not fully known.

Initial screening of numerous annual bluegrass biotypes revealed a 12°C (54°F) difference between the most sensitive and the least sensitive biotypes. In addition, attempts were made to determine the location of the heat shock protein genes within the genomic DNA from turfgrasses.

**Pathology**

***Texas A&M University - Dr. Phillip F. Colbaugh***

***Developing Rhizoctonia Brown Patch and Pythium Disease Resistance in Bentgrass and Zoysiagrass***

The research efforts of this project focused on the development of screening techniques for resistance to brown patch and *Pythium* blight and root rot; assessment of *Pythium* blight and root rot resistance in the bentgrass germplasm and polycross populations; and the evaluation of the National Turfgrass Evaluation Program (NTEP) bentgrasses and zoysiagrasses for resistance to *Pythium* and *Rhizoctonia* blight.

The inheritance of foliar disease resistance appears to be a predictable and stable characteristic based on investigations using crosses of disease resistant bentgrass parental lines. Synthetic polycross populations were tested for resistance to *Pythium* blight. Disease resistant bentgrass progeny were identified after inoculating populations produced from reciprocal crosses of resistant and susceptible bentgrass parental lines. In two inoculation studies, genetic populations from four crossing blocks were more blight resistance than other populations studied.

In addition, a disease heritability analysis was conducted which utilized intercrossed resistant and susceptible parental lines and reciprocal cross

progeny plants obtained from a *Pythium* blight resistant population. The susceptibility of progeny from crosses involving at least one of the resistant parental lines gave an overall mean blight of 6.9 percent, while crosses without a resistant parent resulted in a 14.3 percent mean blight rating. This information will be very useful in determining the segregation of disease resistance in future disease screening research.

A root inoculation procedure was used to screen bentgrass germplasm lines for resistance to *Pythium* root rot. This method was used to screen over 1,550 plants. At present, 123 germplasm lines of bentgrass appear to have some resistance to *Pythium* root rot disease. The surviving population represents about 12% of the total plants screened.

Standard inoculation techniques were used to determine the susceptibility of the National Turfgrass Evaluation (NTEP) bentgrass and zoysiagrass entries to *Rhizoctonia* and *Pythium* blight diseases. In repeated *Rhizoctonia* foliar inoculations, the NTEP bentgrass entry Syn3-88 demonstrated the lowest mean percent blight among the 20 entries tested. Syn3-88, Providence, Penncross and UM8401 were statistically better than National, Forbes and Syn4-88. For the NTEP zoysiagrass trial, the experimental line DALZ 9006 and commercial cultivar Meyer demonstrated a low susceptibility to *Rhizoctonia* foliar blight following inoculation.

Inoculation studies with *Pythium* blight on NTEP bentgrasses demonstrated that Pennlinks, Penncross, National, MSCB-6, Syn3-88 and Cobra were among the most resistant genotypes. Similar inoculation studies with *Pythium* blight on 40 zoysiagrasses demonstrated that germplasm lines TAES3357, TAES3365, TAES3356, TAES3364, TAES3358, DALZ8508 and DALZ8517 were the most resistant among those tested. The relationship of *Rhizoctonia* blight susceptibility and Zoysiagrass leaf blade texture was investigated. In contrast to other grasses, the fine textured zoysiagrass were less susceptible to foliar blight.

***Cornell University - Dr. Richard W. Smiley***

***Resistance of Bentgrass to Leptosphaeria and Phialophora Diseases***

Seedlots of 42 bentgrasses from Pennsylvania State University were screened for resistance to two isolates from root-infecting fungi that cause summer patch and necrotic ring spot diseases. The resistance studies were conducted for an 8 week

period in controlled environment growth chambers. Percentages of plants which survived the test were determined and surviving bentgrass plants were returned to the plant breeder.

Methodology also was developed to conduct similar screening studies on vegetatively propagated bentgrasses. This research revealed the potential for further complexities to exist in the etiology of take-all patch of bentgrasses, which was thought at that time to be caused by *Gaeumannomyces graminis* var. *avenae*. In New York, it was demonstrated that *Phialophora graminicola* caused a hot weather form of take-all patch on bentgrasses, and this was confirmed during the development of disease screening methods for this project. These initial findings had relevance to the likelihood that certain disease management strategies would be ineffective during the summer months. Unfortunately, the project was terminated prematurely because the principal investigator moved to another university.

*North Carolina State University - Dr. Leon T. Lucas*

#### *Spring Dead Spot Disease*

The project on spring dead spot of bermudagrass was completed in the fall of 1987. Fungi were isolated from bermudagrass with spring dead spot symptoms throughout this study. Selected isolates of the fungi were used to inoculate bermudagrass in the greenhouse. The inoculated pots were exposed to outside winter conditions during January to May, and spring dead spot symptoms developed with two of the isolates used. The symptoms produced were typical of spring dead spot symptoms on golf course fairways. The fungus that caused the disease was identified as *Gaeumannomyces graminis*, and was the first report of this fungus being associated with spring dead spot of bermudagrass. The fungus was identified on the inoculated plants and from spring dead spot samples collected in May throughout North Carolina and Alabama.

Fungicides and fertilizer treatments were evaluated at four locations in the southeastern United States for the control of spring dead spot. Rubigan applied in September (1 oz. of product per 1000 square feet) and Tersan 1991 (8 oz. of product per 1000 square feet) applied in November were fungicides that gave the best control. Cold hardiness of bermudagrass following treatments with fungicides was evaluated in a study at Raleigh, North Carolina. Plugs of turf that were treated with Tersan 1991 in the fall survived cold

temperatures better than other treatments.

*Mississippi State University - Dr. J. V. Krons*

#### *Refinement of the Host-Pathogen Interaction System*

The Host-Pathogen Interaction System (HPIS) is an *in vitro* cell selection system developed in conjunction with efforts to obtain creeping bentgrass with resistance to *Rhizoctonia solani*. The HPIS is a unique cell selection technique which permits the simultaneous transfer of various substances from a disease organism to a callus culture during concurrent growth, yet which avoids direct physical contact between the organisms. The assembly and application of HPIS evolved through a series of experiments dating back to 1988.

Isolates from the USGA culture collection of *Rhizoctonia* spp. (courtesy of Dr. Phil Colbaugh, Texas A&M University), were co-cultured (concurrently grown) with creeping bentgrass callus in the HPIS. The pathogenic isolates inhibited callus growth and development, whereas the non-pathogenic isolates had no effect on callus viability. Studies were conducted to determine effects of various tissue culture media on vigor and pathogenicity of *R. solani*, primarily hormones and energy source concentrations. Various HPIS cultural studies were conducted, focusing on the length of incubation, duration of concurrent growth-interactions, establishing cultural practices for calli following co-culturing in the HPIS, and examining the persistence of toxicity within the HPIS plates.

Some important questions pertaining to HPIS protocol were answered by these refinement studies: 1) pathogenicity at the whole plant level is similar to pathogenicity at the cellular level; 2) media components, especially growth hormones and energy sources, play an important role in the pathogenic expression of *R. solani* in the HPIS; and 3) the use of HPIS can be maximized with successive co-cultures.

Recent research efforts have focused on using HPIS to obtain creeping bentgrass germplasm with enhanced resistance to *Rhizoctonia solani*, as well as developing an *in vitro* screening technique to verify enhanced resistance at the plantlet level.

Two co-culture procedures, simultaneous and delayed, were evaluated for obtaining bentgrass callus with resistance to *R. solani*. The simultaneous co-culture procedure was designed to allow the callus a gradual exposure to the toxic substances of *R. solani* over a period of 10 days, whereas the delayed co-culture procedure exposed

the callus to various concentrations of the toxic substances for only 24 hours.

The results from both procedures indicate *R. solani* must be actively growing in the HPIS for at least 7 days before the level of toxic substances is such that only 25 percent of the viable callus population can be recovered. From that 25 percent viable callus population, an average of two plantlets are regenerated. Some of these plantlets display enhanced resistance to *R. solani*.

A special HPIS chamber was developed for screening the germplasm obtained from the HPIS refinement experiments. This system is similar to the HPIS in principle, but is adapted to allow unrestricted growth of the plantlets. The bottom compartment of the chamber consists of the actively growing *R. solani*. The top compartment has been modified by the addition of a 9.5 cm (high) by 9.0 cm (diameter) glass cylinder. This expended space in the upper compartment permits the use of additional growth medium required by larger plantlets, and provides adequate 'head space' which plantlets require for optimum development.

The plantlets were screened in the HPIS chamber for two weeks. Thirty-three percent of the plantlets exposed to *R. solani* died. The surviving plantlets were extremely stressed, displaying purple leaves and stunted growth. They were then transferred to tissue culture boxes where vigorous shoot and root development occurred. The plantlets subsequently have been transferred to soil and will be screened for resistance to *R. solani* at the whole plant level. This will provide critical and much needed evidence on the efficacy of the HPIS approach, as well as providing plants with enhanced resistance to *R. solani*.

**Ohio State University - Dr. William W. Shane and Dr. Stephen T. Nameth**

#### *Monoclonal Antibodies for Rapid Diagnosis of Summer Patch and Necrotic Ring Spot Diseases of Turfgrasses*

Slow-growing patch diseases are among the most difficult problems to diagnose on turfgrasses. This project focused on the development and use of immunological techniques for rapid diagnosis. A monoclonal antibody-producing clone, selective for necrotic ring spot (*Leptosphaeria korrae*), was produced. The antibody, a small protein that can bind to the fungus, can be grown in great quantity within a laboratory flask. The antibody was highly reactive against all fungal strains of *Leptosphaeria korrae* tested.

The usefulness of the antibody for *L. korrae* was tested thoroughly against diseased turfgrass samples collected throughout the United States or submitted to the Ohio State University Plant and Pest Diagnostic Clinic. The *L. korrae* pathogen was successfully isolated from all Kentucky bluegrass samples exhibiting a significant reaction with the LK antibody. In addition, the LK antibody was successfully used to study the distribution of *L. korrae* in the various regions of "frog eye" patches, and on individual turfgrass plant parts to gain a better understanding of the life cycle of this disease. Through this research effort, sampling techniques for the detection of *L. korrae* with the LK antibody were optimized.

In addition, the LK antibody successfully detected *Leptosphaeria korrae* from certain bermudagrass sites with spring dead spot symptoms. Therefore, the antibody could be useful in determining the causal agent of spring dead spot. Currently, at least three fungi (*L. korrae*, *Ophiosphaerella herpotricha*, and *Gaeumannomyces graminis*) have been shown to be cause this disease. Despite the successes associated with the LK clone, no commercial company followed through with formal licensing of the technology.

Development of a monoclonal antibody for summer patch (*Magnaporthe poae*) was not completed. Difficulties occurred with the toxicity of the pathogen to immunized mice and rabbits. Reactivity of the mouse serum which was produced did not adequately select *M. poae* from diseased turfgrasses. Unfortunately, the project was terminated early when the principal investigator left Ohio State University for another position in industry.

#### **Soil Compaction**

**Michigan State University - Dr. Paul E. Rieke**

#### *Hollow and Solid Tine Cultivation Effects on Soil Structure and Turfgrass Root Growth*

Hollow and solid tine cultivation effects, as influenced by soil compaction and moisture content during cultivation, were evaluated on the basis of soil structural properties and root growth.

As expected, compaction resulted in pronounced detrimental effects on soil structure and root growth. Both cultivation methods resulted in positive and negative effects on soil structure. Cultivation increased the amount of large soil pores, with hollow tine coring being the most effective in producing this response. Regardless of

compaction level, solid tine cultivation increased the amount of intermediate sized pores when compared to hollow tine cultivation. Therefore, due to the increased amount of total soil pore space produced, hollow tine cultivation provided the most beneficial changes in soil porosity.

Soil strength within the zone of cultivation (surface 2 to 3 inches) was reduced after cultivation. Initially, solid tine cultivation was more effective in loosening the surface soil than hollow tine cultivation; however, this effect was reversed by the end of this study. Water conductivity rate dropped dramatically after cultivation, indicating that compaction at the bottom of the cultivation zone restricted water flow.

Compaction stress decreased root growth, while cultivation had a limited effect on root growth. Cultivation decreased surface rooting in non-compacted soil, but had no influence on rooting in compacted soil. Cultivation in non-compacted soil tended to increase rooting in June, but again, had no effect on rooting in compacted soil. Throughout the study, hollow tine cultivation ranked equal to or higher than solid tine cultivation in visual quality.

*University of Georgia - Dr. Robert N. Carrow*

#### *Development of Cultivation Programs on Turfgrass to Reduce Water Use and Improve Turf Quality*

The objective of this research project was to compare the relative effectiveness of different turf cultivation procedures to alleviate soil compaction, improve root and shoot growth, and increase soil water use. The most effective cultivation techniques were then incorporated into cultivation "programs." Each program was evaluated for its effectiveness in improving water use efficiency.

Poor soil physical conditions interfere with turfgrass management by limiting water movement, reducing soil aeration, and decreasing root and shoot growth. Compaction of the soil surface and excessively fine-textured soil profiles (i.e., high in clay and silt content) are two of the most common soil problems found on golf courses. Cultivation is an important method of alleviating these problems; however, comparative research studies to evaluate different techniques had not been conducted.

Five cultivation techniques were compared for their effectiveness in improving soil physical properties and growth of common bermudagrass (*Cynodon dactylon*). The soil was a Cecil clay loam, typical of the Piedmont region of the southeast. A non-compacted and compacted

control were included, and all cultivation techniques were evaluated under compacted conditions. Severe compaction was applied with a smooth power roller in April, May and July, 1989, and in March and July, 1990. The cultivation treatments were hollow tine core aeration (3 inches depth of penetration), Verti-Drain (12 inches), Verti-Slicer (4.5 inches), Aera-Vator (3 inches), and Hydro-Ject (6 to 8 inches). Cultivation treatments were applied during May and July in 1989 and during April and August in 1990.

The first study indicated that the Verti-Drain reduced soil strength to a depth of 8 inches and improved infiltration. These effects on soil physical properties enhanced deep rooting in the late summer. The Aera-Vator reduced soil strength in the 2 to 4 inches soil zone on one date and enhanced infiltration. These improvements in the physical properties of the first few surface inches did not result in better rooting since deep root growth in late summer was less than the control.

Hollow tine core aeration improved soil surface conditions, as shown by low bulk density and higher aeration porosity; however, rooting was not affected. The Verti-Slicer and Hydro-Ject treatments did not influence the measured soil physical properties or rooting. Improved soil water extraction during dry-down periods was observed, at least one out of eight times measured, for all procedures. All methods, except the Hydro-Ject, caused some decline in visual quality and/or shoot density within a week after treatment on at least one occasion. The Verti-Slicer and hollow tine core aeration exhibited this trend most often (4 out of 5 treatments). Last, all cultivation procedures, except the Verti-Slicer treatment, resulted in some improvement in visual quality and/or shoot density during some period of the study.

From the previous study, the most effective cultivation technique for making improvements deeper in the soil profile was the Verti-Drain, while hollow tine coring improved soil surface conditions. Thus, the intensity of Verti-Drain treatment (i.e., 1X, 2X times over the plot area), as well as Verti-Drain plus hollow-tine coring combinations, were explored.

The Yeager-Twose Turf Conditioner (a subsurface aerification unit) was not evaluated in previous research studies for comparative effectiveness as a turfgrass cultivation unit. The vibrating shank of this device goes to a depth of 7 inches and, with proper attachments, can inject granular materials to this depth. Since high aluminum (Al) saturation of the cation exchange complex of Piedmont soils is a major cause of

limited rooting, the injection of gypsum and lime were included as additional treatments. Also, these soils have a high bulk density (i.e., soil strength), especially in the B horizon. Therefore, the Turf Conditioner was tested for its potential modification of both the physical and chemical properties of the soil.

All plots, except the non-compacted control, were compacted with a smooth power roller while at near soil saturation. The soil was a Cecil sandy clay loam with 55.1% sand, 17.6% silt, 27.3% clay and 2.14% organic matter content. A common bermudagrass mowed at 0.75 to 1.0 inch was used. Fertilization programs in both 1991 and 1992 were at 1.0 lb N/1000 ft<sup>2</sup> in mid-April (10-10-10), mid-June (33-0-0) and early August (33-0-0).

The Verti-Drain (2X) + Core Aeration combination caused the most rapid decrease in penetration resistance, with reductions from 43 to 45 percent throughout the surface 8 inches, compared to the compacted control. After the first year, elimination of the core aeration treatment in conjunction with the Verti-Drain (2X) produced similar penetration resistance results. The combination of the two cultivation techniques also produced the best root water extraction from deep within the soil root zone. The water extracted by roots from within 8 to 24 inches of soil was 33 to 71 percent greater than the compacted control.

The Verti-Drain (2X) + Core Aeration treatment reduced total root length and deep rooting; however, the remaining roots were more efficient and able to extract more water than roots in the compacted control. Thus, root data alone may not always correlate well to water uptake in cultivation studies. This treatment also enhanced overall water uptake as demonstrated by ET rates with values often 28 to 96 percent higher than the compacted control. Water infiltration and percolation, as measured by saturated hydraulic conductivity, was improved by Verti-Drain (2X) and Verti-Drain (1X) + Core Aeration treatments.

The Turf Conditioner + Lime was the most beneficial of the three treatments for this device in reducing penetration resistance (16 to 28 percent reduction compared to the compacted control). Better root water extraction and overall water uptake (ET) were greater than the compacted control for several measurements during the two year study.

Overall, the research indicated that a vigorous cultivation program (i.e., Verti-Drain + Core Aerification) greatly improved turfgrass water use efficiency by enhancing water uptake from deeper zones within a fine-textured soil profile prone to

surface compaction. The Turf Conditioner cultivation method appeared to be suited for achieving physical and chemical modification, especially when lime is needed, for similar fine-textured soils.

## Salt Screening

*Texas A&M University - Dr. Garald L. Horst*

### *Developing Salt, Drought and Heat Resistant Turfgrasses for Minimal Maintenance*

The salt tolerance of turfgrass species has become more important as poor quality non-potable and effluent water use has increased on golf courses and other recreational turf. Dr. Horst ranked several of the major turfgrass species in order of their salt resistance (Table 14) and developed screening methods for salt resistance to evaluate selections from USGA/GCSAA sponsored buffalograss, zoysiagrass, and bentgrass breeding projects.

Some zoysiagrass selections from Dr. Engelke's breeding program appeared to have very good salt resistance. These selections could be useful in saline environments or as parents in future cultivar

**Table 14. Relative salt resistance of several turfgrass species used in the United States.**

Turfgrass Species <sup>a,b</sup>		Relative Ranking <sup>c</sup>
Cool-Season	Warm-Season	
Alkaligrass	Seashore paspalum	Excellent
	Zoysiagrass <sup>d</sup>	
	St. Augustine	
	Bermudagrass hybrids	Good
Bentgrass <sup>d</sup>	Bermudagrass	
Tall fescue	Bahiagrass	Fair
Perennial ryegrass	Centipedegrass	
Fine fescues	Carpetgrass	Poor
Kentucky bluegrass	Buffalograss <sup>d</sup>	

<sup>a</sup>Based on the most used cultivars of each species.

<sup>b</sup>Variable among cultivars within species.

<sup>c</sup>Ranked by Horst (1992).

<sup>d</sup>Species on which limited salt resistance screening was performed under USGA/GCSAA sponsored research.

improvement work. Bentgrass germplasm from the improvement program under the direction of Dr. Engelke (Texas A&M) and buffalograss germplasm from Dr. Riordan (University of Nebraska) also were screened using this technique to evaluate salt resistance. Promising bentgrass lines were identified, while less satisfactory results were reported for buffalograss.

*University of Illinois - Dr. M.A.L. Smith*

#### *Whole Plant Microculture Selection System*

A novel, highly uniform *in vivo* screening method for monitoring mature turfgrass plant response to increasing salinity levels over time was developed. Video image analysis was utilized to quantify and validate turfgrass responses, and permitted larger sample sizes and a more thorough screening of plants.

A strong linear relationship for shoot and osmotic adjustment occurred between solution culture and whole plant microculture. Root growth, as measured by root length and area, was more variable in both solution and microculture. Whole plant microculture conferred additional advantages as a highly-controlled test system in terms of scale, timing, maintenance, and repeatability.

Salt tolerant lines were regenerated, adapted to the greenhouse, and reestablished in whole plant microculture. In whole plant microculture, the grass plants again were subjected to salinity stress, and the whole plant responses were non-evasively monitored over time using video image analysis. Approximately one third of the lines selected for salt tolerance at the cell level retained salt tolerance traits at the whole plant level.

#### **Water Use**

*University of Georgia - Dr. Robert N. Carrow*

#### *Influence of Soil Moisture Level on Turfgrass Water Use and Growth*

Reducing irrigation frequency is one means of conserving water. Of concern to the turfgrass manager is the quantity of water conserved and any adverse effects on turf quality. Evapotranspiration (ET) data obtained in arid regions is not necessarily valid for estimating turf water use in humid regions. A scale was developed to include ET and overall drought resistance criteria to rank grasses for water conservation in humid regions.

The ET ranges for 'Tifway' bermudagrass, 'Meyer' zoysiagrass, and common centipedegrass were determined under moderate stress irrigation in large field plots. The three warm-season grasses were irrigated under three irrigation regimes, i.e., well irrigated, moderate stress, and severe stress.

For the well watered irrigation regime, common for golf course tees or very high quality fairways, bermudagrass used the least water in summer and fall. Relative to Tifway bermudagrass, Meyer zoysiagrass used 10, 30, and 5% more water for July, August, and October, respectively. Common centipedegrass used 4, 23 and 13% more water than bermudagrass in July, August, and October, respectively.

In the moderate stress irrigation program, typical for many fairways, water use rates were 39 and 11% greater than bermudagrass in August for zoysiagrass and centipedegrass, respectively. Just prior to an irrigation, zoysiagrass showed slight wilt, while the other grasses did not.

Under severe moisture stress, such as for rough areas, water use rates in August were 4% lower and 43% higher than bermudagrass for zoysiagrass and centipedegrass, respectively. The zoysiagrass exhibited severe wilt and bermudagrass no symptoms. The semi-dormant state for zoysiagrass accounted for its lower water use. Zoysiagrass did not appear to develop many roots into the heavy B soil horizon and could not effectively use subsoil moisture.

A second means of reducing water use is to utilize atmospheric, soil or plant based criteria to schedule irrigation in contrast to guessing when to water. Comparative data on these methods were developed to allow turfgrass managers to select the best means of scheduling irrigation.

#### **Entomology**

*Rutgers University - Dr. Peter R. Day and Dr. C. Reed Funk*

#### *Endophytes of Turfgrasses: New Tools and Approaches*

The purpose of this project was to find naturally occurring endophytes within the *Poa* and *Agrostis* genera that would improve insect resistance. Endophytes are fungi which grow within the turf plant and produce chemical compounds, (i.e., Alkaloids) which make the plant less desirable to some insect pests. If naturally occurring endophytes could not be found within *Poa* and *Agrostis* species, particularly creeping bentgrass and



Kentucky bluegrass, then biotechnology techniques were to be employed to help produce new endophytes that would work in these important turfgrass species.

The research project acquired a large turfgrass germplasm and endophyte culture collection from throughout the United States and other parts of the world. After extensive screening of more than 700 collections, some 14 fungal endophyte-infected species of *Poa* and *Agrostis* were obtained. A collection of 30 fungal endophyte cultures was established on agar medium and contains representative isolates from a variety of turfgrass genera.

Fungal endophyte-specific DNA probes were produced by the polymerase chain reaction (PCR). Ribosomal RNA internally transcribed spacer sequences (ITS-A) were isolated from *A. typhinum*, *A. starrii*, and *A. coenophialum* using PCR primers. These are of similar size and their DNA sequences are being compared. The RAPD (randomly assigned primer DNA) method of using PCR with single ten-base DNA primers was tested with DNA extracts of eleven endophytes using different primers with varying guanine/cytosine contents. The technique is expected to be useful for developing probes for detecting the presence of endophytes in grasses.

Callus cultures were obtained from six cultivars of Kentucky bluegrass (*Poa pratensis*) and four of creeping bentgrasses (*Agrostis palustris*) tested in tissue culture using mature seeds germinated on a callus induction medium. Several embryogenic callus lines were selected from 'Emerald' and 'Putter' bentgrass and 'Baron' Kentucky bluegrass. The usefulness of embryogenic callus as a target to create new endophyte-turfgrass combinations is under evaluation. The possibility of introducing foreign genes into turfgrass cells by DNA particle bombardment techniques also was investigated.

*Sea Island, Georgia - Dr. A. Leon Stacy*

#### *Mole Cricket Pheromones and IPM*

This project evaluated scouting methods to monitor population dynamics and the potential use of pheromones to reduce pesticide applications for the control of mole crickets on golf courses. Biologically active materials were discovered and, with further refinements, could be produced for commercial marketing. No previous research had been done with mole cricket pheromones when this study was initiated.

Various glands and body parts were dissected

from both male and female crickets. During the cricket flight season, acetone homogenate of the spermatheca (♀ crickets) and an unknown gland (♂ crickets) were biologically active and appeared to act as attractants (sex or aggregating pheromones). An alarm substance from the rectum (♀ and ♂) significantly reduced "fly-in" crickets. Additional tests are still needed to improve on the pheromone dispensing system and to further refine optimum rates of activity.

Results from the study were extremely encouraging. The attractants and the alarm substance could eventually fit well into a pest management system by influencing the population dynamics of crickets, i.e. concentrating crickets into one area while repelling them from others. This use possibly could reduce the turf area requiring treatments.

Although no previous work had been done with mole cricket pheromones, the concept was used successfully in eradication programs for several insect pests of agronomic importance and millions of dollars were saved. This project successfully identified biologically active materials; however, cooperation with a qualified pheromone chemist will be needed before efficient testing of the effects of these compounds on the population dynamics can proceed.

#### *Mycorrhizae*

*University of Rhode Island - Dr. Noel Jackson*

#### *Use of Mycorrhizae in the Establishment and Maintenance of Greens Turf*

This research project took yet another approach to improve turfgrass water use in sandy soils. Mycorrhizal fungi grow in close association with plant roots and increase the surface area for nutrient and water uptake. Dominant species of mycorrhizal fungi associated with creeping bentgrass and *Poa annua* were isolated from old putting greens receiving routine fungicide applications. The dominant species of mycorrhizal fungi occurring in sand dune soils in New England also were collected. In fact, mycorrhizal fungi isolated from sand dunes were superior to non-dune fungi in stimulating growth of turfgrasses grown in the sand putting green medium.

Responses of creeping bentgrass to mycorrhizal fungi and growth mixes continue to be evaluated. Two methods for producing inoculum were developed for greenhouse conditions. A method to inoculate bentgrass plants with mycorrhizal fungi

under sterile laboratory conditions was developed to conduct basic research studies and provide an additional screening technique to identify promising strains of mycorrhizae.

### **Turfgrass Breeding**

The quality and stress tolerance of a turf is the product of environment, management practices and genetic potential of the grass plant. In many cases, the major limitations to quality turf is its inability to limit various stress effects, many of which can be modified or controlled through plant breeding.

Turfgrass breeding projects were directed toward reducing water use and maintenance costs, and developing resistance to several stresses. The intent was that scientists responsible for the breeding projects incorporate and utilize results of the stress mechanism and cultural practices studies.

The characteristics most desirable in potential new turfgrasses include:

- drought tolerance
- high and low temperature tolerance
- tolerance of non-potable water
- tolerance to acid, alkaline or saline soils
- reduced mowing and fertilization requirements
- traffic tolerance
- genetic stability of characters
- disease, insect and nematode resistance
- weed competition to reduce herbicide use
- tolerance to smog and other pollutants
- shade tolerance

The primary attention in turfgrass breeding focused on the improvement of zoysiagrass, native grasses, *Poa annua*, bermudagrass and bentgrass. Other turfgrass species and ground covers of potential merit also were considered. The quality of turfgrasses or other ground covers resulting from the proposed research were required to meet the needs of golf courses. In Table 15, the breeding projects, species, and status of varieties were summarized.

#### **General - Cool Season Species**

##### ***Rutgers University - Dr. C. Reed Funk***

##### ***Kentucky Bluegrass, Tall Fescue, and Perennial Ryegrass***

The USGA, golf and the entire turfgrass industry will be forever indebted to Dr. Funk for the turfgrass varieties his breeding program has

developed. His experience, methodology, keen eye and spirit of cooperation with industry has produced landmark varieties in our major cool-season turfgrass species. The USGA is very proud of the long and productive relationship with Dr. Funk, his research staff, graduate students, and colleagues at Rutgers University.

Dr. Funk, through the years, has had many significant accomplishments. He developed the first successful method of producing Kentucky bluegrass cultivars by intra-specific hybridization of apomictic parents. He revolutionized the use of perennial ryegrasses through the development of 'Manhattan' which is considered a landmark cultivar that significantly enhanced the usefulness of this species for golf and sports turf. Subsequent to the development of Manhattan, Dr. Funk has participated in the development of many widely used turf-type perennial ryegrasses.

In addition to breeding work with Kentucky bluegrass and perennial ryegrass, Dr. Funk developed the first and most widely used turf-type roughstalk bluegrass (*Poa trivialis*) in North America and ushered in a new generation of turf-type tall fescues. He has participated in the development of several strong creeping red fescues and hard fescues. During his travels and career, he has accumulated one of the most valuable collections of *Poa* and *Festuca* germplasm available in the world.

Dr. Funk participated in the discovery that endophytic fungi are associated with enhanced performance of perennial ryegrass, tall fescue, hard fescue, creeping red fescue, and Chewings fescue. This research demonstrated an association between the presence of endophytic fungi and resistance to chinch bugs, sod webworms and bill bugs. Within the fine and tall fescues, endophytic fungi produce resistance to chinch bugs, and also improve performance during summer stress. The breeding program has developed methods and procedures for creating turfgrass cultivars possessing endophyte enhanced performance.

#### **Bentgrass**

Creeping bentgrass (*Agrostis palustris*) and colonial bentgrass (*A. castellana*) are the two major types utilized in the United States. The major use of creeping bent is on golf greens and fairways. Colonial bent is used for golf course fairways, lawns and wherever there is a need for low growing, closely mowed turf. Greater activity in breeding colonial bentgrass was promoted by the Research Committee.

*Bentgrass Breeding*

This research program has made a tremendous impact on golf through the development of 'Penncross', 'Penneagle', and 'Pennlinks' creeping bentgrass. The USGA/GCSAA research program has contributed a modest amount toward the continuing efforts of Dr. Duich to develop improved creeping and colonial bentgrass varieties.

In 1986, Pennlinks (PSU 126) was released and named. This cultivar featured an upright growth habit, finer leaves, minimal segregation, and improved seasonal turf quality and overall performance. A putting green evaluation trial with 38 varieties was established in 1989 and included 28 new PSU experimentals. Six of the experimentals were very promising, and resulting progeny continue to be evaluated under close clipping to develop close-cut tolerant creeping bentgrasses.

In addition, gel electrophoresis (finger printing) was evaluated to help develop methods which identify differences between bentgrass varieties. Fairway management studies with new and old bentgrass varieties also were conducted with growth regulators and clipping removal as methods to reduce *Poa annua* and disease reduction (i.e., leafspot, dollarspot, and brownpatch).

Studies were completed to enhance efforts to develop improved colonial bentgrasses. Early flowering response, improving rhizome production, tissue culture attempts to produce haploid plants from anthers, and refining somatic tissue culture media were some of the areas investigated.

*University of Rhode Island - Dr. C. Richard Skogley*

*Selection and Breeding of Superior Bentgrasses*

Since 1960, ongoing USGA research grants have been utilized to support an extensive effort in plant improvement at the University of Rhode Island. In 1989, 'Providence' creeping bentgrass was released and seed was sold to several New England golf courses and many others nationally. Through the years, the turfgrass breeding program conducted by Dr. Skogley has produced several other important turfgrass cultivars, including, 'Jamestown' and 'Jamestown II' Chewings fescues, 'Georgetown' Kentucky bluegrass, 'Kingstown' velvet bentgrass, and 'Exeter' colonial bentgrass.

*Breeding and Development of Bentgrass*

Even though creeping bentgrass provides a superior putting surface, its use is limited in the South due to its intolerance of high heat. Moisture stress can be relieved with good irrigation management; however, very little can be done to relieve the plant stresses caused by high temperatures. The major objective of this project was to develop bentgrass cultivars with superior heat tolerance for both high soil and air temperatures.

High ambient and soil temperatures impair the transpirational cooling process of bentgrass. Most bentgrasses also exhibit a definite degeneration of root tissue and shortening of roots under high soil temperatures, close frequent mowing, and heavy traffic.

Through the efforts of Dr. Engelke and his research staff, screening techniques were developed which examined leaf and shoot water content as it relates to bentgrass plants grown in high ambient and soil temperatures. In addition, a root screening procedure which identifies individual plants with superior root growth characteristics was developed. Numerous parental plants were identified with superior agronomic and biological characters.

The increased use of bentgrass on fairways, in addition to putting greens, and support of bentgrass breeding on the part of the USGA/GCSAA, renewed the interest of seed companies and universities to release or develop new varieties. Several new experimental varieties from Texas A&M University and new commercial varieties, including Providence, Pennlinks, Putter, SR-1020, Cobra and others will meet the future demands of golf course greens and fairways.

*Department of Scientific and Industrial Research, New Zealand - Dr. William Rumball*

*Colonial Bentgrass Breeding*

The original objective of this project was to breed a colonial bentgrass (*Agrostis castellana*) cultivar for U.S. golf courses using New Zealand breeding materials. Breeding work was conducted in New Zealand, and many selections were tested in the United States. The resulting cultivar would, hopefully, require much less water and maintenance than those currently available in the United States, but still be attractive and persistent.

The project took the pragmatic approach that breeding material meeting these characteristics would probably be found on sites such as non-irrigated, low-input fairways of golf courses in hot, dry regions of New Zealand.

Thus far, the colonial bentgrass breeding project has provided an experimental cultivar for evaluation in the United States. Results from the performance of colonial bentgrass in the National Turfgrass Evaluation Program Trials indicate that the species may be useful in our maritime climates. The entry in these trials was developed under low input conditions with virtually no irrigation, fertilizer, or pest control and has not performed well in the high maintenance putting green trials.

This selection also could be used as a component for blending with cultivars of *Agrostis capillaris* to extend their drought tolerance and cool-season color. Dr. Rumball provided 108 half-sib progenies of *A. capillaris* which were evaluated at Rutgers University by Dr. Reed Funk. The data collected from these materials was used to develop a selection for further testing in the United States.

### **Bermudagrass**

Bermudagrass is a widely used turfgrass throughout the warm season climates of the world. Breeding work, supported by the USGA, was initiated with bermudagrass in 1946. A number of improved vegetative selections resulted from these efforts. These grasses have virtually revolutionized the turfgrass industry in the regions of their adaptation yet there is still need for continued improvement in this all-important turfgrass species.

*U.S. Department of Agriculture and University of Georgia - Dr. Glenn W. Burton*

### *Vegetative Bermudagrass Breeding*

Turf research at Tifton, Georgia, began in 1946 with a \$500 annual USGA Green Section grant to supplement the USDA-University of Georgia forage grass breeding program begun in 1936. Developing a better bermudagrass to replace sand greens or seeded bermudagrass greens became the first objective of the new research program.

During the period from 1950 to 1965, this research program developed 'Tiflawn', 'Tiffine', 'Tifgreen', 'Tifway', and 'Tifdwarf'. Tiflawn, like common bermudagrass (*Cynodon dactylon*), was a tetraploid with 36 chromosomes. The remaining cultivars were produced by crossing fine-leaved *Cynodon transvaalensis* with 18 chromosomes and

*C. dactylon* to produce sterile 27 chromosome hybrids. In particular, Tifgreen and Tifdwarf provided a vast improvement for putting greens, while Tifway was a superior cultivar for tees, fairways, and athletic fields.

The sterile triploid hybrids cannot be improved by conventional plant breeding methods. They can be modified by exposing dormant sprigs of the triploids to 7,000 to 9,000 r of gamma radiation from a cobalt-60 source. This was done at Tifton in 1970 and resulted in 158 mutants of Tifway, Tifgreen, and Tifdwarf that were evaluated until 1981, when a mutant of Tifway was released as 'Tifway II'. Tifway II looks like Tifway but is more resistant to root knot, ring, and sting nematodes, is more frost tolerant and greens up a littler earlier in the spring.

In 1983, 'Tifgreen II', a mutant of Tifgreen that has a lighter green color, greater cold tolerance, lower maintenance requirements, and better spring recovery was released. It is a little coarser than Tifgreen and makes a less desirable putting surface.

The most recent release is Tifton 10, a clone found by Dr. Burton in a lawn in Shanghai, China, in 1974. It has 54 chromosomes instead of 27 or 36, sets few seeds, and must be propagated vegetatively, but spreads faster than the Tifton bermudas. It has dark bluish-green color, good winter-hardiness, salt tolerance, and ring nematode resistance. Tifton 10 is coarser than the other Tifton bermudas.

Recent research efforts attempted to cross the Kentucky Quicksand common with the best *Cynodon transvaalensis* clones to obtain a more winter hardy hybrid. When these efforts failed, the Kentucky Quicksand clone was crossed with Tifton 68, an excellent pollen producer. After many pollinations using Quicksand as the female, four plants finally were produced and were most certainly selfs. These plants were sterile and showed no promise in the first evaluation and no potential as parents for future breeding. Unfortunately, the winter hardy Kentucky Quicksand bermudagrass cannot be used in a breeding program designed to develop more winter hardy hybrids.

Winter survival in plants has been associated with carbohydrate reserves stored in their roots and underground parts. In 1962, "A Method for Measuring Sod Reserves," *Agronomy Journal* 54:53-55 was described. The method involved cutting 6-inch plugs of sod, putting them in large empty cans, letting them develop etiolated stems in the dark and measuring the dry matter produced. This method was modified for use in current greenhouse

Table 15. Summary of USGA/GCSAA Turfgrass Breeding Programs.

Turfgrass	University	Status of Varieties
Creeping Bentgrass <i>Agrostis palustris</i>	Texas A&M University	88 Syn-3, and 88 Syn-4 released.
	University of Rhode Island	'Providence' released
Colonial Bentgrass <i>Agrostis castellana</i>	DSIR-New Zealand	A preliminary line, BR-1518, was entered in the NTEP trials.
Bermudagrass <i>Cynodon dactylon</i>	New Mexico State University	NuMex Sahara, Sonesta, and several other experimental seed propagated varieties were developed.
	Oklahoma State University	Two entered in 1992 NTEP Trials.
<i>C. transvaalensis</i>	Oklahoma State University	Thirty experimental cultivars in initial turfgrass evaluations.
<i>C. dactylon</i> X <i>C. transvaalensis</i>	University of Georgia	'Tifton 10' released, several 'Midiron' and 'Tifway' mutants are under evaluation.
Buffalograss <i>Buchloe dactyloides</i>	University of Nebraska	Several are entered in the 1991 NTEP Trial. Vegetative: NE 84-315, NE 84-378, NE 84-436, NE 84-453, and NE 84-609. Seeded: NTDG-1, NTDG-2, NTDG-3, NTDG-4, and NTDG-5
Alkaligrass <i>Puccinellia</i> spp.	Colorado State University	Ten improved families are under evaluation in preparation for release.
Blue grama <i>Bouteloua gracilis</i>	Colorado State University	'Elite', 'Nice', 'Plus' and 'Narrow' are under evaluation in preparation for release.
Fairway Crested Wheatgrass <i>Agropyron cristatum</i>	Colorado State University	Narrow leaved and rhizomatous populations are entering preliminary turfgrass trials and a second cycle of selection.
Curly Mesquitegrass <i>Hilaria belangeri</i>	University of Arizona	Seed increases of 'fine' and 'roadside' populations are underway in preparation of germplasm releases.
Annual bluegrass <i>Poa annua</i> var <i>reptans</i>	University of Minnesota	Selections #42, #117, #184, #208, and #234 under evaluation for seed production, naming and release.
Zoysiagrass <i>Zoysia japonica</i> and <i>Z. matrella</i>	Texas A&M University	Several are entered in 1991 NTEP Trial: DALZ8501, DALZ8502, DALZ8507, DALZ8508, DALZ85012, DALZ85014, DALZ85016, DALZ8701, and DALZ9006.

and field trials to evaluate carbohydrate reserves in bermudagrass. With these methods, significant reserve differences were found among 16 genotypes

that involved the winter hardy Berlin bermuda as one parent. These had been mowed regularly and received low maintenance for 20 years.

New Mexico State University - Dr. Arden A. Baltensperger

*Breeding Improved Seeded Bermudagrass for Turf*

Until the recent research support of the USGA, most of the bermudagrasses used on golf courses were established by vegetative methods, i.e., sod, plugs, or sprigs. Dr. Baltensperger's bermudagrass breeding program made significant progress toward the development of seed propagated bermudagrass varieties. His project successfully estimated the genetic variation and heritability for turfgrass quality, shade tolerance, and seed production characters.

These research efforts led to the release and production of NuMex 'Sahara' bermudagrass in 1987. Sahara is the first improved, seed propagated turf-type bermudagrasses released exclusively for golf course and sports turf usage. During this time, the USGA also partially funded recurrent selection for shorter internodes, increased density, bermuda stunt mite resistance, and increased seed yield.

Oklahoma State University - Dr. Charles M. Taliaferro

*Breeding and Evaluation of Cold-Tolerant Bermudagrass Varieties for Golf Course Putting Greens and Fairways*

The bermudagrass breeding program at OSU has devoted attention to the development of seed propagated, cold tolerant, fine textured bermudagrass varieties for the transition zone climates of the United States. In addition, the last three years were devoted to developing improved, vegetatively propagated bermudagrasses for golf course putting greens in southern climates. Both breeding objectives aim to reduce water use and maintenance costs by providing a better adapted warm-season turfgrass species where poorly adapted cool-season species are over-utilized.

For the seeded bermudagrasses, three cycles of phenotypic recurrent selection for increased seed fertility within a cold hardy germplasm resulted in a three-fold increase in the percentage of florets setting seed. A breeding nursery was established in Yuma, Arizona to evaluate seed production potential in the part of the United States where most bermudagrass seed is produced. Four experimental seeded bermudagrasses were successfully tested in Fort Collins, Colorado and in Columbia, Missouri. Two new seeded

bermudagrasses were entered in the 1992 National Turfgrass Evaluation Trial.

Very fine-textured, cold-tolerant *C. transvaalensis*, identified as having good seed set, were used to produce over 6,000 segregating progeny plants. Over 3,000 individual plants currently are being evaluated under putting green conditions in Oklahoma. Plants with superior performance under Florida and Oklahoma climates have been advanced to preliminary cultivar trials. These trials should help identify new putting green bermudagrasses in the next two to three years.

In addition to progress made in the development of new seeded and vegetatively propagated bermudagrass varieties, new and effective screening techniques were implemented. Repeatable laboratory techniques, such as the "electrolyte leakage" and "freeze-regrowth" tests, have been used for evaluating actual and relative cold tolerance. Alterations in protein synthesis associated with cold acclimation in 'Tifgreen' and 'Midiron' bermudagrass indicate differences in the amount of low molecular weight proteins.

Techniques were perfected for regenerating bermudagrass plants from cultured tissues using vegetative and seed explants. Somaclonal variants have been identified among regenerated populations. Drought avoidance mechanisms, using techniques developed in other USGA sponsored projects, were used to document differences among promising parents and commercial varieties.

**Native Grasses**

There are native or other introduced grasses which are potentially valuable for use as turf. Among these are buffalograss, fairway crested wheatgrass, blue gramagrass, kikuyugrass and species of *Distichlis*, *Puccinella*, and *Paspalum*. Very little previous work had been done assessing these species; therefore, two early objectives were to determine the extent of their genetic variation and potential usefulness as turfgrasses.

A long term objective included the collection and evaluation of potentially useful biotypes. In the cases where species showed promise for improvement, the appropriate breeding techniques would be employed.

Specific objectives varied among the species and with the possible use of each species. Most of these species demonstrated an ability to persist under unfavorable conditions such as drought or salinity. Improvement efforts were directed toward the characteristics which would contribute to the usefulness of each species for turfgrass application.

*University of Nebraska - Dr. Terrance P. Riordan*

*Breeding, Evaluation and Culture of Buffalograss for Golf Course Turf*

Native grasses have the greatest potential in regions of the country where water, poor soils, or climate are limiting factors in providing quality playing surfaces. Taking advantage of the natural selection that has occurred over millions of years obviously will be more successful than a ten-year breeding program; however, the domestication of native species is not a simple task.

Buffalograss is a good example of how a species native to North America can be utilized for golf courses. To date, buffalograss has been improved to the point that it will make an adequate playing surface for golf course roughs. Continued research efforts will allow this species to be used on fairways in areas of the United States where more traditional grasses are not well adapted.

Buffalograss is not a panacea, but represents a major step in the recognition of a valuable natural resource for the turfgrass industry to utilize.

Under the direction of Dr. Riordan, the buffalograss breeding project has developed and released 'NE 84-609'. The 609 cultivar is a drought tolerant grass intended for use on golf course roughs in the south central plains and desert southwest. In addition to 609, four other vegetative and five seed propagated buffalograsses were entered in the National Turfgrass Evaluation Program. In fact, half of the 22 entries in the buffalograss trial were sponsored, in part, by the USGA/GCSAA Turfgrass Research program.

A breeding program must pass many milestones to make continued progress toward the development of better turf-type varieties. Buffalograss is a dioecious plant, or one which requires male and female plants to produce fertile seed. For this reason, research to determine the sex ratios of male and female progeny produced by female parental lines was carried out. Hybridization techniques were developed, and the light required for flowering determined, so pollination could be optimized for seed set.

Seedling germination and establishment differences of seed caryopses versus buffalograss burs, which contain 2 to 3 seed, were compared to determine the best way to process and market seed for the consumer. For the increase of vegetative varieties, a mechanical method of extracting plugs from the field was developed. Methods were developed to "pre-root" plugs in greenhouse nursery liners for faster establishment.

*Colorado State University - Dr. Robin L. Cuany*

*Development of Dryland Western Turfgrass Cultivars*

Alkaligrass, blue grama, and fairway wheatgrass are native grasses under evaluation for use as turfgrass by Dr. Cuany at Colorado State University. Alkaligrass was determined to be a cross-pollinated grass which segregates for leaf color, growth habit, and seed panicle characters. Alkaligrass accessions from Eurasia were screened for turf color variation in response to weather changes, disease resistance, and seed production characteristics.

The four best alkaligrass families for rust resistance in Colorado, and at least 2 years of good seed production, were sent to Oregon for seed production and turf trials. Over 25 collections from western states were screened for seed productivity and turf performance; however, only one was equal to the performance of Eurasian alkaligrasses.

Blue grama clones derived from collections originating from the Great Plains of the United States were screened for seed productivity, caryopsis weight and plant type over two generations. New parent plants were chosen from within 20 families and grouped into four recombination blocks. A large blue grama seed production block with the best 25 clones was planted to produce breeder's seed (ELITE). A smaller, secondary blue grama block with 24 parents moderately good in seed production and size also was established (PLUS). Two small blocks selected for leafiness and narrower leaf blades were established for special use with less certainty of seed yield.

Fairway crested wheatgrass was surveyed from 17 Eurasian sources, and parents were selected in two successive generations for rhizome development, disease resistance, leaf width, and seed yield. Two seed production blocks of 60 tetraploid and 30 diploid fairway crested wheatgrasses were established, all rhizomatous types with medium to coarse leaf blades. Narrow-leaf fairway crested wheatgrass seed production blocks with 21 and 27 parents of diploid and tetraploid origin were established.

In addition, inland saltgrass (*Distichlis* sp.) collections were surveyed for growth pattern, and many of the accessions were strongly rhizomatous and produced a dense canopy requiring little maintenance. Several female clones had taller seed heads useful in seed harvest. Seed germination required pre-chilling and the seedlings which emerged were weak. Management studies,

including variable mowing heights and fertility rates, were conducted to evaluate alkaligrass, blue grama, and fairway crested wheatgrass selections.

*University of Arizona - Dr. Charles F. Mancino*

*Breeding and Development of Curly Mesquitegrass as a Desert Turf*

Curly mesquitegrass (*Hilaria belangeri*) is a potential turfgrass for low maintenance areas in the Southwestern Desert regions of the United States. Under the direction of Dr. Mancino, germplasm was collected throughout Arizona. Several basic studies were conducted, including cytological examination of chromosome behavior prior to seed formation, effects of chemicals on germination, the effects of seed storage times and conditions on germination, and the effects of seeding dates and rates on establishment. Management studies examined interacting effects of mowing heights and nitrogen rates. In cooperation with Texas A&M University, genetic rooting potential of curly mesquitegrass was determined.

Much of the variation observed among the curly mesquitegrasses collected from Arizona was due to genetic differences, and therefore, the species appears to have the potential to be improved for use as a "low maintenance" turfgrass. The results from cultural practice studies demonstrated that mesquitegrass can perform well (i.e., display acceptable color, density, uniformity, etc.) under turfgrass management practices. Good color and adequate density (> 70%) was achieved for some of the accessions at low nitrogen rates (48 kg N ha<sup>-1</sup> yr<sup>-1</sup> or 1 lbs. per 1000 ft<sup>2</sup>) and a mowing height of 10 cm (1.5 inches). The research project also demonstrated that seed could be produced and that establishment of mesquitegrass by seed was a viable method.

**Annual Bluegrass**

*Poa annua*, annual bluegrass, is widely adapted throughout the world. In cool climates it represents a major, often undesirable, component of golf course turfgrass. In warm climates, as well as in zones of marginal adaptation, it is considered a weed because of its intolerance to extremes of temperature and moisture stress.

The evolutionary parents of *Poa annua* are *P. supina* (a diploid perennial type) and *P. inferna* (a diploid annual type). It was hoped that a breeding program involving standard breeding techniques, as well as tissue culture, could yield superior plants

with desirable genetic characteristics.

*University of Minnesota - Dr. Donald B. White*

Through the efforts of Dr. White, a breeding program to develop annual bluegrasses for golf course putting greens was implemented. With over fifty years of failed attempts to achieve 100 percent annual bluegrass control, it was decided to evaluate the improvement potential of the species. Dr. White states his philosophy simply, "... when served lemons, why not make lemonade!"

Research efforts have developed methods to control flowering, long term viability of seed, determination of chromosome number, and most important, identification of individual parents with superior agronomic characteristics which will be used to develop turf-type cultivars. Research indicates that both the perennial form, *Poa annua* var *reptans*, and an annual species, *P. supina*, exhibit the most potential for new varieties.

Seed production plots of the most promising parents were established in the Pacific Northwest to produce seed for cultivar trials. A limited amount of seed from these production blocks was planted on golf course putting green nurseries in Southern California, Massachusetts, and at the University of Minnesota turfgrass research plots.

In addition, the development of the excised stem/mist technique allows for controlled crosses between elite materials to produce intra- and interspecific hybrids for characters of interest. This technique has allowed for the development and evaluation of several F<sub>1</sub>, F<sub>2</sub>, F<sub>3</sub> and back-crossed materials segregating for plant type, color, texture, seedling vigor, culm length, stolons, and perennial growth habit.

Research concerning the temperature and photoperiod requirements for seedhead initiation indicates that plants segregate into day-neutral and seasonal flowering categories. One exciting discovery was that segregation ratios for progeny from day-neutral parents suggest that the characteristic may be controlled by a single gene. This type of information could help lead to the development of *P. annua* var *reptans* varieties with reduced flowering periods under mowing.

**Zoysiagrass**

Zoysiagrass was introduced into the United States from the Orient around 1900. Some selections have been used throughout the transition zone since about 1950. Use has been limited because zoysiagrass selections are propagated



vegetatively. Seed germination is usually low and there are no domestic supplies of seed. Imported seed does not produce satisfactory turfgrass for golf courses.

Zoysiagrass produces a very dense, tight turf of pleasing color and is able to crowd out most competing species. Also, it possesses good temperature and moisture stress tolerance.

*Texas A&M University - Dr. Milton C. Engelke*

#### *Breeding and Development of Zoysiagrass*

The purpose of this project was to develop zoysiagrasses which are better adapted to natural environmental conditions. Specific emphasis was placed on low water-use, competitive ability against weed invasion, recovery from injury, reduced fertilization, and sod or seed production characters.

In 1991, several new zoysiagrasses were entered in the National Turfgrass Evaluation Program (NTEP). Material of 24 unique experimental and commercial cultivars were vegetatively increased and distributed to 39 locations throughout the United States. The zoysiagrass breeding program had a total of nine elite entries in this trial. These entries range in texture from broad leaved, aggressive *Zoysia japonica* types to fine textured, highly rhizomatous *Z. matrella* types. The nine entries are all vegetative; however, numerous hybrids have been produced which show seed production potential and will be included in the next cycle of NTEP evaluations.

Additional achievements include the development of effective heat resistance and root screening procedures utilized to identify superior plants. Several parental clones with superior agronomic and biological characters were selected to provide improved turf under conditions of significant water stress. Characteristics of interest included color retention, leaf rolling, leaf water content, leaf firing, and low water use.

#### **IV. Appendix**

# Appendix A: 1983-1992 Turfgrass Research Budget Summary

Project	Sub-Project	University/Investigator	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Total
Turfgrass Breeding	General	Rutgers/Funk	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	50,000
	Bentgrass	Penn State/Duich	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	40,000
		TX A&H-Dallas/Engelke			47,000	40,000	40,000	40,000	60,000	64,000	64,000	64,000	419,000
	New Zealand/Rumball				10,000	10,000	10,000	10,000	13,000	10,000	10,000	5,000	68,000
		Univ of RI/Skogley	1,500	1,500	1,500	1,500	5,000	5,000	5,000				21,000
	MS State/Krans		2,500	2,500									5,000
		Univ of GA/Burton	5,000	5,000	5,000	5,000	5,000	5,000	5,000	8,000	8,000	8,000	59,000
	Bermudagrass	NH State/Baltenberger		4,500	20,000	20,000	20,000	3,000					67,500
		OK ST/Taliaferro-Barber			20,000	20,000	20,000	20,000	35,000	75,000	75,000	75,000	320,000
	Cultivar Evaluation	Native Grasses	CO State/Cuany-Koski		10,000	20,000	20,000	25,000	25,000	30,000	30,000	30,000	190,000
Univ of AZ/Mancino				4,100	20,000	18,000	19,000	25,000	35,000	35,000	45,000	246,100	
Poa annua		Univ of NE/Riordan		11,600	15,000	15,000	20,000	30,000	35,000	35,000	35,000	231,600	
Zoysiagrass		TX A&H-Dallas/Engelke	2,500	42,585	42,000	40,000	40,000	40,000	45,000	45,000	45,000	387,085	
Multiple Sites		SUBTOTALS:	20,500	80,785	169,500	198,500	208,000	217,000	279,000	323,800	333,800	328,800	2,159,685
		University Trials											
Screening													
Bentgrass		Univ of GA/Carrow											
Zoysiagrass		Univ of GA/Carrow											
Cultural Practices		Management	SUBTOTALS:	0	0	0	0	0	58,000	58,000	50,400	66,200	232,600
	MI State/Branham				10,000	15,000	15,000					40,000	
	Pathology	OH State/Danneberger				15,000	15,000					30,000	
		WA State/Braun		1,243	1,000								2,243
	Soil Compaction	TX A&H-Dallas/Colbaugh					10,000	10,000	10,000	10,000	10,000	10,000	60,000
		MI State/Vargas		15,000									15,000
	Salt Screening	Cornell/Petrovic		1,500									1,500
		Cornell-OR ST/Smiley			7,000						1,000		8,000
	Interactions	NC State/Lucas			10,000	10,000	10,000						30,000
		MI State/Rieksa	3,000	3,000	3,000	5,000							14,000
Stress Mechanisms	Morphology	Univ of GA/Carrow			15,000	15,000	15,000	15,000	18,000	18,000	18,000	117,000	
		TX A&H-El Paso/Horst		3,480	15,000	15,000	15,000	15,000	15,000	25,000	29,000	78,480	
	Endophytes	Univ of NE/Horst		4,000	23,000	20,000	20,000	25,000	25,000	25,000	29,000	171,000	
		MS State/Krans							2,500				2,500
	Pathology	Independent/Stacy								10,000	10,000	20,000	
		Univ of RI/Jackson								40,000	40,000	40,000	120,000
	Salt Tolerance	SUBTOTALS:	3,000	28,223	69,000	95,000	100,000	65,000	70,500	103,000	108,000	68,000	709,723
		MI State/Cookingham	5,000	96,326	68,000	55,000	65,000	65,000	60,000	70,000	70,000	70,000	624,326
	Lit Review	SUBTOTALS:	5,000	96,326	68,000	55,000	65,000	65,000	60,000	70,000	70,000	70,000	624,326
		Univ of IL/Smith						8,400		9,000	9,000	9,000	35,400
Meetings	OH State/Shane					10,000			10,500			30,500	
	MS State/Krans									21,900	21,900	43,800	
Annual Report	Rutgers/Funk-Day					10,000	8,400	10,000	59,500	70,900	70,900	229,700	
	SUBTOTALS:	84,500	87,000	91,000	73,000	70,000	55,000	67,800	29,000			528,300	
Legal Fees	Heat & Drought	TX A&H-Col. Stn./Beard											
	Salt Tolerance	TX A&H-El Paso/Horst											
Environmental Administration	Inspections	SUBTOTALS:	84,500	87,000	91,000	73,000	70,000	55,000	67,800	29,000	0	0	557,300
		Lit Review	Spectrum Res./Balogh										
Annual Report	Legal Fees	SUBTOTALS:	0	0	0	0	0	0	25,000	14,000	39,000	39,000	107,000
		Meetings											
Annual Report	Legal Fees	Inspections											
		Annual Report											
Legal Fees	SUBTOTALS:												
		TOTALS:	13,500	13,766	19,319	11,100	16,500	30,500	35,000	36,422	30,000	42,000	248,107
Legal Fees	SUBTOTALS:												
		TOTALS:	136,500	306,100	416,819	432,600	480,000	470,000	620,300	747,317	740,500	712,900	5,053,036

## Appendix B: List of Graduate Students

### University of Arizona

Andrew Ralowicz (Ph.D. completed)

### Colorado State University

Alan Abellanos (Ph.D. candidate)

Emmie Msiska (M.S. 1991)

Julie Etra (M.S. 1983)

Ronald M. Dahlin (M.S. 1992)

Steve Keeley (Ph.D. candidate)

Scott Reid (M.S. candidate)

Eric Earvin (M.S. candidate)

### University of Illinois

M. J. Meyer (M.S. candidate)

Y. Kuo (M.S. candidate)

Stanely Chen (Ph.D. candidate)

Jeff Meyer (JBT scholar)

### Rutgers University

Chan-Seok Oh (student of Dr. Brad Hillman)

Dr. Lisa Lee (Post doctoral)

David Huff (Post doctoral)

Melodee Kemp (Ph.D. 1991)

Sucichang Sun (M.S. candidate)

### Texas A&M

Ki S. Kim (Ph.D.)

Virginia Lehman (Ph.D.)

David M. Casnoff (Post doctoral)

David Huff (Post doctoral)

Bridget Ruemmele (Post doctoral)

Richard White (Post doctoral)

Michael Kenna (Post doctoral)

### Oklahoma State University

David Gerken (M.S. candidate, Horticulture)

Kevin Hays (M.S. 1989, Horticulture)

Rodrigo Artunduaga (Ph.D. 1987, Crop Science)

Mohamed Chakroun (Ph.D. 1991, Crop Science)

Mark Gatschet (Ph.D., candidate, Crop Science)

John Lamle (M.S., 1992, Agronomy)

### University of Nebraska

Sarah Browning (M.S. completed)

S. A. de Shazer (M.S. candidate)

Kimberly S. Erusha (M.S., Ph.D.)

Rob Hilton (M.S. completed)

Katie Kerner (M.S.)

Kyoung Nam Kim (Ph.D.)

Jeff Klingenberg (Ph.D.)

Jennifer Johnson-Cicalese (Ph.D. candidate)

Ron Moore (M.S. completed)

Sam Royes (M.S. candidate)

Thomas Salaiz (M.S.)

Debbie Schwarze (M.S. completed)

Jeana Frogge Svoboda (M.S. completed)

### University of Georgia

Greg Wiecko (Ph.D. completed)

### New Mexico State University

David S. Wofford (Ph.D. completed)

B. N. Coffey (Ph.D.)

R. E. (Roch) Gaussoin (M.S.)

J. P. (Jeff) Klingenberg (M.S.)

### North Carolian State University

L. B. McCarty (Post doctoral student)

### University of Minnesota

Bridget Ruemmele (Ph.D.)

### Michigan State University

R. E. (Roch) Gaussoin (Ph.D.)

James A. Murphy (M.S., Ph.D.)

### Ohio State University

J. C. Stier (M.S.)

### University of Georgia

G. Wiecko (Ph.D.)

## Appendix C: List of Theses

### Ohio State University (Danneberger - Heat Shock Proteins)

Stier, J. C. 1991. Detection of Leptosphaeria korrae in Turfgrass Using Monoclonal Antibody in Indirect Enzyme-linked Immunosorbent Assay. M.S. Thesis, The Ohio State University. 119 pp.

### Texas A&M University (Engelke - Bentgrass Breeding)

Lehman, Virginia. 1990. Selection for Summer Stress Resistance in Creeping Bentgrass. Texas A&M University.

### Oklahoma State University (Taliaferro - Bermudagrass Breeding)

Hays, Kevin L. 1989. Drought Avoidance Mechanisms of Selected Bermudagrass Genotypes. M.S. Thesis, Oklahoma State University, Stillwater, OK 74078.

Artunduaga, Ivan Rodrigo. 1987. Development and Evaluation of Techniques for Regenerating Plantlets From Somatic and Gametophytic Tissues of Selected Grasses. Ph.D. Thesis, Oklahoma State University, Stillwater, OK 74078.

Lamle, John T. 1992. Cytological analysis of self incompatibility in bermudagrass. M.S. Thesis, Oklahoma State University, Stillwater, OK 74078.

Mohamed Chakroun, 1991. In vitro culture and selection strategies for selected forage and turf grasses. Ph.D. Thesis, Oklahoma State University, Stillwater, OK 74078.

### University of Nebraska (Riordan - Buffalograss Breeding)

Browning, Sarah J., 1990. Buffalograss Sex Expression and Correlation with Turf-Type Characteristics, M.S. Thesis. University of Nebraska, Lincoln, NE.

Hilton, Robin J., 1991. Functional Evaluation of a Mechanical Plugger for Buffalograss Turf, M.S. Thesis. University of Nebraska, Lincoln, NE.

Moore, Ronald, 1991. The In Vitro Culture of Buchloe Dactyloides (Nutt.). Engelm., M.S. Thesis. University of Nebraska, Lincoln, NE.

Schwarze, Debra J., 1991. The Influences of Prerooting of Plugs on the Establishment of Buffalograss, M.S. Thesis. University of Nebraska, Lincoln, NE.

Svoboda, Jeana L. Frogge, 1991. Seedling Germination and Establishment of Buffalograss Caryopses vs. Burs, M.S. Thesis. University of Nebraska, Lincoln, NE.

Kingenberg, Jeffery P., 1992. Evaluation, Genetic Variation, and Selection for Improvement of a Seeded Turf-Type Buffalograss Population. Ph.D. Dissertation. University of Nebraska, Lincoln, NE.

### University of Arizona (Mancino - Curly Mesquitegrass Breeding)

Ralowicz, A. E. 1991. Evaluation and Breeding of Hilaria belangeri for Turfgrass Use. Ph.D. Dissertation, University of Arizona

### University of Nebraska (Cultural Practices - Shearman)

Erusha, Kimberly S. 1986. Turfgrass Rooting Response in Hydroponics. M.S. Thesis. University of Nebraska, Lincoln, NE.

Erusha, Kimberly S. 1990. Irrigation and Potassium Effects on a Kentucky Bluegrass Fairway Turf. Ph.D. Dissertation. University of Nebraska, Lincoln, NE.

Salaiz, T. A. 1991. Mowing Height and Vertical Mowing Frequency Effects on Putting Green Quality. M.S. Thesis. University of Nebraska, Lincoln, NE.

### University of Georgia (Carrow - Soil Compaction and Water Use)

Wiecko, G. 1990. Effects of Cultivation and Wetting Agents on Turfgrass Growth and on Alleviation of Soil Compaction. Ph.D. Thesis.

### New Mexico State University (Baltensperger - Bermudagrass Breeding)

Klingenberg, J.P. 1987. Self-Fertility Study of Ten Bermudagrass Genotypes. M.S. Thesis, New Mexico State University, Las Cruces, NM 88003.

**University of Illinois (Smith - Micropropagation Techniques)**

Kuo, Y. 1992. Cell level selection for salt tolerance (ST) in some turfgrass species and confirmation of whole plant salt tolerance characteristics. M.Sc. candidate.

## Appendix D: List of Publications

### Texas A&M University (Dr. James B. Beard)

- Beard, James B. 1992. Trees or turf?. *Grounds Maintenance* 27(10): 12-14. TGIF# 25447
- Beard, J. B., R. L. Green, and S. I. Sifers. 1992. Evapotranspiration and leaf extension rates of 24 well-watered, turf-type *Cynodon* genotypes. *HortScience* 27(9): 986-988. TGIF# 24947
- Beard, James B. 1991. Water hogging turf: fact or fancy. p. 62-68. *In Proceedings of the 62nd International Golf Course Conference and Show*. TGIF# 25240
- Beard, James B. 1991. Positive benefits of turfgrass. *In Proceedings of the 62nd Annual Michigan Turfgrass Conference* 21:73-74. TGIF# 24979
- Atkins, C. E., R. L. Green, S. I. Sifers, and J. B. Beard. 1991. Evapotranspiration rates and growth characteristics of ten St. Augustinegrass genotypes. *HortScience* 26(12): 1488-1491. TGIF# 22118
- Beard, J. B. 1991. Turfgrass Saves Water Resources. *Greenmaster* 25(3): 40,42. TGIF# 20994
- Beard, James B. 1990. Turfgrass Color: When Green is Bad. *Grounds Maintenance* 25(9): 28-32. TGIF# 20245
- Oprisko, Marianne J., Robert L. Green, James B. Beard, and Charles E. Gates. 1990. Vital staining of root hairs in 12 warm-season perennial grasses. *Crop Science* 30(4): 947-950. TGIF# 18309
- Green, R. L., J. B. Beard, and D. M. Casnoff. 1990. Leaf blade stomatal characterizations and evapotranspiration rates of 12 cool-season perennial grasses. *HortScience* 25(7): 760-761. TGIF# 18262
- Green, R. L., K. S. Kim, and J. B. Beard. 1990. Effects of Flurprimidol, Mefluidide, and Soil Moisture on St. Augustinegrass evapotranspiration rate. *HortScience* 25(4): 439-441. TGIF# 11407
- Casnoff, D. M., R. L. Green, and J. B. Beard. 1989. Leaf blade stomatal densities of ten warm-season perennial grasses and their evapotranspiration rates. *In Proceedings of the Sixth International Turfgrass Research Conference [Tokyo, Japan]* 6:129-131. TGIF# 17101
- Beard, J. B. 1989. Turfgrass water stress: drought resistance components, physiological mechanisms, and species-genotype diversity. *In Proceedings of the Sixth International Turfgrass Research Conference [Tokyo, Japan]* 6:23-28. TGIF# 17030
- Beard, James B., and Ki S. Kim. 1989. Low-water-use Turfgrasses. *USGA Green Section Record* 27(1): 12-13. TGIF# 14011
- Beard, James B. 1989. The Role of Turf. *Grounds Maintenance* 24(9): 36,38,107. TGIF# 19319
- Beard, J. B. 1988. Controlling turfgrass water use rates. *New Zealand Turf Management Journal* 2(2):12. TGIF# 18974
- Kim, Ki S., James B. Beard, and Samuel I. Sifers. 1988. Drought Resistance Comparisons Among Major Warm-Season Turfgrasses. *USGA Green Section Record* 26(5): 12-15. TGIF# 13841
- Beard, James B. 1988. Checklist of Water Conservation Strategies. *Grounds Maintenance* 23(4):6-18. TGIF# 12233
- Beard, James B. and Ki S. Kim. 1988. Turfgrass evapotranspiration research at Texas A&M University provides new information on low water use turfgrasses. *New Zealand Turf Management Journal*, August 1988:17. TGIF# 14250
- Kim, K. S., and J. B. Beard. 1988. Comparative turfgrass evapotranspiration rates and associated plant morphological characteristics. *Crop Science* 28(2):328-331. TGIF# 11968
- Beard, James B. 1987. Perennial Ryegrass Cultivar Update. *Grounds Maintenance* 22(7): 22-66. TGIF# 10689
- Beard, James B. 1987. New Warm Season Turfgrass Cultivars. *Grounds Maintenance* 22(4): 10-12. TGIF# 10027
- Beard, James B. 1986. Zoysiagrass Assessment. *Grounds Maintenance* 21(4): 92. TGIF# 8394
- Beard, James B. 1986. Temperature Stress Hardiness of Perennial Ryegrasses. *Grounds Maintenance* 21(4): 84,86. TGIF# 8392
- Beard, James B. 1986. Controlling Turfgrass Water Use Rates. *Grounds Maintenance* 21(4): 80-83. TGIF# 8391
- Beard, James B. 1986. Turfgrass Water Use Rates. *Grounds Maintenance* 21(1): 60,62. TGIF# 8054
- Casnoff, D. M., and J. B. Beard. 1986. Comparative Rooting of Warm Season Turfgrasses. *Grounds Maintenance* 21(9): 64. TGIF# 13423
- Beard, J. B., and M. C. Engelke. 1985. An environmental genetics model for turfgrass improvement: physiological aspects. *In Proceedings of the Fifth International Turfgrass Research Conference* 5:107-118. TGIF# 9000
- Beard, James B. 1985. Turfgrass water conservation strategies. p. 96-107. *In Proceedings of the Turf Conference of the Midwest Regional Turf Foundation*. TGIF# 7897
- Beard, James B. 1985. Nutritional strategies for summer heat and drought tolerance. p. 108-109. *In Proceedings of the Turf Conference of the Midwest Regional Turf Foundation*. TGIF# 7682
- Beard, J. B. 1985. Turfgrass physiology research: 1981-85. *In Proceedings of the Fifth International Turfgrass Research Conference* 5:81-104. TGIF# 8998
- Beard, James B. 1985. The 1980's - A decade of challenge for the turfgrass industry. p. 6-7. *In Proceedings of the Turf Conference of the Midwest Regional Turf Foundation*. TGIF# 7356
- Beard, James B. 1985. Turfgrass Water Conservation Strategies. *Oklahoma Turf* 3(1 and 2):6-10. TGIF# 6332
- Beard, J. B., and D. Johns. 1984. Research Update: Water Conservation - A Potentially New Dimension in the Use of Growth Regulators. *Golf Course Management* 52(4): 86-87. TGIF# 18829
- Beard, James B. 1984. The Contribution of Research to Quality Playing Conditions. *Greenmaster* 20(8):23-28. TGIF# 2308
- Johns, D., J. B. Beard, and C. H. M. Van Bavel. 1983. Resistances to evapotranspiration from a St. Augustinegrass turf canopy. *Agonomy Journal* 75(3):419-422. TGIF# 487

### Michigan State University (Dr. Bruce E. Branham)

- Branham, Bruce., 1991. Dealing with *Poa annua*. *Golf Course Management* 59(9): 46,48,50,52,54,58, and 60. TGIF# 21699
- Branham, B. E. 1990. 1989 Weed Control, PGR, and Management Update - Fairway management study. *Proceedings of the 60th*

- Annual Michigan Turfgrass Conference 19:22,38. TGIF# 18612
- Branham, B. E. 1990. A Selective Annual Bluegrass Control - Finally!. USGA Green Section Record 28(1):6-8. TGIF# 17425
- Branham, Bruce. 1989. 1988 Turf Weed Control, PGR, and Management Studies. Proceedings of the 59th Annual Michigan Turfgrass Conference 18:4-16. TGIF# 20471, 20472, 20473, and 20474
- Gaussoin, R. E., and B. E. Branham. 1989. Influence of cultural factors on species dominance in a mixed stand of annual bluegrass/creeping bentgrass. Crop Science 29(2):480. TGIF# 14466
- Gaussoin, R. E., and B. E. Branham. 1988. Plant growth regulator effects on annual bluegrass/creeping bentgrass competition. In Proceedings of the 58th Annual Michigan Turfgrass Conference 17:52-56. TGIF# 24360 and 24362
- Hendricks, M. G., and B. E. Branham. 1988. Management of mixed annual bluegrass/creeping bentgrass fairways. Proceedings of the 58th Annual Michigan Turfgrass Conference 17:39-43. TGIF# 24351, 24532, and 24353
- Branham, B. E., and K. V. Hanson. 1988. Progress - A selective annual bluegrass control. 1988. Proceedings of the 58th Annual Michigan Turfgrass Conference 17:32-36. TGIF# 24348 and 24349
- Jacobs, B. A., and B. E. Branham. 1988. 1987 Postemergence crabgrass control results: tolerance of creeping bentgrass to fenoxaprop. In Proceedings of the 58th Annual Michigan Turfgrass Conference, 1988;17:27,31. TGIF# 24347
- Hendricks, M. G., B. E. Branham, and M. Collins. 1987. Managing mixed annual bluegrass creeping bentgrass fairways: Field Experiment 2. In Proceedings of the 57th Annual Michigan Turfgrass Conference 16:70-77. TGIF# 14722
- Gaussoin, R. E., and B. E. Branham. 1987. Annual bluegrass and creeping bentgrass germination response to flurprimidol. HortScience 22(3):441-442. TGIF# 10374
- Hendricks, M. G., Branham, B. E., and M. Collins. 1987. Managing mixed annual bluegrass creeping bentgrass fairways: Field Experiment 1. In Proceedings of the 57th Annual Michigan Turfgrass Conference 16:70-77. TGIF# 10253
- Gaussoin, R. E., and B. E. Branham. 1987. Annual bluegrass/creeping bentgrass competition. In Proceedings of the 57th Annual Michigan Turfgrass Conference 16:62-69. TGIF# 10252
- Danneberger, T. K., B. E. Branham, and J. M. Vargas Jr. 1987. Mefluidide applications for annual bluegrass seedhead suppression based on degree-day accumulation. Agronomy Journal 79(1):69-71. TGIF# 9260
- Branham, B. E., and K. V. Hanson. 1987. 1986 PGR and weed control research: Rooting studies. Proceedings of the 57th Annual Michigan Turfgrass Conference 16:78-83. TGIF# 10254
- Gaussoin, R. E., B. E. Branham, and P. E. Rieke. 1986. Creeping bentgrass/annual bluegrass competition. In Proceedings of the 56th Annual Michigan Turfgrass Conference 15:24-28. TGIF# 10293
- Branham, B. E., and M. Collins. 1986. 1985 Research update: Ethofumesate for annual bluegrass control. In Proceedings of the 56th Annual Michigan Turfgrass Conference 15:32-33. TGIF# 16208
- Gaussoin, R. E., B. E. Branham, and P. E. Rieke. 1985. Cultural factors in annual bluegrass and creeping bentgrass Competition. In Proceedings of the 55th Annual Michigan Turfgrass Conference 14:35-38. TGIF# 13328

**Cornell University (Dr. Richard W. Smiley)**

- Smiley, R. W. 1989. Biology of soilborne pathogens causing patch diseases of turfgrasses. In Proceedings of the Sixth International Turfgrass Research Conference [Tokyo, Japan] 6:55-60. TGIF# 17055
- Smiley, Richard W. 1988. Bluegrass Patch Diseases: The Etiologic Dilemma. ALA 9(1):42-45. TGIF# 12005
- Smiley, Richard W. 1987. The etiologic dilemma concerning patch diseases of bluegrass turfs. Plant Disease 71(9):774-781. TGIF# 10994
- Smiley, Richard. 1987. Summer Patch and Necrotic Ring Spot. Golf Course Management 55(2):74-78. TGIF# 10645
- Smiley, Richard. 1986. Summer Patch and Necrotic Ring Spot in New York and Adjacent States. TurfNews [ASPA] 9(3):24,26,29-30,33. TGIF# 23001
- Smiley, R. W., and D. E. Giblin. 1986. Root cortical death in relation to infection of Kentucky bluegrass by *Phialophora graminicola*. Phytopathology 76(9):917-922. TGIF# 8672
- Smiley, R. W., M. Craven-Fowler, and L. Buchanan. 1985. Bioassay of phytotoxins associated with healthy and patch disease-affected *Poa pratensis* turfgrass. In Proceedings of the Fifth International Turfgrass Research Conference 5:619-628. TGIF# 9053
- Smiley, R. W., R. T. Kane, M. Craven-Fowler. 1985. Identification of *Gaeumannomyces*-like fungi associated with patch diseases of turfgrasses in North America. In Proceedings of the Fifth International Turfgrass Research Conference 5:609-618. TGIF# 9052
- Smiley, Richard W. 1985. Summer patch and necrotic ring spot: Newly described components on the Fusarium Blight Syndrome. In Proceedings of the 55th Annual Michigan Turfgrass Conference 14:75-83. TGIF# 13451
- Smiley, R. W. 1985. Techniques for inducing summer patch symptoms on *Poa pratensis*. Plant Disease 69(6):482-484. TGIF# 5008
- Smiley, R. W., M. Craven-Fowler, and R. C. O'Knefski. 1985. Arsenate herbicide stress and incidence of summer patch on Kentucky bluegrass turfs. Plant Disease 69(1):44-48. TGIF# 1598
- Smiley, R. W., and M. Craven-Fowler. 1984. *Leptosphaeria korrae* and *Phialophora graminicola* associated with Fusarium Blight Syndrome of *Poa pratensis* in New York. Plant Disease 68(5):440-442. TGIF# 1385

**Colorado State University (Cuany and Koski - Native Grass Breeding)**

- Cuany, R. L., and G. L. Thor. 1988. Native grasses for dryland turf and reclamation. Proceedings 30th N. American Grass Breeders Conf., Silver Falls, OR, p. 51.
- Cuany, R. L., and G. L. Thor. 1988. Breeding western grasses for turf. Proceedings Western Society of Crop Sci., Fort Collins, CO, p. 2.
- Nason, Debora A., Robin L. Cuany, and A. M. Wilson. 1987. Recurrent selection in blue grama. I. Seedling water uptake and shoot weight. Crop Science 27(5):847-851. TGIF# 10960
- Cuany, R. L., A. M. Wilson, and G. L. Thor. 1984. Grasses for reclamation and multiple uses. Proceedings 28th N. American Grass



Breeders Conf., College Station, TX, p. 96-97.

#### University of Illinois (Smith - Micropropagation Techniques)

- Smith, M. A. L., J. Meyer, S. L. Knight, and G. S. Chen. 1997. Gauging turfgrass salinity responses in whole plant microculture and solution culture. *Crop Science* (in press).
- Kuo, Y. J., and M. A. L. Smith. 1997. Plant regeneration of St. Augustinegrass 'Texas Common' from immature embryo-derived callus. (in review).
- Kuo, Y. J., M. A. L. Smith, and L. A. Spomer. 1997. Single step cell culture selection for more salt tolerance of seaside creeping bentgrass. (in review).
- Smith, M. A. L. 1991. Bridging plant biotechnology and field research. *Illinois Research Spring/summer 1991*, p. 25.
- Meyer, M. J., M. A. L. Smith, and S. L. Knight. 1989. Salinity effects on St. Augustinegrass: A novel system to quantify stress response. *Journal of Plant Nutrition* 12:893-908.
- Meyer, M. J., M. A. L. Smith, and S. L. Knight. 1989. A new system for evaluating turfgrass response to salt stress. *Illinois Turfgrass Reports* 9:7.
- Meyer, M. J., M. A. L. Smith, and S. L. Knight. 1989. An improved system for detecting turfgrass stress responses. *HortScience* 24:134.
- Smith, M. A. L. 1991. In vitro microshoot development. *Rice Biotechnology Quarterly* 6:32.
- Pieper, M. A., and Smith, M. A. L. 1988. A whole plant microculture selection system for Kentucky bluegrass. *Crop Science* 28(4):611-614. TGIF# 12646

#### The Ohio State University (Shane and Nameth - Patch Diseases)

- Shane, W. W. 1991. Prospects for early detection of pythium blight epidemics on turfgrass by antibody-aided monitoring. *Plant Disease* 75(9):921-925. TGIF# 21556
- Nameth, S. T., W. W. Shane, and J. C. Stier. 1990. Development of monoclonal antibody for detection of *Leptosphaeria korrae*, the causal agent of necrotic ringspot disease of turfgrass. *Phytopathology* 80:1208-1211. TGIF# 19907
- Stier, J. C., and W. W. Shane. 1988. Time course of pythium blight development on turfgrass under controlled environmental conditions. *Phytopathology* 78(12):1612. TGIF# 14157
- Shane, W. W., and S. T. Nameth. 1988. Monoclonal antibodies for diagnosis of necrotic ringspot of turfgrass. *Phytopathology* 78:1521. TGIF# 14146

#### Texas A&M-Dallas (Engelke - Bentgrass Breeding)

- Lehman, V. G., and M. C. Engelke. 1997. Response and heritability of creeping bentgrass shoot water content under soil dehydration and temperature stress. *Crop Science* (in review).
- Engelke, M. C., and V. G. Lehman. 1997. Comparative heat tolerance of commercially available creeping bentgrass cultivars. *HortScience* (in review).
- Lehman, V. G. and M. C. Engelke. 1997. Heritability of leaf water potential of creeping bentgrass germplasm under soil dehydration and temperature stress. *Crop Science* (in review).
- Lehman, V. G., and M. C. Engelke. 1991. Heritability estimates of creeping bentgrass root systems grown in flexible tubes. *Crop Science* 31(6):1680-1884. TGIF# 22127
- Lehman, V. G., and M. C. Engelke. 1990. Use of Flexible Tubes to Characterize Creeping Bentgrass Root Systems. In *Texas Turfgrass Research Reports - 1990* PR-4736:5-9.
- Lehman, V. G., and M. C. Engelke. 1990. 1989 Performance of Creeping Bentgrass Cultivars on a Sand Modified Green: Dallas. In *Texas Turfgrass Research Report - 1990* PR-4746:29-30.
- White, R. H., M. C. Engelke, and S. J. Morton. 1990. Nitrogen Sources Affect Pennncross Bentgrass Turf Quality. In *Texas Turfgrass Research Report - 1990* PR-4768:78-80.
- Engelke, M. C. 1990. As One Decade Ends and Another Begins: A Scientist's Report and Reflections on a Technical Conference Overseas. *Golf Course Management* 58(1):118-124. TGIF# 16883
- Engelke, M. C. 1988. Dealing with the Drought: Guidelines for Management - A Turfgrass Breeder's Views. *Golf Course Management* 56(8):50. TGIF# 13851
- Engelke, Milt. 1987. Texas Studies Water Requirements. *Grounds Maintenance* 22(8):50-52. TGIF# 10981
- Lehman, V. G., and Engelke, M. C. 1985. A rapid screening technique for genetic variability in turfgrass root systems. In *Proceedings of the Fifth International Turfgrass Research Conference* 5:769-776. TGIF# 9071
- Engelke, M. C., J. B. Beard, P. F. Colbaugh. 1985. An environmental genetics model for turfgrass improvement: Developmental aspects. In *Proceedings of the Fifth International Turfgrass Research Conference* 5:127-136. TGIF# 9002

#### Oklahoma State University (Taliaferro - Bermudagrass Breeding)

- Chakraborty, M., C. M. Taliaferro, B. B. Johnson, and A. C. Guenzi. 1997. Induction of embryogenic callus and plant regeneration from mature *Cynodon* caryopses. *Plant Tissue, Cell and Organ Culture* (in review).
- Chakraborty, M., C. M. Taliaferro, B. B. Johnson, and A. C. Guenzi. 1997. Effects of basal media and auxins on embryogenic callus induction and regeneration from three bermudagrass accessions. *Vitro Cellular & Development Biology* (in review).
- Carver, Brett F. and C. M. Taliaferro. 1997. Selection Theory and Procedures in Progenies of Distant Hybrids. In Kallio and J. B. Chowdhury (eds.) *Distant Hybridization of Crop Plants. Monograph of Theoretical and Applied Genetics*. Springer Verlag. F.

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- Conway, K. E., C. M. Taliaferro, and R. A. Shelby. 1992. First report on formation of sclerotia of *Claviceps purpurea* on bermudagrass (*Cynodon dactylon*). Plant Disease 76(10):1077. TGIF# 25376
- Taliaferro, Charles M. 1992. Out of Africa - A New Look at "African" Bermudagrass. USGA Green Section Record 30(4):10-12. TGIF# 24775
- Hays, K. L., J. F. Barber, M. P. Kenna, and T. G. McCollum. 1991. Drought avoidance mechanisms of selected bermudagrass genotypes. HortScience 26:180-182.
- Conway, K. E., and C. M. Taliaferro. 1990. Occurrence of *Claviceps purpurea* and hyperparasites on bermudagrass (*Cynodon dactylon*) and Old World bluestem (*Bothriochloa* spp.). Phytopathology 80(10):1043. TGIF# 20001
- Springer, T. L., and C. M. Taliaferro. 1989. Effect of forage harvest frequency on bermudagrass seed yield under dryland conditions. J. Appl. Seed Prod. 7:46-49.
- Brede, J. L., A. D. Brede, and C. M. Taliaferro. 1989. Development of improved, cold-tolerant, seed-propagated, turf-type bermudagrass cultivars. p. 99-101. In Proceedings 6th International Turfgrass Conference, Tokyo, Japan, July 31-August 5, 1989. TGIF# 17079
- Artunduaga, I. R., C. M. Taliaferro, and B. B. Johnson. 1988. Effects of auxin concentration on induction and growth of embryogenic callus from young inflorescence explants of Old World bluestem (*Bothriochloa* spp.) and bermuda (*Cynodon* spp.) grasses. Plant Cell, Tissue and Organ Culture 12:13-19.
- Anderson, J. A., M. P. Kenna, and C. M. Taliaferro. 1988. Cold hardiness of 'Midiron' and 'Tifgreen' bermudagrass. HortScience 23(4):748-750. TGIF# 13163
- Taliaferro, C. M. 1984. Research Update: A New Seed-Propagated Bermudagrass. Golf Course Management 52(2):85. TGIF# 18764
- Taliaferro, C.M. 1983. Guymon - A New Seed-Propagated Bermudagrass Variety. Oklahoma Turf 1(4):3. TGIF# 8451

#### University of Nebraska (Riordan - Buffalograss Breeding)

- Riordan, T. P., S. A. De Shazer, F. P. Baxendale, M. C. Engelke. 1992. Registration of '609' buffalograss. Crop Science 32(6):1511. TGIF# 25972
- Moore, Ronald W., K. M. Eskridge, P. F. Read, F., and T. P. Riordan. 1991. Optimizing callus initiation using stolon nodal segments of Buffalograss NE 84-609 and a response surface design. HortScience 26(6):766. TGIF# 21689
- Riordan, Terrance P. 1991. Alternative Grasses for Roughs. Golf Course Management 59(6):82-84. TGIF# 21212
- Riordan, Terry. 1991. Buffalograss. Grounds Maintenance 26(2):12-14. TGIF# 21116
- Riordan, Terry. 1991. An Old Grass is Getting a New Look. USGA Green Section Record 29(1):6-9. TGIF# 20094
- Riordan, T. P. 1990. Low Maintenance Turfs Recommended for Roughs. Landscape Management. April 1990, p. 16.
- Riordan, Terrance P. 1990. Low maintenance alternative species for golf course roughs. p. 9. In Proceedings of the 61st International Golf Course Conference and Show. TGIF# 21627
- Riordan, Terrance, and Sarah Browning. Buffalograss: An Option for Drought-Wary Operators. 1989. Lawn and Landscape Maintenance, November 10(11):60-61. TGIF# 20699
- Riordan, Terrance P. 1985. Selecting turfgrasses for quality turf. p. 94-95. In Proceedings of the Turf Conference of the Midwest Regional Turf Foundation, March 1985. TGIF# 7681
- Riordan, Terrance P. 1985. Developing alternative turf species for golf course use. p. 92-93. In Proceedings of the Turf Conference of the Midwest Regional Turf Foundation, March 1985. TGIF# 7680
- Riordan, Terrance P. 1985. Selecting and using grasses for water conservation. p. 90-91. In Proceedings of the Turf Conference of the Midwest Regional Turf Foundation, March 1985. TGIF# 7679

#### University of Arizona (Mancino - Curly Mesquitegrass Breeding)

- Ralowicz, A. E., C. R. Mancino, and D. M. Kopec. 1997. Evaluation of curly mesquite for turfgrass use - Management practices and turfgrass qualities. HortScience (in review).
- Ralowicz, A. E., C. F. Mancino, and D. M. Kopec. 1997. Chemical enhancement of germination in curly mesquite seed. J. Range Manage. (accepted).
- Ralowicz, A. E., and C. F. Mancino. 1992. After-ripening in curly mesquite seeds. J. Range Manage. 45:85-87.
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- Ralowicz, A. E., C. F. Mancino, A. Maricic, D. Nelson, and D. M. Kopec. 1990. Turfgrass Evaluations of Curly Mesquitegrass. p. 53-57. In David M. Kopec (ed.) Turf and Ornamentals Research Summary 1989, Arizona Agric. Exp. Sta. Series P-80.
- Ralowicz, A. E., C. F. Mancino, and D. M. Kopec. 1989. Variation in Flowering and Germination in *Hilaria belangeri*. p. 21-22. In David M. Kopec (ed.) Turf and Ornamentals Research Summary 1988, Arizona Agric. Exp. Sta. Series P-75.
- Ralowicz, A. E., C. F. Mancino, L. Salo, and D. M. Kopec. 1988. Flowering characteristics in *Hilaria belangeri*. J. Arizona-Nevada Acad. Sci. 23:23-24.

#### Texas A&M-Dallas (Engelke - Zoysiagrass Breeding)

- White, R. H., M. C. Engelke, and S. J. Morton. 1997. Competitive turgor maintenance in zoysiagrass as compared to performance under linear gradient irrigation. Crop Science (in review).
- Marcum, K. B., and M. C. Engelke. 1992. Rooting characteristics of 25 zoysiagrasses grown in flexible plastic tubes. HortScience

- 27(6):675. TGIF# 25254
- Ruemmele, Bridget A., Robert Cunningham, and M. C. Engelke. 1992. Alternate sod production system for zoysiagrass. *HortScience* 27(6):588. TGIF# 25031
- White, R. H., S. J. Morton, B. A. Ruemmele, and M. C. Engelke. 1992. Competitive turgor maintenance in tall fescue. *Crop Science* 32(1):251-256. TGIF# 22956
- White, R. H., and M. C. Engelke. 1990. Shade Adaptation of Zoysiagrass Cultivars and Elite DALZ Experimental Lines. p. 26-27. *In* Richard White (ed.) Texas Turfgrass Research Report - 1990 PR-4744.
- White, R. H., M. C. Engelke, and S. J. Morton. 1990. Performance of Zoysiagrass Cultivars and Elite DALZ Lines Under Linear Gradient Irrigation. p. 33-36. *In* Richard White (ed.) Texas Turfgrass Research Report - 1990 R-4748.
- Ruemmele, B. A., and M. C. Engelke. 1990. Zoysiagrass Cultivars Today and Tomorrow. *Grounds Maintenance* 25(4):92-96,124-125. TGIF# 19448
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