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[a,b]		Mean Summer ET rate, mm d⁻¹	Rel. rank[c]
Cool Season	Warm Season		
	Buffalograss	5-7	Very low
	Bermuda hybrids[d]	6-7	Low
	Centipedegrass	6-9	
	Bermudagrass[d]	6-9	
	Zoysiagrass[d]	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 bluegrass		>10	
Kentucky bluegrass		4->10	
Italian rye		>10	

[a]Mean rate of water use averaged over 28 years of previous research and values determined by Beard (1989) and co-workers.
[b]Based on the most widely used cultivars of each species.
[c]Based on ranking by Beard (1989).
[d]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-leafed 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. • Deep, extensive root system • High root length density • High root hair density • Good root viability • Rolling, folding leaves • Thick cuticle on the leaves • Hairy leaf surfaces • Reduced leaf area through smaller leaves • Reduced leaf area through death of lower leaves or tillers • Slow leaf extension rates after mowing • Leaf densities and orientations contributing to high canopy resistances • Stomatal closure • Stomatal density • Stomata that are located so as to reduce transpiration • Smaller conducting tissue • Smaller mesophyll cells in leaves • Possible proline or betaine accumulation
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[a,b]		Relative ranking
Cool Season	Warm Season	
	Bermuda[b]	Superior
	Bermuda hybrids[b]	
	Buffalograss	Excellent
	Seashore paspalum[b]	
	Zoysiagrass	
	Bahiagrass	
Fairway wheatgrass	St. Augustine[b]	Good
	Centipedegrass	
	Carpetgrass	
Tall fescue		Moderate
Perennial ryegrass[b]		Fair
Kentucky bluegrass[b]		
Creeping bentgrass[b]		
Hard fescue		
Chewings fescue		
Red fescue		
Colonial bentgrass		Poor
Annual bluegrass		
Rough bluegrass		Very poor

From Beard 1989
[a]Based on the most used cultivars of each species.
[b]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 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.

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

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.