1997 Turfgrass and Environmental Research Summary

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1997
Turfgrass and Environmental Research Summary

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This report is prepared each year by the USGA Green Section. Dr. Michael P. Kenna, Rresearch Director, and James T. Snow, National Director, assemble and edit the annual progress reports submitted by USGA-sponsored researchers. If you would like a copy of the entire annual progress report for one of the research projects in this summary, please write to:

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Executive Summary

Overall Goals:

- *Reduce turfgrass water requirements, pesticide use, and maintenance costs.*
- *Protect the environment while providing good quality playing surfaces.*
- *Encourage young scientists to become leaders in turfgrass research.*

The Turfgrass and Environmental Research Program sponsored by the United States Golf Association, in cooperation with the Golf Course Superintendents Association of America, has three primary goals:

First, develop turfgrasses for golf courses that substantially reduce water use, pesticide use and maintenance costs;

Second, develop management practices for new and established turfs that protect the environment while providing quality playing surfaces;

Third, encourage young scientists to become leaders in turfgrass research through the USGA's direct involvement in and financial support of higher education in the United States.

This annual research summary reviews the progress made by USGA-sponsored researchers in projects directed toward:

1. Plant breeding for the development of turfgrasses with better resistance to stress and pest problems;
2. Evaluation of cultural practices that have potential to improve the ability of golf course turf to tolerate stress;
3. Evaluation of alternative pest control methods for use in integrated turf management systems;
4. Demonstrating that pesticides and fertilizers can be applied to golf course turf while protecting environmental quality;
5. Evaluation of the mobility and persistence in turfgrass systems of parent compounds and transformation products of commonly applied pesticides and fertilizers;
6. Identification of the best combinations of putting green construction, grow-in procedures and post-construction maintenance practices that prevent long-term problems, reduce environmental impacts, and produce high quality playing surfaces.

Highlights for 1993 through 1997

1. Turfgrass Breeding

The quality and stress tolerance of a turf is the product of the environment, management practices, and genetic potential of the grass plant. In many cases, various stress effects are the major causes of poor quality turf.

The turfgrass breeding projects are directed at reducing water and pesticide use through the development of resistance to several stress and pest problems. The most desirable characteristics of potential new turfgrasses include:

- Drought tolerance
- High and low temperature tolerance
- Tolerance of non-potable water
- Tolerance of acid, alkaline or saline soils
- Reduced mowing requirements
- Efficient use of fertilizers
- Traffic tolerance
- Genetic stability of characters
- Disease, insect and nematode resistance
- Competitiveness against weeds
- Tolerance to smog and other pollutants
- Shade tolerance

The USGA turfgrass breeding programs have focused on the improvement of bentgrass, bermudagrass, buffalograss, *Poa annua,* seashore paspalum, and zoysiagrass. The turfgrasses resulting from the sponsored research will meet the future needs of golf courses.

Breeding and Development of Bentgrass, *Texas A&M Univ.*

- *After 13 years of improving bentgrass, six cultivars with improved heat tolerance and disease resistance have been released: CATO, CRENSHAW, MARINER, CENTURY, IMPERIAL, and BACKSPIN. Three advanced lines are ready for release: Syn 96-1, Syn 96-2, and Syn 96-3.*
- *Several young scientists were trained and are becoming leaders in the turfgrass industry.*
- *New, innovative screening techniques were developed throughout the course of the project. For example, heat tolerance (heat bench), rooting depth (slant tube), linear gradient irrigation system (LGIS), insect and disease resistance, and salinity screening techniques were used.*

Breeding Seed- and Vegetatively-Propagated Turf Bermudagrasses for Golf Courses, *Oklahoma State University*

- *Two seeded, fine textured, cold hardy bermudagrasses were released (OKS 91-11 and OKS 91-3) allowing greater ease in establishment versus vegetative establishment.*
- *Developed a reproducible technique for evaluating cold tolerance of bermudagrass plants which shortens cultivar development.*
- *Incorporated the use of molecular tools to identify cold hardy genes.*
- *Collected several new bermudagrasses from around the world to add greater genetic diversity for cold hardiness, seed yield, and acceptable turf quality.*
- *Project reached out to other scientists in the Southern Great Plains region to aid in the development of bermudagrasses. For example, spring dead spot and insect resistance.*
- *Five graduate students and two postdoctral students were trained.*

Breeding, Evaluation, and Culture of Buffalograss for Golf Course Turf, University of Nebraska

- *Increased awareness and interest for use of buffalograss as a turfgrass species because of its inherent drought resistance and low maintenance.*
- *Developed vegetative buffalograss cultivars with better turf quality, tolerant to lower cutting heights, and extended range of adaptation. Cultvars include: 609, 378, 315, NE 86-61, NE 86-120 and NE 91-118.*
- *Sod production techniques, and improvement in sod quality of the new cultivars was achieved.*
- *Developed two seeded varieties,* CODY *and* TATANKA, *in cooperation with the Native Turfgrass Development Group.*
- *Through a team research approach, successfully developed management and establishment studies to go along with the release of the cultivars (insects, disease, mowing, irrigation, weed control, establishment, etc.).*
- *More than than 10 graduate students received M.S. or Ph.D. degrees during the project.*

Development of Multiple Stress Tolerant Seashore Paspalums for Golf Course Usage, *University of Georgia*

- *Three cultivars are ready for commercialization (AP 10, AP 14, and PI 509018-1). Seashore paspalum offers an alternative to bermudagrass with regards to greater salinity tolerance.*
- *Development of the species is environmentally beneficial because of its low nitrogen consumption (i.e., approximately half of bermudagrass)*
- *Developed management programs for the new cultivars. Field testing has been extensive in the development of the management programs for weed and insect control.*
- *An extensive worldwide collection (germplasm) is very diverse and has great potential to produce future varieties for golf courses.*

Breeding and Development of Zoysiagrass, *Texas A&M University*

- *Four new vegetative cultivars were developed:* DIAMOND, CAVALIER, PALISADES, *and* CROWNE.
- *Zoysia fairways can produce a quality golf surface in the transition zone. Improvements were made for fine texture, cold hardiness, salinity tolerance, shade tolerance, and color retention.*
- *Improved sod production quality (establishment rate and recoverability after harvest).*
- *Zoysiasgrass offers an alternative for semi-shaded in the southern part of the United States and can help prevent bermudagrass encroachment into bentgrass greens.*
- *Cooperation with other scientists to investigate host plant resistance to insects.*
- *Seven postdoctoral students were trained on the project.*

Improvement of *Poa annua* for golf courses, *University of Minnesota*

- *Developed first commercially available creeping bluegrass (*Poa annua var. reptans*) variety for use on putting greens.*
- *Learned much about the genetic aspects of* Poa annua.
- *Better understanding of the population dynamics of* Poa annua.
- *Scientists trained in the project. Three Ph.D. students.*

2. Cultural Practices

A series of research projects with the aim of substantial reduction in water use, pesticide use and maintenance costs have been and continue to be conducted on a regional basis. This is necessary because of regional differences in climate, soil, and stress conditions. The objectives of these studies have 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 that substantially reduce weedy species in golf turf
- Development of cultural practices that allow efficient turf management under conditions of poor quality soils or severe air pollution, or that permit the use of effluent or other marginal-quality waters
- New research techniques that reduce pesticide and other chemical usage

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.

Interseeding New Bentgrasses, Irrigation Management, and Selection of Bentgrasses with Superior Drought Resistance, *Texas A&M University*

- *Interseeding new bentgrass cultivars into* PENNCROSS *was successful. Population shifts of 5 to 30 percent were observed following a single interseeding in conjunction with minimal cultivation followed by topdressing.*
- *Frequent irrigation caused a decrease in turf quality and an increase in algae. However, some varieties proved to be more tolerant of frequent irrigation. Less frequent irrigation allowed a favorable water balance in specific cultivars without sacrificing putting green quality.*
- *Greenhouse and field drought resistance results were correlated, indicating that plant-water-status measurements (i.e., water potential at zero turgor, osmotic potential at full turgor, relative water content, apoplastic water fraction, bulk modulus of tissue elasticity, and turgid weight:dry weight ratios) could be used as a screening technique in breeding programs.*
- *Blending affected turf quality. Superior varieties had a positive impact on the stand while lesser varieties had a negative impact on the stand quality.*

Growth and Performance Differences among New Bermudagrass Cultivars and Ecotypes, *Auburn University*

- *Proper thatch management of ultra-dwarf cultivars and off-types (ecotypes) was only possible with intensive management (i.e., aerification, topdressing, grooming procedures, etc.)*
- *Ecotypes often appear in hybrid bermudagrass putting greens over time. Some of the ecotypes showed potential suitability as putting green turfgrasses in the Southeastern United States.*
- *Newly released* TIFEAGLE *and the ecotype Mobile 9 performed well and showed promise in this study.*

Biochemical and Molecular Analyses of Cold Acclimation in Bermudagrass (*Cynodon* spp.), *Clemson University*

- *Differences in cell membrane composition between cold-hard and cold-sensitive bermudagrass cultivars were identified during cold acclimation.*

- *Biochemical analysis of total cell membrane lipids identified important differences in the fatty acids chains of phospholipids.*
- *Bermudagrasses with 18 carbon fatty acid chains and three double bonds acclimated to cold temperatures better. This was quantified by calculating the double bond index (DBI).*
- *Considerable genetic variability among bermudagrasses and seashore paspalums was documented and should help turfgrass breeders develop cold-hardy, warm-season grasses.*

Turfgrass Irrigation with Municipal Effluent: Nitrogen Fate, Turf Crop Coefficients and Water Requirements, *University of Arizona*

- *The five popular methods of estimating evapotranspiration (ET) differ by as much as 30 perecent and demonstrates the importance to match crop coefficient (Kc) with the method used to estimate ET.*
- *Estimated winter crop coefficients for bermudagrass fairways overseeded with ryegrass were more variable than summer crop coefficients.*
- *Turf irrigated with effluent water generated higher growth rates and raised seasonal Kc by three percent.*
- *Water that moved through the ten-foot deep lysimeter had negligible amounts of fertilizer nitrogen. Tissue analysis reveals less than 30 perecent of applied nitrogen resides in clippings.*

Putting Green Characteristics Associated with Surface Depressions Caused by Selected Forms of Traffic, *Rutgers University*

- *Rigid tire (2.5 cm) wheel chair traffic caused greater depressions than pneumatic tires (3.5 cm) on the putting green surface.*
- *A relatively inexpensive penetrometer can be used to predict the damage caused by assistive equipment.*
- *Some assistive devices can be used on putting greens without reducing putting quality. However, the impact of these assistive devices will vary depending on green construction materials, management practices, and environmental conditions.*
- *Wheel traffic caused greater ball roll deflection than foot traffic.*
- *Pneumatic tires caused less damage than rigid tires.*
- *Moist soils resulted in more damage than dry soils.*

Determining Best Management Practices To Convert A Putting Green From Penncross To A New Variety. *North Carolina State University*

- *With one year of data, the greatest conversion from* PENNCROSS *to* A4 *occurred with JobSaver® plus Primo® resulting in a conversion of 20 percent. The least effective treatments were verticutting and verticutting plus Primo®.*
- *Reults indicated that conversion from* PENNCROSS *is probably feasible, but it will take a number of years.*
- *Complete conversion from Penncross to another variety will require fumigation or total renovation.*
- *A molecular method for measuring change in bentgrass populations over time was developed.*

3. Alternative Pest Management

Alternative pest management is intended to reduce the amount of pesticide needed to maintain golf course turfgrasses. An alternative method of pest control needs to be highly effective and must be field-testing under realistic golf course conditions in order to receive widespread acceptance by golf course superintendents.

The USGA has provided funding for the development and evaluation of alternative methods of pest control. Even though a great deal of time and effort has been devoted to the area of biological control, there are very few scientifically documented cases were these alternative controls perform as well as their pesticide counterparts.

In addition to new biological controls, more information is needed on the life cycle and behavior of common turfgrass pests. The correct treatment thresholds, cultural practices, use of resistant grasses, proper pesticide timing and placement all need to be considered carefully in all turfgrass management programs, especially in the case of soil-borne insect or disease problems.

The purpose of these research projects was to evaluate alternative methods of pest control for use in integrated turf management systems. Projects investigated alternative pest control methods that include:

- Genetic engineering or biotech approaches
- Biological control
- Non-chemical control, including cultural and mechanical practices
- Allelopathy
- Selection for host plant resistance to pests
- Application of integrated turf management practices utilizing IPM and low cultural inputs

Development of Improved Turfgrass with Herbicide Resistance and Enhanced Disease Resistance through Transformation. ***Rutgers University***

- *Creeping bentgrass is one of the more disease susceptible grasses maintained for turf purposes. This project has produced genetically engineered (transgenic) plants with disease resistance, salinity tolerance, and herbicide resistance genes.*
- *This project has pest resistant plants showing promise in the field which are ready to be integrated into the breeding program for cultivar development.*

Genetic Engineering of Creeping Bentgrass with a Disease Resistance (Chitinase) Gene and the Bialaphos-Herbicide Resistance Gene (bar), ***Michigan State University***

- *Researchers were able to incorporate the chitinase gene into bentgrass plants. This gene has the potential to aid in bentgrass disease resistance. Chitinase digests the cell walls of fungal pathogens.*
- *The bialophos gene was successfully incorporated into bentgrass plants and makes these plants tolerant of the pesticide. Bialophos has both herbicidal and fungicidal properties.*
- *This project has genetically engineered plants under evaluation in the field that are ready to be integrated into the breeding program for cultivar development.*

Genetic Basis of Biological Control in a Bacterium Antagonistic to Turfgrass Pathogens, ***Cornell University***

- *Using molecular biology, a bacteria strain was discovered that reduced the germination of soil borne diseases, especially* Pythium.
- *Researchers established the relationship between seed or plant exudates and the germination of* Pythium.

- *This information can be valuable to plant breeders for incorporation into breeding programs (i.e., breed turfgrasses with low exudate levels).*
- *This study provided convincing evidence for a biological control mechanism in which the bacterial biocontrol agent interacts directly with the plant, and only indirectly with the pathogen.*

Cultural Control, Risk Assessment, and Environmentally Responsible Management of White Grubs and Cutworms in Turfgrass, *University of Kentucky*

- *The project developed effective control strategies for cutworms and white grubs using cultural, environmental, and insect behavioral considerations that will reduce pesticide usage.*
- *The tremendous biodiversity of beneficial insects in golf course turfgrasses, and the importance of certain predators in the reduction of pest populations, were clearly demonstrated.*
- *Effective control strategies for cutworms, such as mowing putting greens early in the morning, not distributing clippings around the putting green, or controlling insect populations in the surround areas, will reduce pesticide use on golf courses.*
- *Cutworms do not like Kentucky bluegrass as a food source. Endophyte-infected cultivars did not provide significant resistance.*
- *Two insecticides (Merit and Mach 2) were identified that have low impact on beneficial and non-target species.*

Behavioral Studies of the Southern and Tawny Mole Cricket, *North Carolina State University*

- *Behavioral, biological and environmental factors which influence mole cricket activity on golf courses were identified.*
- *The lack of a pheromone may be significant in control of the mole crickets. The two species are aware of the presence of the other but a pheromone is not involved in their ability to detect each other.*
- *The Tawny mole cricket has a unique Y-shaped tunneling behavior that allows for easy feeding, escape from predators, and selection of comfortable temperature and moisture soil conditions.*
- *Management factors influence mole cricket behavior behavior (i.e., soil texture, moisture, temperature, pesticides, etc). These factors should be considered together to achieve better insect control.*

Pasteuria sp. for Biological Control of the Sting Nematode, *Belonolaimus longicaudatus*, in Turfgrass, *University of Florida*

- *A new species of bacterium,* Pasteuria, *that parasitizes the sting nematode was discovered.*
- *Results demonstrated that the sting nematode relationship with* Pasteuria *is density dependent. For example, as nematode number increase, so does the number of* Pasteuria *bacteria.*
- *The study showed that a relatively small amount of* Pasteuria-*infested soil can be introduced into a USGA green with a high number of sting nematodes and bring about suppression within about 12 months.*

4. Best Management Practices

The USGA completed a three-year research program in 1994 that examined the degradation and fate of turfgrass chemicals, as well as the development of alternative pest control methods and documentation of the turfgrass and golf courses benefits to humans, wildlife and the environment. As a continuation of a responsible and scientifically-based investigation of the environmental impact of golf courses, the

USGA sponsored additional research to understand the effects of turfgrass pest management and fertilization on water quality and the environment. This goal was achieved through a series of three-year research projects initiated in 1995 that focused on *Best Management Practices* and *Pesticide and Nutrient Fate.*

The purpose of the Best Management Practices research is to develop pesticide and fertilizer programs for golf courses that protect environmental quality. The current research projects focus on:

- Evaluating the effects of specific pesticides and nutrients that have a perceived environmental problem
- Identifying cultural practice systems that minimize pesticide and nutrient volatilization, surface runoff, and groundwater contamination

Evaluation of Best Management Practices to Protect Surface Water from Pesticides and Fertilizer Applied to Bermudagrass Fairways, *Oklahoma State University*

- *Chemical losses in surface runoff from turf can be reduced by maintaining non-treated buffers between surface water and areas treated with chemicals.*
- *The effective buffer length is dependent upon site conditions (longer buffers, in excess of 16 feet will perform better).*
- *A three-inch buffer mowing height is more effective than 0.5 or 1.5 inches.*
- *Avoid chemical applications following heavy irrigation or rainfall events.*
- *Choose pesticides and nutrients with low runoff potential.*

Evaluation of Management Factors Affecting Volatile and Dislodgeable Foliar Residues of Turfgrass Pesticides, *University of Massachusetts*

- *Of the 13 pesticides examined, 10 were deemed safe (based on USEPA Hazard Quotients).*
- *Organophosphorous insecticides with high vapor pressures and inherent high toxicity (ethoprop, isazafos, and diazinon) were deemed not completely safe.*
- *Golfers may be exposed to pesticide via volatilization.*
- *Thatch management or the use of spreader/stickers will likely be ineffective in mitigating unwanted exposure.*
- *The critical vapor pressure below which no turfgrass pesticide will volatilize to the extent that it will result in an inhalation HQ greater than 1.0 to be between 3.3 x 10-6 mm Hg.*

Mobility and Persistence of Turfgrass Pesticides in a USGA Green, *University of Florida*

- *Supported the idea that most compounds are bound to the thatch.*
- *Clippings are not a major pathway for removal of these herbicides from treated turfgrass areas.*
- *Heavy rain, even much later, can still result in leaching of fenamiphos.*
- *Fenamiphos was not a major concern from a volatility viewpoint.*
- *Rapid decrease in dislodgeable residue after irrigation.*
- *Working with a synthetic amendment to sand that has demonstrated the ability to increase pesticide retention.*

5. Pesticide and Nutrient Fate

Understanding and quantifying the fate of applied turfgrass pesticides and fertilizers are required for accurate prediction of the environmental impacts of golf courses. From 1991 through 1994, USGA-sponsored research demonstrated that 1) the measured nitrogen and pesticide leaching generally is minimal, 2) the turf/soil ecosystem enhances pesticide degradation, and 3) the current agricultural models need calibration/validation in order to accurately predict the fate of pesticides and fertilizers applied to turfgrasses grown under golf course conditions.

The purpose of the projects described in the following pages was to further evaluate the mobility and persistence of parent compounds and transformation products of commonly applied pesticides and fertilizers. Research results from these projects provides information on:

- Degradation and volatilization rates for commonly used pesticides in several important turfgrass environments
- Identification of conditions that affect microbial degradation
- Determination of adsorption coefficients for pesticides on turfgrass leaves, thatch, and organicmatter
- Mass balance assessment of the fate of applied pesticides that takes into account the initial distribution among volatilization, turfgrass, soil, runoff, and leachate
- The importance of factors that influence nitrogen surface runoff and leaching

Modeling Pesticide Transport in Turfgrass Thatch and Foliage, *University of Maryland*

- *The thatch produced by different grasses is not the same in its ability to retain pesticides. Bentgrass thatch retains (or adsorbs) more pesticide than zoysiagrass thatch.*
- *The amount of highly soluable 2,4-D retention to thatch and soil was less than carbaryl.*
- *Desorption losses of both pesticides were greatest during the first leaching event and declined with subsequent leaching.*
- *There was a significant interaction between the solubility of the pesticide and the media (soil or thatch type) to which it was applied.*

Evaluation of the Potential Movement of Pesticides Following Application to Golf Courses, *University of Georgia*

- *Assuming that a simulated putting green rootzone mixture is a worst case scenario, it was concluded that pesticide transport in soil water from this system is not a major problem if the pesticides are applied according to the label instructions and heavy amounts of water are not applied after application.*
- *Irrigation management is a key factor in pesticide movement. Soil moisture content (at or above field capacity) at the time of application results in the greatest potential for runoff.*
- *The buffer zone between the point of application and the exit point did not reduce the fraction of applied water-soluble pesticide transported from the site, but dilutes the solution concentration due to reduced area of treatment.*
- *The pressure injection application method reduced the quantity of pesticides in runoff.*
- *The research documented that the water solubility of the pesticide influenced the quantity of pesticide transported from the fairways. The more water-soluble pesticides readily dissolved in runoff water and were transported from the treated fairway. The less water-soluble*

pesticides were resistant to transport in surface runoff.

Quantifying the Effect of Turf on Pesticide Fate, *University of Illinois*

- *The results document that a healthy turf with thatch prevents most of the pesticide from moving into the soil below.*
- *As the amount of turf and thatch decreased, the amount of pesticide reaching the soil increased.*

Model Calibration and Validation for Turf Pesticides in Runoff and Leachate, *Environmental and Turf Services*

- *The results indicate that PRZM 2.0 overestimated runoff and was less effective in predicting runoff than GLEAMS.*
- *With adjustments to runoff curve number and pesticide degradation rate, the GLEAMS model was able to accurately predict pesticide runoff from a bermudagrass fairway.*
- *If a thatch layer is used in the model, the physical characteristics must be accurately described.*
- *Modeling leaching data is more problematic than runoff data. The new PRZM 3.0 model shows more promise for accurate prediction of pestcide transport from turfgrass systems.*

Degradation of Fungicides In Turfgrass Systems, *Purdue University*

- *Two-thirds of the applied fungicide remained bound to the leaf surface, unavailable for microbial degradation or loss into the environment.*
- *The amount of pesticide adsorbed to the leaf surface was dependent on the chemical characteristics of the applied material (i.e., adsorption coefficient, water soluability).*
- *Analysis of leaf fungicide residues indicated that the dissipation rates were similar, regardless of application frequency.*
- *The similarity of the fungicide dissipation curves suggests that there was no change in the loss mechanism and that enhanced microbial degradation was not present.*

6. Construction and Management of Putting Greens

After years of investigation, the USGA Green Section introduced its *Specifications for a Method of Putting Green Construction* in 1960. The method utilized sand as the principal component of the rootzone mix to provide adequate drainage and resistance to compaction, and incorporated a perched water table in the profile to provide a reservoir of moisture for use by the turf. When built and maintained properly, USGA greens have provided good results over a period of many years for golf courses in most regions of the United States and the world.

During the past 10 to 15 years, changes have occurred in the way greens are maintained and in the number of products and technologies that have been developed. Play has increased, golfers have demanded closer mowing and perfection in maintenance, new grasses have been developed that have different maintenance requirements, and many more golf courses are using recycled water or poor quality water sources for irrigation. Wide arrays of organic and inorganic soil amendments have been introduced, and ideas for new green construction methods have been proposed. In addition to agronomic changes, the cost of golf course construction has increased dramatically, threatening to limit the growth of the game.

To take advantage of new ideas and technologies, and to address the environmental and economic challenges of the coming decades, the USGA is sponsoring research on the construction and maintenance of golf course greens. The goal of this research is to:

- Identify the best combinations of construction, grow-in procedures and post-construction maintenance practices that prevent long-term problems, reduce environmental impacts, and produce high quality playing surfaces
- Reduce the maintenance costs and resource inputs, and simplify the construction procedures where possible

Engineering Properties and Maintenance of Golf Putting Greens, *Michigan State University*

- *Methods were evaluated to accurately predict actual field performance of putting green rootzones.*
- *A sand will be more capable to support greater surface loads as the particle size distribution broadens, and as the smaller particles within that broadly distributed mixture increase.*
- *The laboratory tests were directly related the field test results.*
- *Particle size distribution strongly impacts the hardness, stability, and overall performance of a golf green.*
- *Putting green soil types (i.e., USGA sand, 80:20 sand:soil, and sandy loam) did not produce significant differences in ball roll distance.*
- *Rolling caused a decrease in macropores and an increase in micropores, while total porosity remained unchanged.*
- *Rolled plots had higher* Poa annua *invasion than plots not receiving a rolling treatment.*
- *Crumb rubber topdressing on collars reduced surface hardness (Clegg impact readings).*

Methods of Classifying Sand Shape And The Effects Of Sand Shape On USGA Specification Rootzone Physical Properties, *Pennsylvania State University*

- *Sand shape has a strong impact on rootzone performance in areas including bulk density, total porosity, and capillary and non-capillary porosity.*
- *The round sand typically showed a greater decrease in bulk density than the angular sand as a result of a greater increase in total porosity, but total porosity increased because of an increase in capillary porosity, not aeration porosity.*
- *The angular sand had similar trends, but total porosity increased less than for the round sand and capillary porosity increased more in the angular sand.*
- *Computer imaging is helping to identify sand shapes more efficiently.*
- *Four sand shape classification methods have been tested. Of these, the dense soil angle of repose and cone penetrometry methods show some promise.*

Understanding the Hydrology of Modern Putting Green Construction Methods, *Ohio State University*

- *For equivalent rootzone mixes, the USGA green was drier after 48 hours (interpreted as more completely drained) than the California green.*
- *In the USGA green, moisture content levels were more uniform laterally throughout the sloped rootzones after 48 hours.*
- *At high rainfall intensities, the USGA green was able to handle the volume of water better than the California green.*

Assessing Differential Root Zone Mixes for Putting Greens Over Time Under Two Environmental Conditions, *Rutgers University*

- *Total porosity was usually increased by the addition of organic or inorganic amendment.*
- *Sand size distribution and the type of amendment determined whether the increase occurred primarily in the air-filled porosity or the capillary porosity.*
- *The research illustrates that amendment effects on the rootzone varied for the rootzone material being amended. Laboratory testing is necessary to accurately predict the results of amendment additions to a rootzone.*
- *Sphagnum peat may have a slight inhibitory effect on the microbial community.*

Grow-in and Cultural Impacts on USGA Putting Greens and Their Microbial Communities, *University of Nebraska*

- *Higher inputs will initially increase the rate of establishment during grow-in. This increase may not translate to earlier opening for play if environmental stress conditions cause damage to lush, immature turf.*
- *A rootzone mix containing soil will establish quicker and recover from environmental stress faster than a soilless mix. A soil-containing mix also will be firmer.*
- *Addition of soil to the root zone mix will not effect water infiltration during the establishment year.*

Organic Matter Dynamics in the Surface Zone of a USGA Green: Practices to Alleviate Problems, *University of Georgia*

- *Organic matter accumulation occurred, even under excellent management and regardless of construction method.*
- *The surface 3 cm is highly porous, but composed primarily of capillary pores (water holding).*
- *The Hydro-Ject in a raised position improved water infiltration the most.*
- *Saturated hydraulic conductivity drastically decreased in surface zone.*
- *Oxygen levels were frequently less than desirable at 2 to 31 hours after irrigation.*

Evaluation of New Technologies in Construction and Maintenance of Golf Course Greens, *North Carolina State University*

- *Inorganic amendments improved soil moisture holding capacity but less so than peat.*
- *Ecolite® and Profile® reduced ammonium (NH_4) leaching*
- *None of the amendments reduced nitrate leaching.*

Nontarget Effects of Turfgrass Fungicides on Microbial Communities in USGA Putting Greens, *Cornell University*

- *No significant differences occurred in the fungal or bacterial populations on roots or leaves after fungicide applications.*
- *Some shifts in make-up of microbial populations were observed.*
- *The only major effect of fungicide applications noted was an increase in microbial respiration.*
- *Fungicide applications did have the potential to reduce the quantity of a specific fungal organism while the overall fungi population remained unchanged.*

Bacterial Populations and Diversity within New USGA Putting Greens, *University of Florida, Clemson University, Auburn University*

- *Organic matter sources vary in their microbial populations.*
- *Fumigation materials have different effects on the microbial population at first, but within four months everything returned to the pre-fumigation levels. This was due to primarily to microorganisms brought in on the turfgrass sprigs.*
- *Rhizo-bacterial populations were successfully separated using selective media.*
- *A total of 640 bacterial isolates were selected and stored for GC FAME analysis.*
- *Management and other abiotic conditions contributed to the changes in microbial populations observed.*

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Table 1. USGA Turfgrass and Environmental Research Budget - 1993 through 1997.

Project/Subproject	University/Investigator	1993	1994	1995	1996	1997	Total
Turfgrass Breeding:							
Bentgrass	Texas A&M Univ./Engelke	60,000	63,000	66,150	69,458	72,930	331,538
Cool Season	Rutgers University/Funk	8,000	8,000	8,000	8,000	8,000	40,000
Bermudagrass	USDA-UGA/Burton	8,000	8,000	8,000	8,000	8,000	40,000
Bermudagrass	Oklahoma St. Univ./Taliaferro	60,000	63,000	66,150	69,458	72,930	331,538
Buffalograss	Univ. of Nebraska/Riordan	60,000	63,000	66,150	69,458	72,930	331,538
Colonial Bentgrass	Univ. Rhode Island/Ruemmele	20,000	21,000	22,050			63,050
Seashore Paspalum	Univ. of Georgia/Duncan	20,000	21,000	22,050	40,000	40,000	143,050
Poa annua	Univ. of Minnesota/White	40,000	20,000	10,000	10,000	10,000	90,000
Zoysiagrass	Texas A&M Univ./Engelke	60,000	63,000	66,150	69,458	72,930	331,538
	Subtotal:	336,000	330,000	334,700	343,830	357,722	1,702,252
Alternative Pest Management:							
Mole Cricket	NC State Univ./Brandenburg		20,000	20,000	20,000	20,000	60,000
Black Turfgrass Ataenius	Univ. of California/Cowles		10,000				10,000
Black Turfgrass Ataenius	Cornell University/Villani		10,000				10,000
Sting Nematode Control	Univ. of Florida/Giblin-Davis		20,000	20,000	20,000	20,000	60,000
Allelopathy	Univ. of Arkansas/King		10,000	10,000	10,000		30,000
White Grubs	Univ. of Kentucky/Potter		20,000	20,000	20,000	20,000	60,000
Brown Patch Resistance	Mississippi State Univ./Krans	25,000	26,250	27,563			78,813
Disease Resistance	Michigan State Univ./Vargas		20,000	20,000	20,000	20,000	60,000
Disease Resistance	Virginia Poly Tech Univ./Ha	25,000	26,250	27,563			78,813
Herbicide/Disease Resistance	Rutgers University/Day	45,000	47,250	49,613	48,824	50,939	241,626
Disease Suppression	Cornell University/Nelson		20,000	20,000	20,000	20,000	60,000
Summer Patch Suppression	Rutgers University/Kobayashi	20,000	21,000	22,050			63,050
	Subtotal:	115,000	250,750	236,788	158,824	150,939	812,301
Cultural Practices:							
Water Use/Buffalograss	Univ. of Nevada/Bowman	15,000	15,750	16,538			47,288
Water Use/Bermudagrass	Univ. of Georgia/Carrow	12,273	12,359	13,488			38,120
Water Use/Zoysiagrass	Univ. of Georgia/Carrow	21,500					21,500
Water Use/Bentgrass	Univ. of Georgia/Carrow	6,000					6,000
Effluent Water	Univ. of Arizona/Brown	25,000	26,250	27,563			78,813
Low Temperature/Drought	Clemson University/Baird	20,000	21,000	22,050	20,000	20,000	103,050
Drought Stress/Bentgrass	Texas A&M Univ./White		22,453	23,576	24,754		70,783
Putting Green/Bermudagrass	Auburn University/Guertal			10,000	10,000	10,000	30,000
Mycorrhizae	Univ. Rhode Island/Jackson	40,000					40,000
	Subtotal	139,773	97,812	113,214	54,754	30,000	435,553
Best Management Practices:							
Runoff Management	Oklahoma State Univ./Baird		0	39,440	40,977	44,869	125,286
Volatilization	Univ. of Massachusetts/Clark		0	42,779	45,501	46,416	134,696
	Subtotal:		0	82,219	86,478	91,285	259,982
Pesticide and Nutrient Fate:							
Pesticide Leaching	Univ. of Illinois/Branham		65,000	46,911	45,527	46,518	203,956
Pesticide Leaching/Volatilization	University of California/Yates		0	44,322	44,728	44,097	133,147
Pesticide Leaching	Univ. of Florida/Snyder-Cisar		22,000	48,244	47,084	45,924	163,252
Pesticide Leaching/Runoff	University of Georgia/Smith		0	33,640	48,720	58,000	140,360
Degradation Rates	Purdue Univ./Turco-Throssell		0	45,291	41,152	42,214	128,657
Transport Modeling	University of Maryland/Carroll		0	38,042	36,569	35,380	109,991
Golf Course Siting	Iowa State University/Kuiper					25,000	25,000
Model Modification	Cohen/Smart		0	30,000	40,000	40,000	110,000
	Subtotal:		87,000	286,450	303,780	337,133	1,014,363
Golf Course Benefits:							
USGA Cooperative Sanctuary	Golf House		1,000	1,000	1,000	1,000	4,000
Cooperative Sanctuary Program	Audubon International		100,000	100,000	100,000	100,000	400,000
Wildlife Links Program	National Fish & Wildlife Foundation		0		100,000	100,000	200,000
	Subtotal:		101,000	101,000	201,000	201,000	604,000
Putting Green Construction:							
Engineering Characters	Michigan State Univ./Crum				20,000	20,000	40,000
Classifying Sand Shape	Penn State Univ./Mancino				10,000	10,000	40,000
Layers in Golf Greens	STRI/Baker				18,383	10,395	28,778
Hydrology of Greens	Ohio St. Univ.-OARDC/McCoy				10,000	10,000	40,000
Root Zone Mixes	Rutgers Univ./Murphy				10,000	10,000	40,000
New Construction Technology	NC State Univ./Bowman				20,000	20,000	40,000
Grow-in and Cultural Practices	Univ. of Nebraska/Gaussoin				10,000	10,000	40,000
Organic Matter Dynamics	Univ. of Georgia/Carrow				10,000	10,000	40,000
Non-target Fungicide Effects	Cornell University/Harmon				20,000	20,000	40,000
Bacterial Populations/Diversity	Univ. of Florida/Elliott				13,333	13,333	26,666
Bacterial Populations/Diversity	Auburn University/Guertal				13,333	13,333	26,666
Bacterial Populations/Diversity	Clemson University/Skipper				13,333	13,333	26,666
	Subtotal:				168,382	160,394	428,776
Other:							
International Turf Conference.	ITS/Watson	5,000				5,000	10,000
	Subtotal	5,000				5,000	10,000
	Total:	595,773	866,562	1,154,370	1,317,048	1,308,473	5,242,226

Turfgrass Breeding

The quality and stress tolerance of a turf is the product of the environment, management practices, and genetic potential of the grass plant. In many cases, various stress effects are the major causes of poor quality turf.

The turfgrass breeding projects are directed at reducing water and pesticide use through the development of resistance to several stress and pest problems. The most desirable characteristics of potential new turfgrasses include:

- Drought tolerance
- High and low temperature tolerance
- Tolerance of non-potable water
- Tolerance of acid, alkaline or saline soils
- Reduced mowing requirements
- Efficient use of fertilizers
- Traffic tolerance
- Genetic stability of characters
- Disease, insect and nematode resistance
- Competitiveness against weeds
- Tolerance to smog and other pollutants
- Shade tolerance

The USGA turfgrass breeding programs have focused on the improvement of zoysiagrass, native grasses, *Poa annua*, bermudagrass, bentgrass and seashore paspalum. The turfgrasses resulting from the sponsored research must meet the needs of golf courses. In the following table, the breeding projects, species, and status of varieties are summarized.

Table 2. Summary of USGA Turfgrass Breeding Projects.

Turfgrass	University	Status of Varieties
Creeping Bentgrass *Agrostis stolonifera var. palustris*	Texas A&M University	CRENSHAW (Syn3-88), CATO (Syn4-88) and MARINER (Syn1-88), CENTURY (Syn92-1), IMPERIAL (Syn92-5), BACKSPIN (92-2) were released. All are entered in 1993 NTEP trials.[1]
	University of Rhode Island	PROVIDENCE was released.
	Pennsylvania State University	PENNLINKS was released
Colonial Bentgrass *Agrostis tenuis*	DSIR-New Zealand and University of Rhode Island	A preliminary line, BR-1518, was entered in the NTEP trials. This line was not developed any further.
Bermudagrass *Cynodon dactylon*	New Mexico State University	NuMex SAHARA, SONESTA, PRIMAVERA and other seed propagated varieties were developed from this program.
	Oklahoma State University	Two seeded types, OKS 91-11, and OKS 91-1 were entered in the 1992 NTEP trials. OKS 91-11 was released.
C. transvaalensis	Oklahoma State University	A release of germplasm for university and industry use is under consideration. New triploid ($2n = 3x = 27$) and hexaploid ($2n = 6x = 54$) F_1 hybrids are under evaluation.
C. dactylon X *C. transvaalensis*	University of Georgia	TIFTON 10 and TIFTON 94 (MI-40) were released; a TIFWAY mutant, TIFEAGLE (TW-72), was released fro vegetative production.
Buffalograss *Buchloe dactyloides*	University of Nebraska	Vegetative varieties 609, 315, and 378 were released. Seeded varieties CODY and TATANKA were released. Three new vegetative selections, NE 86-61, NE 86-120 and NE 91-118, are currently being processed for release.
Alkaligrass *Puccinellia* sp.	Colorado State University	Ten improved families were developed; nothing released.
Blue grama *Bouteloua gracilis*	Colorado State University	ELITE, NICE, PLUS and NARROW populations were developed; nothing released.
Fairway Crested Wheatgrass *Agropyron cristatum*	Colorado State University	Narrow leafed and rhizomatous populations were developed; nothing was released.
Curly Mesquitegrass *Hilaria belangeri*	University of Arizona	Seed increases of 'fine' and 'roadside' populations are available for germplasm release and further improvement.
Annual bluegrass *Poa annua* var. *reptans*	University of Minnesota	Selections #42, #117, #184, #208, and #234 were released. Small amounts of MN #184 are commercially available.
Zoysiagrass *Zoysia japonica* and *Z. matrella*	Texas A&M University	Ten vegetative selections were entered in the 1991 NTEP trial. DIAMOND (DALZ8502), CAVALIER (DALZ-8507), CROWNE (DALZ8512) and PALISADES (DALZ8514) were released in 1996.
Seashore Paspalum *Paspalum vaginatum*	University of Georgia	Germplasm has been assembled and is under evaluation. Two green types (AP 10, AP 14) and one fairway type (PI 509018-1) are being evaluated on golf courses.

[1]National Turfgrass Evaluation Program, Beltsville Agricultural Research Center, Beltsville, MD 20705

Breeding and Development of Bentgrass

Dr. Milt Engelke

Texas A&M University

Goals:

- *Develop stress tolerant bentgrass cultivars with specific emphasis on heat tolerance, root growth characters, turf quality, and resistance to natural disease and insect pests.*
- *Continue genetic studies involving heritability and stability of biological traits associated with stress tolerance.*

Cooperators:

Ikuko Yamamoto
Jamie M. Mills
Marine Doin

The bentgrass program has enjoyed a long run of financial support from Bentgrass Research, Inc (Fort Worth, TX) and the United States Golf Association. The program was initiated in 1985 with the primary objective of developing creeping bentgrass varieties that reduce the cultural requirements for maintaining bentgrass under stressful environments.

During the past 13 years we have had the opportunity to collect, evaluate, and hybridize several thousand individual plants. During this process, numerous young scientists evolved with the program making significant contributions along the way. Notably, Dr. Virginia Lehman received her Ph.D. working on the development of *CRENSHAW*, *CATO* and *MARINER* and the 92 series germplasm. Dr. Lehman is presently the Director of Research for Loft Seed Co. Winston-Salem, N.C.

Drs. Richard White and Bridgett Ruemmele aided in the development of stress tolerant germplasm. These plants were then used in the development of the 1992 Series leading to development of *CENTURY* and *IMPERIAL*, which were released in 1996, and *BACKSPIN* to be released in 1998.

Significant as the varieties are, the individual scientists involved in the program over the years are likewise making substantial contributions to the industry in their own right.

Table 3. 1996 mean turfgrass quality ratings of bentgrass cultivars for each month grown on a putting green at twenty-five locations in the U.S. and Canada.

Name	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct	Nov.	Dec.	Mean
LOFT'S L-93	5.6	6.1	6.2	6.4	6.5	6.8	6.9	7.1	7.0	6.9	5.8	4.7	6.6
PENN A-1	5.3	5.9	6.5	6.5	6.3	6.6	6.9	6.8	6.9	6.9	5.8	5.0	6.5
PENN A-4	5.9	6.6	6.6	6.4	6.1	6.8	6.8	6.9	6.7	6.8	5.3	4.8	6.5
PENN G-2	5.3	5.8	6.3	6.0	6.2	6.5	6.6	6.6	6.6	6.8	5.3	5.0	6.3
CATO	4.8	5.9	6.3	6.2	6.0	6.6	6.9	6.8	6.6	6.5	4.9	4.3	6.3
PROVIDENCE	5.3	5.8	6.1	6.4	6.1	6.5	6.6	6.4	6.5	6.3	5.3	4.5	6.3
PENN G-6	4.7	5.4	6.4	6.2	5.9	6.3	6.6	6.4	6.3	6.5	5.1	4.7	6.2
SOUTHSHORE	4.9	5.8	6.0	6.2	6.1	6.4	6.5	6.2	6.2	6.2	5.0	4.4	6.1
CENTURY	5.2	6.1	6.6	6.0	5.9	6.5	6.2	6.3	6.2	6.2	5.1	4.8	6.1
IMPERIAL	5.0	5.4	6.0	5.8	5.9	6.4	6.2	6.4	6.3	6.3	5.1	4.8	6.1
BAR WS 42102	4.1	5.1	5.5	5.8	5.8	6.3	6.4	6.4	6.1	5.9	4.8	4.2	6.0
BACKSPIN	4.6	5.7	5.9	5.7	5.7	6.3	6.3	6.4	6.1	5.9	5.1	4.5	5.9
PENNLINKS	4.8	5.2	5.6	5.7	5.8	6.1	6.1	6.0	6.3	6.1	4.9	4.4	5.9
DG-P	5.1	5.5	5.8	5.9	5.6	6.1	6.2	5.9	6.2	6.0	5.1	5.1	5.9
SR 1020	4.9	5.7	6.4	5.7	5.7	5.9	6.1	6.1	6.1	6.1	5.2	4.6	5.9
CRENSHAW	4.1	4.5	5.8	5.5	5.5	6.1	6.4	6.3	6.1	6.1	4.9	4.2	5.8
ISI-AP-891500	5.0	5.5	5.8	5.7	5.6	6.0	5.9	5.9	6.0	5.9	5.4	4.7	5.8
REGENT	4.7	5.3	5.4	5.4	5.6	6.0	6.0	5.9	6.0	5.9	5.1	4.6	5.8
PRO/CUP	4.4	4.9	5.4	5.8	5.7	6.0	6.1	5.8	5.9	5.8	4.7	4.3	5.7
TRUELINE	4.2	5.0	5.3	5.6	5.6	6.0	6.1	5.8	6.0	5.8	4.8	4.0	5.7
MSUEB	5.0	5.2	4.9	5.6	5.5	5.8	6.1	5.8	6.1	5.8	4.6	4.5	5.7
LOPEZ	4.4	4.8	5.5	5.6	5.5	6.0	6.0	6.0	5.9	5.9	4.4	4.2	5.7
MARINER	5.0	4.8	5.2	5.2	5.2	5.6	5.7	5.7	5.7	5.5	4.7	4.4	5.4
PENNCROSS	4.5	5.0	5.0	5.3	5.3	5.6	5.8	5.5	5.7	5.5	4.7	4.3	5.4
18^{TH} GREEN	3.8	4.7	5.5	5.1	5.3	5.7	5.9	5.7	5.4	5.1	3.9	3.8	5.3
SEASIDE	4.3	4.0	4.6	4.2	4.2	4.6	4.6	4.6	5.0	4.5	4.4	4.2	4.6
BAR AS-492	3.9	4.1	4.0	4.1	4.2	4.4	4.5	4.8	5.0	4.4	4.4	3.8	4.4
TENDENZ	3.8	3.9	4.4	4.4	4.3	4.5	4.4	4.5	4.5	4.2	4.1	3.8	4.3
$LSD_{0.05}$	1.0	0.9	0.9	0.6	0.5	0.4	0.4	0.5	0.5	0.5	0.9	1.1	0.4

[1]Turfgrass quality ratings on a 1 to 9 scale where 9 = ideal turf. To determine statistical differences among entries, subtract on entry's mean from another entry's mean. Statistical differences occur when this value is larger than the corresponding $LSD_{0.05}$ value

Breeding and Evaluation of Cold-tolerant Bermudagrass Varieties Golf Courses

Dr. Charles Taliaferro

Oklahoma State University

Goals:

- *Assemble, evaluate, and maintain Cynodon germplasm with potential for contributing to the genetic improvement of the species for turf.*
- *Improve bermudagrass germplasm populations for seed production potential, cold tolerance, and other traits conditioning turf performance.*
- *Develop, evaluate and release superior seed-propagated, cold-tolerant, fine-textured, turf bermudagrass varieties for the U.S. transition zone and similar climates.*
- *Develop, evaluate and release improved vegetatively propagated bermudagrass varieties with specific adaptations and uses in the southern U.S., e.g. varieties for golf course putting greens in the deep South.*

Cooperators:

James Baird
Dennis Martin
Jeffery Anderson
Michael Anderson

The turf bermudagrass breeding program was initiated in 1986 at Oklahoma State University. The initial objective was to develop fine-textured, winter-hardy, seed-propagated varieties for the U.S. transition zone. This objective has expanded to develop improved seed- and vegetatively-propagated cultivars for the transition zone.

Research supporting the breeding effort includes: 1) the procurement and evaluation of new turf bermudagrass germplasm, 2) development of laboratory and field methods to measure plant response to low temperature and disease stress, and 3) identification of genes involved in plant response to low temperatures and disease stress.

The development of seeded turf bermudagrass cultivars for the transition zone requires combining into breeding populations cold hardiness, economic seed yield potential and acceptable turf quality. Phenotypic recurrent selection (PRS) for these traits in broad genetic base *C. dactylon* populations has resulted in incremental improvement with each cycle of selection. A first product of this breeding effort, OKS 91-11, was released in January 1997. OKS 91-11, initially synthesized in 1991, was included in the 1992-96 NTEP bermudagrass test. Breeding improvement in the broad base populations has now reached threshold levels that will allow more rapid progress in seeded turf bermudagrass cultivar development.

African bermudagrass, *C. transvaalensis*, is important because of its role as a parent in crossing with *C. dactyon* plants to produce the sterile triploid (2n=3x=27 chromosome) hybrids like *TIFGREEN* and *TIFWAY*. African bermudagrass has not been extensively studied and only a few plant introductions have been available for breeding research in the United States. Research with African bermudagrass over the past seven years has demonstrated significant genetic variation for adaptation and turf performance characteristics. African progeny plants with superior performance characteristics were identified and are being used in breeding and other research.

Intra- and inter-specific crossing has been employed over the past five years to develop vegetatively-propagated hybrid turf bermudagrass cultivars. Selected parental plants of *C. dactylon* and *C. transvaalensis* were crossed to produce large progeny populations which were screened for turf performance.

Approximately 50 select hybrid plants are now in advanced stages of evaluation. Potentially valuable fertile hybrid plants from 2n=6x=54 chromosome *C. dactylon* x 2n=2x=18 chromosome *C. transvaalensis* crosses have been obtained. These tetraploid (2n=4x=36 chromosome) plants have one full genome (9 chromosomes) from *C. transvaalensis* and 3 full genomes (27 chromosomes) from *C. dactylon*. Open-pollinated and hybrid progeny from these plants have shown desirable turf characteristics.

A laboratory procedure was developed to quantify relative cold hardiness of bermudagrass plants. The freeze tolerance of bermudagrass plants has traditionally been assessed by observing survival following test winters. Because freeze injury under field conditions is strongly influenced by many environmental factors, multiple observations through time and space are required to elucidate differences in freeze tolerance and geographic adaptation of cultivars. This laboratory procedure may be used in combination with field studies to more quickly and accurately assess freeze tolerance of bermudagrass plants. The procedure also enables and facilitates other cold hardiness research with turf bermudagrass.

The survival of bermudagrass cultivars exposed to freezing temperatures is determined by their ability to cold acclimate. A cold regulated protein from *MIDIRON* and *TIFGREEN* bermudagrass was identified as chitinase. More recent research used Differential Display-Reverse Transcription PCR procedures to study changes in translatable mRNA populations during cold acclimation of freezing tolerant *MIDIRON* bermudagrass. At least 30 differentially expressed cDNA species were identified using 40 arbitrary and anchored primer combinations. Nine up-regulated and two down-regulated cDNA species have been confirmed. These cDNA's range from 170 to 470 base pairs in length. These partial cDNAs were sequenced and aligned with other known genes in genome databases. Homologies were found with *lti*65 (low temperature-induced) from *Arabidopsis thaliana*, a transcription factor (*nus*G) from *Thermus thermophilus*, a non-dormancy cDNA clone from *Avena fatua*, and a secretory/excretory heat shock protein cDNA from B*rugia malayi*. Efforts are underway to isolate the full length sequences corresponding to the partial cDNAs in order to characterize the cDNAs and confirm identity of these genes.

Sixty-two accessions representing 11 *Cynodon* taxa (species and taxonomic varieties) were used in a molecular study of genetic relatedness. Phylogenetic analysis of accessions was performed using the DAF (DNA Amplification Fingerprinting) procedure. Parsimony and bootstrap analysis was performed to produce the consensus phylogenetic tree using the PAUP 3.0 program. The results demonstrate interesting genetic relationships among and within *Cynodon* taxa. For instance, much diversity was found within the cosmopolitan species *C. dactylon*. Accessions within taxonomic varieties generally were grouped together, except for *C. dactylon var. dactylon*, in which wide differences were evident. Small, but definite, variations were found in *C. arcuatus, C. transvaalensis, and C. plectostachyus,* all endemic species to small geographic regions of southern Africa.

Table 4. 1996 mean turfgrass qauality ratings of bentgrass cultivars for each month grown on a green at twenty-five locations in the U.S. and Canada.

Name	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct	Nov.	Dec.
TIFWAY	4.0	3.5	4.3	5.8	6.6	7.0	7.4	7.3	7.6	6.7	5.5	4.4
BABY (TDS-BM1)	3.4	3.7	4.5	5.7	6.0	7.0	7.1	7.0	7.0	6.0	4.7	4.0
MIDIRON	3.6	3.8	4.5	6.1	6.2	6.6	6.6	6.4	6.7	5.7	4.2	3.8
TIFGREEN	3.4	3.5	4.6	5.1	5.6	6.4	6.6	6.9	6.8	5.8	4.7	3.9
MIDLAWN	3.4	3.2	4.0	5.9	5.7	6.2	6.5	6.4	6.3	5.4	4.4	3.8
MIDFIELD	3.6	3.3	4.1	5.8	5.7	6.1	6.6	6.2	6.0	5.4	4.9	3.9
OKS 91-11	3.4	3.0	3.9	5.6	5.4	5.7	5.9	6.0	5.8	5.4	4.1	3.7
STF-1	3.3	3.0	4.3	5.2	5.0	5.8	5.8	5.9	6.1	5.1	4.1	3.8
MIRAGE (90173)	3.4	3.3	4.5	5.1	5.2	5.7	6.0	5.8	5.9	5.5	4.3	3.8
TEXTURF 10	3.6	3.2	3.8	5.1	4.7	5.4	5.9	6.1	6.3	5.5	4.7	4.0
JACKPOT(J-912)	3.4	3.2	4.2	4.9	4.9	5.7	5.9	5.8	5.9	5.5	4.3	3.8
FMC-6 (FMC 6-91)	3.6	3.3	4.1	5.1	4.8	5.3	5.5	5.8	5.8	5.3	4.4	3.7
J-27	3.6	3.5	4.1	5.3	5.3	5.4	5.6	5.6	5.4	5.1	3.9	3.7
FMC 5-91	3.6	3.5	3.9	4.5	4.7	5.1	5.3	5.5	5.6	5.0	4.3	3.9
GUYMON	3.6	3.2	4.3	5.3	5.1	5.1	5.4	5.4	5.3	4.6	3.9	3.8
SUNDEVIL	3.4	3.2	4.2	4.5	4.7	5.1	5.4	5.4	5.4	5.1	4.1	3.9
FMC 3-91	3.7	3.2	4.3	4.7	4.5	4.9	5.3	5.4	5.6	5.3	4.3	3.9
OKS 91-1	3.6	3.5	3.6	4.3	4.5	4.9	5.1	5.3	5.2	5.1	3.9	3.7
FMC 2-90	3.4	3.2	3.8	4.1	4.4	4.9	5.0	5.4	5.7	4.9	3.9	3.9
CHEYENNE	3.6	3.2	3.7	4.0	4.4	4.7	4.9	5.3	5.4	5.0	3.8	3.8
NUMEX-SAHARA	3.3	3.2	4.2	4.6	4.4	4.6	4.8	5.2	5.3	4.7	3.9	3.7
PRIMAVERA	3.6	3.3	3.5	3.8	4.1	4.6	4.8	5.1	5.4	4.9	4.1	3.8
SONESTA	3.4	3.3	3.7	4.6	4.3	4.5	4.6	5.0	5.1	4.7	3.7	3.7
ARIZ. COM. SEED	3.4	3.2	3.6	3.8	3.9	4.1	4.4	4.8	5.0	4.7	3.9	3.6
FLORADWARF	3.6	3.2	3.2	3.7	3.3	3.9	4.2	4.4	4.2	3.9	3.4	3.2
ARIZ. COM. VEG.	3.4	3.5	3.3	3.7	3.5	3.7	4.0	4.2	4.4	3.9	3.9	3.7
LSD	0.8	1.2	1.1	1.1	0.7	0.6	0.6	0.6	0.6	0.9	0.6	0.6

[1]Turfgrass quality ratings on a 1 to 9 scale where 9 = ideal turf. To determine statistical differences among entries, subtract on entry's mean from another entry's mean. Statistical differences occur when this value is larger than the corresponding $LSD_{0.05}$ value.

Breeding, Evaluation and Culture of Buffalograss for Golf Courses

Dr. Terrance Riordan

University of Nebraska

Goals:

- *Develop vegetative and seeded turf-type buffalograsses that conserve energy and water.*
- *Develop buffalograss establishment protocols and management systems to provide acceptable golf course rough and fairway turf with significantly reduced cultural inputs.*
- *Determine the range of adaptation of turf-type buffalograss.*
- *Evaluate potential insect and disease pests of buffalograss.*
- *Evaluate physiological and biochemical principles of environmental stress and nutrient utilization in buffalograss.*

Cooperators:

Paul Johnson
Fred Baxendale
Roch Gaussoin
Leonard Wit
Kevin Frank
Shuizhang Fei
T.M. Heng-Moss
Garald Horst
Robert Grisso
John Watkins
Gary Yuen
Robert Klucas

The current goals of the University of Nebraska buffalograss project are to improve germplasm and improve management of buffalograss for use in golf course turf, as well as other turf uses. Specifically, our objectives include selecting for exceptional turfgrass quality and color, heat and drought resistance, tolerance to low-mowing (for use in golf course fairways), insect resistance, and establishment vigor.

Overall, the top performers in our 1997 evaluations were NE91-118 and NE86-120 and NE86-61. A number of other accessions have shown great potential in low maintenance and low mowing evaluation trials and will be evaluated further and in larger plot areas. These include NE93-185, NE93-181, NE-91-181, and NE93-170. Three of these accessions are males, which now can be used in seeded varieties or recombination blocks. Identification of superior male germplasm has been an important objective in our recent breeding efforts. NE93-181 is a good compromise between summer color and fall color, ranking high in both categories. Many quality accessions have been included in new crossing blocks to evaluate F1 hybrid potential and for use in genetic studies.

Low mowing tolerance is an important selection criteria for part of our program. NE86-61, NE86-120 have both performed well under low-mowing conditions as well as several other newer accessions. Our efforts have turned to identifying additional germplasm to allow for further improvement and to study the genetics of low-mowing tolerant traits. In an evaluation of progeny families, ND86-61 and NE85-648 gave the best overall summer ratings and vigor characteristics, which follow parent performance. Families with desirable and uniform progeny performance will be evaluated for use in seeded cultivars tolerant to low mowing.

Buffalograss management research has shown management of 378 and NE 91-118 is best at 2.5 or 5.1 cm mowing heights and a nitrogen rate of 10 g N m-2 year-1. Recommendations for *CODY* and *TEXOKA* are 5.1 or 7.6 cm mowing heights and a nitrogen rate of 10 g N m-2 year-1. A field study was initiated to further study effects of management on buffalograss to determine the quantity and turn-over rate of soil and fertilizer nitrogen in above-ground vegetation, thatch, roots, and soil for buffalograss and two other turfgrass species.

We now routinely use flow cytometry to evaluate ploidy level of accessions used in our program. Most are hexaploid (60 chromosomes) but a significant number are tetraploid (40 chromosomes). One pentaploid (50 chromosomes), cultivar 315, was observed. This is the first record of a pentaploid buffalograss. Interestingly, 315 is fertile, and is a parent in the seeded variety *TATANKA*. When the NTG seed producers began reporting poor seed harvests and management problems, we began to suspect genetic causes due to the pentaploid parent(s). We are studying this variety for chromosomal irregularities and inbreeding depression.

Total numbers of beneficial arthropods collected from buffalograss sites maintained at the high and low management regimes were not significantly different, suggesting that beneficial arthropods can be conserved over a fairly wide range of buffalograss maintenance levels. This information will be valuable for implementing site specific management practices that preserve existing natural enemies.

Patents have been filed for new releases NE 86-61, NE 86-120 and NE 91-118. Official UNL release statements will be finished by December 15, 1997. Sales for 1997 of 609 will be approximately at the 1996 level, or $1.5 million dollars. Sales have continued to increase for 378 from Todd Valley Farms.

Development of Stress Tolerant Seashore *Paspalum* for Golf Courses

Dr. Ron Duncan

University of Georgia

Goals:

- *Establish an extensive collection of genetic material.*
- *Improve the adaptability of the species with special emphasis on: acid soil stress tolerance with deep rooting and root plasticity in high bulk density (compacted) soil, winter hardiness to expand its adaptation zone, and wear resistance that will meet or surpass golf course requirements.*

Cooperators:

B.J. Johnson
Kris Braman
Wayne Hanna
Bob Carrow

Eight paspalums out of 300 types in the collection, more than 5,000 tissue culture regenerants, and 100-plus hybrids have been identified for evaluation. Three ecotypes (Fwy-1, AP-10 and AP-14) are currently being evaluated on golf courses. Eighteen golf courses are assessing the performance of one or more of these types on fairways, tees, or greens. Four sod companies are attempting to develop management practices for long-term sod and stolon production. A seed company in Arizona is collaborating on assessment of production problems.

Six paspalums (two from Guam, four from Australia) were entered into quarantine grow-out after collection during the summer 1997. Fwy-1, AP-10, and AP-14 were sent to quarantine in Hawaii and will be available for evaluation in the islands beginning in July 1998.

Herbicide studies involving paspalum encroachment into bermuda revealed Trimec (Plus or Classic), Daconate 6, and Asulox would suppress paspalum growth, but more than one type of herbicide and multiple applications may be necessary to eliminate the paspalum. With bermuda encroachment into paspalum, preliminary research has revealed that multiple applications of Prograss (1.5 lb ai/A) + Cutlass (0.75 lb ai/A) may suppress the bermuda (temperatures > 70° F).

Herbicides non-injurious to paspalum turf include: Betasan, Kerb, Balan, Dacthal, Ronstar G, Pre-M (preemergence); Prograss, Drive, Trimec Southern, Dimension, Super Trimec, Vanquish, Manage, and Mecomec (postemergence).

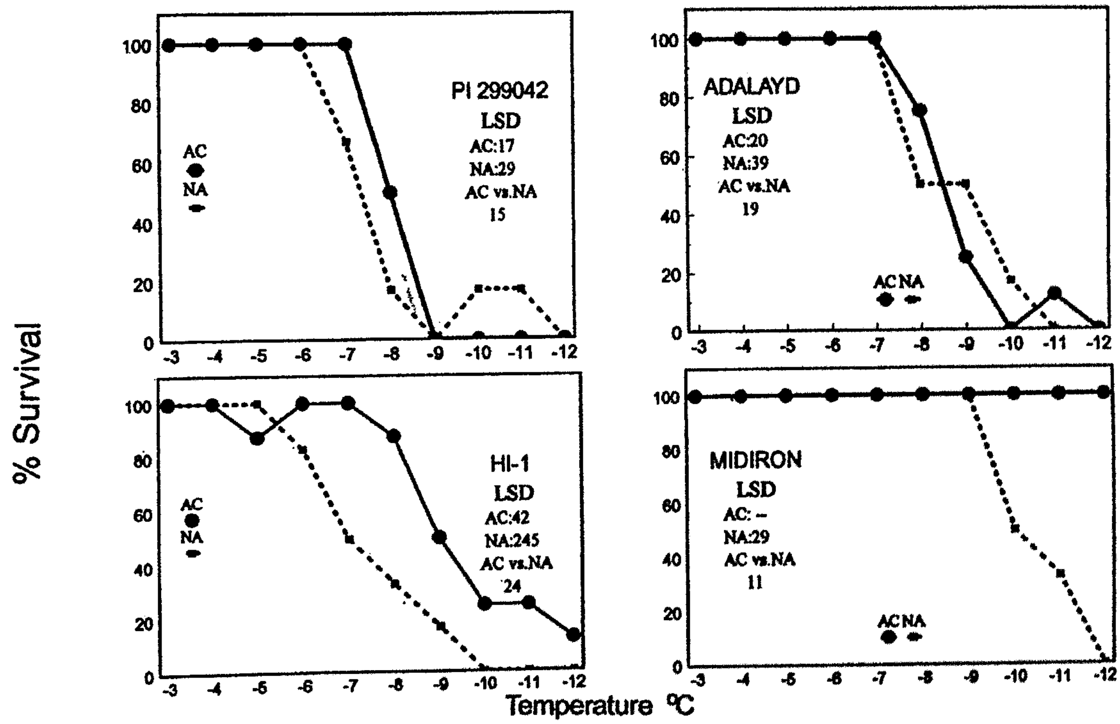


Figure 1. Effect of acclimation on plant survival for three paspalum ecotypes and Midiron bermudagrass under freeze shock-recovery treatments (AC = acclimated; NA = non-acclimated).

Breeding and Development of Zoysiagrass

Dr. Milt Engelke

Texas A&M University

Goals:

- *Develop improved zoysiagrass cultivars with multiple character performance involving low water-use, persistence under drought and temperature stress, and tolerance to poor water quality.*
- *Develop seeded zoysiagrasses that are genetically stable, with improved turf quality, persistence, and competitive ability.*
- *Continue genetic studies involving the heritability and stability of biological traits.*

Cooperators:

Ikuko Yamamoto
Yaling Qian

The Zoysiagrass breeding program was initiated in 1984 and during the past 13 years has enjoyed a long productive relationship with the United States Golf Association. This constitutes the final report for the joint research project between Texas A&M and the United States Golf Association.

The success of the breeding program is measurable. The success of this project is notable because of both the cultivars that were developed and released into the market, and the training and development of young scientists. *DIAMOND, CAVALIER, PALISADES,* and *CROWNE* zoysiagrass were released. The young scientists involved in this program over the years include Dr. Michael Kenna, Research Director, United States Golf Association; Dr. David Huff, Assistant Professor, Pennsylvania State University, Dr. Richard White, Associate Professor, Texas A&M University; Dr. Bridget Ruemmele, Assistant Professor, University of Rhode Island; Dr. Ken Marcum, Assistant Professor University of Arizona; Dr. Ikuko Yamamoto, now married and serving as a foreign language interpreter in Boston Mass; and Dr. Yaling Qian, Assistant Professor, Colorado State University.

Additionally we have enjoyed the interaction and significant contribution of a host of technical support staff including Mr. Sam Riffell, who is now working on his Ph.D. in the Zoology Department, Michigan State University and Ms. Sharon (Morton) Anderson, who is presently pursuing her Ph.D. on zoysiagrass taxonomy at Texas

A&M University. With the close interaction and contribution of each of these individuals, we have successfully developed and released into the industry four unique zoysiagrass cultivars each targeting a niche of the environment.

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

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

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

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

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

Table 5. Summary of agronomic merits and limitations of four new zoysiagrasses.

New Zoysiagrass	Agronomic merits	Agronomic limitations
DIAMOND (DALZ8502) is a fine textured highly rhizomatous, vegetatively propagated *Z. matrella* noted specifically for its excellent tolerance to low light and high salt conditions, and rapid recuperative ability. Diamond is suitable for use as a warm-season turfgrass for putting greens and tee boxes on golf courses especially in the coastal regions of the southern United States where shade and salinity are a problem.	Excellent salt tolerance Excellent shade tolerance Highly rhizomatous Excellent sod strength Low water requirements Early spring green up Good genetic color Fall color retention Fine leaf texture High shoot density Disease Resistance: *Rhizoctonia* blight resistance Insect Resistance: Fall army worm and tawny mole cricket	Lacks winter hardiness Tropical and sub-tropical climates Susceptible to the tropical sod web worm Susceptible to zoysiagrass mite Tendency to thatch and scalp Will not tolerate overseeding Slow initial establishment from sprigs
CAVALIER (DALZ8507) is a fine-textured, long-leaf, vegetatively propagated Z. *matrella* noted specifically for uniformity in appearance and distinct summer presentation. It is genetically stable, basically self-infertile and vegetatively propagated through weak rhizome and strong stolon growth.	Cold hardy Shade tolerant Salt tolerant High visual quality Fine leaf texture Spreads by stolons Good genetic color Insect resistance: tropical sod web worm, fall army worm, tawny mole cricket Disease resistance: *Pythium* blight and *Rhizoctonia* blight	Requires sharp reel mower Slow rate of establishment Slow rate of recovery Vegetative propagation required Potential tendency of thatch Susceptible to zoysiagrass mite
CROWNE (DALZ8512) is a coarse-textured, vegetatively propagated clone of Z. *japonica* which is suitable for use as warm-season turfgrass for golf course roughs, home lawns, industrial parks, and highway right-of-ways throughout the central mid-western states. Optimum mowing height will range from 5.0 to 7.5 cm; however, it can be mowed as close as 1.5 cm.	Medium-coarse texture High visual quality Rapid establishment and regrowth Good fall color retention Shade tolerant Salt tolerant Cold hardy Heat tolerant Variable mowing height (1.0 to 7.5 cm)	Susceptible to *Rhizoctonia* Tendency to scalp
PALISADES (DALZ8514) is a medium-coarse textured vegetatively propagated clone of Z. *japonica* which is suitable as a warm-season turfgrass throughout the transition zone for golf course fairways and roughs, home lawns, sports fields, industrial parks, and highway medians. Optimum mowing height ranges from 1.0 to 5.0 cm. On tees and fairways, mowing heights of 8 mm is possible with acceptable results.	Medium-coarse texture High visual quality Rapid establishment and regrowth Good fall color retention Shade tolerant Salt tolerant Cold hardy Heat tolerant Variable mowing height 1.0 to 5.0 cm)	Susceptible to fall army worm

Improvement of Poa annua var. reptans for Golf Turf

Dr. Donald White

University of Minnesota

Goals:

- *Expand the evaluation and development of the advanced selections for turf quality, seed production and testing recommendations.*
- *Continue and expand seed production evaluations in Oregon.*
- *Continue and expand the development of a breeder's seed supply.*
- *Expand seeded evaluation plantings at selected golf course and university locations.*

Three selections of Poa annua var reptans, MN#42, MN#184 and MN#208, were released in an exclusive agreement to Peterson Seed Company of Savage, Minnesota in 1994. Limited quantities of seed were available for the first time in 1997.

Efforts continue to focus on learning about seed production. Additional tests were initiated to evaluate seed harvested in Oregon for trueness to type. Cultural trials continue on a high sand content (90:10, sand:peat) green that was established with 10 selections in the program, including MN#42, MN#184, and MN#208. The green was covered during the winter. Although some winter damage was observed to some selections, all recovered sufficiently.

In 1996, the trial was attacked by dollar spot and Rhizoctonia that were identified from lab samples during the summer. However, symptoms also indicated the possibility of a severe Anthracnose or Pythium problem on several of the selections. MN#184 and some of the other numbered selections displayed remarkable resistance to the organism(s) involved.

In addition, MN#184 exhibited some resistance to Fusarium patch in both Washington and Oregon putting green trials. The 1995-96 winter was a particularly difficult year for Fusarium problems in the Pacific Northwest. MN#42 and MN#208 also exhibited some resistance in the Oregon trial.

Several variety trials were established during 1996 or late in the Fall of 1995.

Plantings at The Columbia Country Club in Columbia, Maryland; Bloomfield Hills, Michigan; University of Rhode Island; and the Greenbrier Country Club, White Sulphur Springs, West Virginia.

Arrangements were made and seed delivered for future trials at the Broadmoor Country Club in Seattle, Washington; the Vancouver Country Club in Vancouver, Canada; and Pebble Beach.

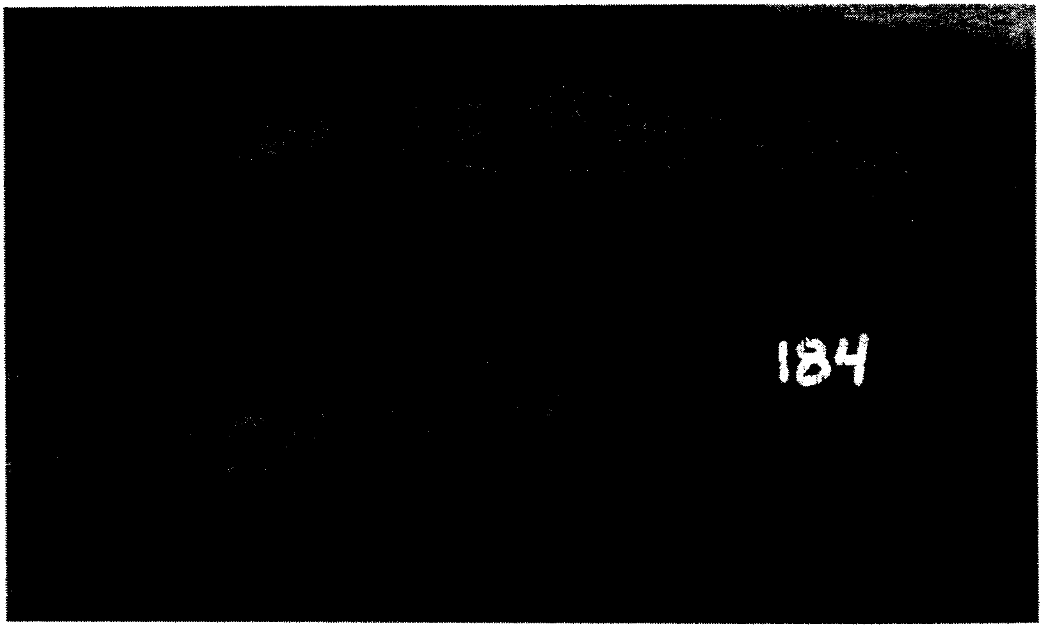


Figure 2. View of MN#184 bordered on two sides by disease susceptible selections. Dollar spot and brown patch were isolated from blighted areas. Small plots of some of the new selections (lower right of photograph) also exhibited some resistance.

Breeding and Evaluation of Kentucky Bluegrass, Tall Fescue, Perennial Ryegrass, and Bentgrass for Turf

Dr. C. Reed Funk
Rutgers University

Goals:

- *Collect and evaluate potentially useful turfgrass germplasm.*
- *Collect and evaluate endophytes associated with cool-season turfgrass species.*
- *Continue the breeding and development of new cool-season turfgrasses.*

Cooperators:

William A. Meyer
Jennifer Johnson-Cicalese
James Murphy
Michael Richardson
James White
Dirk Smith
Ronald Bara
Melissa Mohr
Rachael Roux
Christine Kubik
Pedro Perdomo
Stacy Bones
Joseph Clark
William K. Dickson
Barbara Smith

The USGA has enjoyed a very long and productive relationship with Dr. Reed Funk at Rutgers University. Today, the financial contribution of the USGA to his breeding program is small compared other royalty income received. Due to the efforts of Dr. Funk and the international stature of his breeding program, Dr. William Meyer has joined Rutgers University to carry on the outstanding contribution this institution and its faculty have made to the turfgrass industry.

Dr. William A. Meyer was assigned leadership of the newly invigorated turfgrass-breeding program in April 1996. More than 50,000 plots of turfgrass cultivars, experimental selections, and germplasm sources are under observation and evaluation in field trials at Adelphia, North Brunswick, and Pittstown, New Jersey.

Over 8,500 new seeded turfgrass evaluation plots, over 20,000 clonal evaluation plots, and over eleven acres of spaced-plant nurseries were established in 1996.

Promising turfgrass germplasm and associated endophytes were collected from Poland, Austria, Switzerland, Germany, New Jersey, Connecticut, New York, and Oregon. Increased emphasis was placed on collecting creeping, colonial, dryland, and velvet bentgrasses.

Studies were initiated to develop a more rapid method of screening for resistance to the stripe smut disease. Kentucky bluegrasses with good field resistance to current races of stripe rust are being evaluated for other useful characteristics.

A seedling screening technique has proven successful in identifying promising hybrids in large populations obtained from crossing highly apomictic Kentucky bluegrasses. Continued progress is being made in identifying and developing Kentucky bluegrasses with improved performance under severe summer stress.

Moderate wear treatments on newly established turfs have been effective in identifying fescues and perennial ryegrasses with improved resistance to net blotch and leaf spot diseases.

Chinch bugs caused severe damage to endophyte-free strong creeping and Chewings fescues, whereas half-sib progenies of the same fine fescues containing endophytes showed enhanced resistance in both field and laboratory tests. Petri dish preference tests, using first instar chinch bugs, were used to compare E+ fine fescue combinations with the E- counterparts. A significantly higher percentage of nymphs were found on the E- tillers for four of the five comparisons. These studies demonstrated endophyte-enhanced chinch bug resistance for the first time in strong creeping red fescue.

Population improvement programs continue to show progress in the genetic improvement of perennial ryegrasses, tall fescues, Chewings fescues, hard fescues, strong creeping red fescues, and creeping bentgrass. Similar population improvement programs have been initiated on recent collections of colonial, dryland, and velvet bentgrasses.

Alternative Pest Management

Alternative pest management methods are intended to reduce the amount of pesticide needed to maintain golf course turfgrasses. An alternative method of pest control needs to be highly effective and must be field-testing under realistic golf course conditions in order to receive widespread acceptance by golf course superintendents. The USGA has provided funding for the development and evaluation of alternative methods of pest control. Even though a great deal of time and effort has been devoted to the area of biological control, there are few scientifically documented cases were these alternative controls perform as well as their pesticide counterparts.

In addition to new biological controls, more information is needed on the life cycle and behavior of common turfgrass pests. The correct treatment thresholds, cultural practices, use of resistant grasses, proper pesticide timing and placement all need to be considered carefully in all turfgrass management programs, especially in the case of soil-borne insect or disease problems.

The purpose of these research projects is to evaluate alternative methods of pest control for use in integrated turf management systems. Projects investigate alternative pest control methods that include:

- Biological control
- Non-chemical control, including cultural and mechanical practices
- Allelopathy
- Selection and breeding for pest resistance
- Ecological balance of plant species in turfgrass swards
- Application of integrated turf management practices utilizing IPM and low cultural inputs

Development of Improved Turfgrass with Herbicide Resistance and Disease Resistance through Transformation

Dr. Peter Day

Rutgers University

Goals:

- *Establish a transformation system for creeping bentgrass.*
- *Improve the utility of creeping bentgrass by incorporating genes to confer herbicide resistance or enhanced resistance to fungal pathogens.*

Cooperators:

Faith Belinger
C. L. Hartman
N.E. Tumer
C. Laramore
William Meyer
Bruce Clark
Eric Lam

This project seeks to improve creeping bentgrass through transformation to provide golf course managers with more effective and selective weed control with herbicides and more environmentally sound and cost-effective control of plant diseases with reduced use of fungicides. During the past two years, we have made considerable progress towards accomplishment of these goals.

Our work with the herbicide resistant plants has progressed to the stage of incorporation into the breeding program. Herbicide-resistant progeny plants produced from crosses carried out in 1995 and 1996 are currently in the field for evaluation. In the spring of 1997, six of the herbicide resistant progeny were selected for crosses with breeding material from Dr. Bill Meyer.

We also have produced a number of independent transgenic lines of creeping bentgrass containing potential disease resistance genes. In the summer of 1997, some of these lines were put into a randomized replicated field test for evaluation. The plot includes six independent transgenic lines each containing the pokeweed antiviral protein and bacterio-opsin, five independent lines of glucose oxidase, and 22 nontransgenic controls. Disease in the plot was from natural infection. Our preliminary results from this test are very encouraging regarding efficacy of the genes. Overall, the transgenics are exhibiting considerably less disease incidence than the controls.

Development of Transgenic Creeping Bentgrass Resistant to the Major Pathogenic Fungi

Dr. Joseph Vargas, Jr.

Dr. Mariam Sticklen

Michigan State

Goals:

- *Express our cloned chitinase gene in E. coli, and purify and collect chitinase protein.*
- *Identify the level of chitinase required to control three major turfgrass pathogens.*
- *Transform bentgrass with plasmids containing the chitinase gene.*
- *Evaluate the transgenic plants for resistance to major turfgrass pathogenic fungi.*

Dollar spot *(Sclerotinia homoeocarpa),* brown patch *(Rhizoctonia solani)* and *Pythium* blight *(Pythium aphanidermatum)* are major pathogenic diseases of turfgrass. All of these pathogens contain chitin. The laboratory team has cloned and characterized a full-length chitinase gene that contains the necessary chitin-binding domain ([1; 2; 3] Gene Bank Number L22032). This laboratory also has constructed several plasmids containing a potato proteinase inhibitor controlled by different (wound-inducible and constitutive) promoters. We also have obtained genes for drought resistance and bialaphos resistance from other laboratories.

We have genetically engineered tobacco as a model system, and then creeping bentgrass, with the chitinase gene construct that was developed in our laboratory. We also engineered creeping bentgrass with a few other useful genes including protease inhibitor II, *bar* (bialaphos resistance), and the mannitol dehydrogenase (drought tolerance) genes.

The herbicide resistance of these transgenic plants was confirmed over two years ago. These plants have been transferred to our field facilities, as well as to a seed company's field facilities. We examined the chitinase-transgenic plants containing the chitinase gene for their resistance to brown patch, and *bar*-transgenic plants after they were sprayed with bialaphos for dollar spot, brown patch, and Pythium diseases. Preliminary work on chitinase-transgenic plants at the greenhouse level indicated tolerance to brown patch. Furthermore, the results of our inoculation studies have shown that after bialaphos application, bar-transgenic creeping bentgrass have reduced weed problems, dollar spot and brown patch diseases at the greenhouse level. Eventually, all these transgenic plants must be crossbred and tested for their resistance to the major pathogenic diseases at the field level.

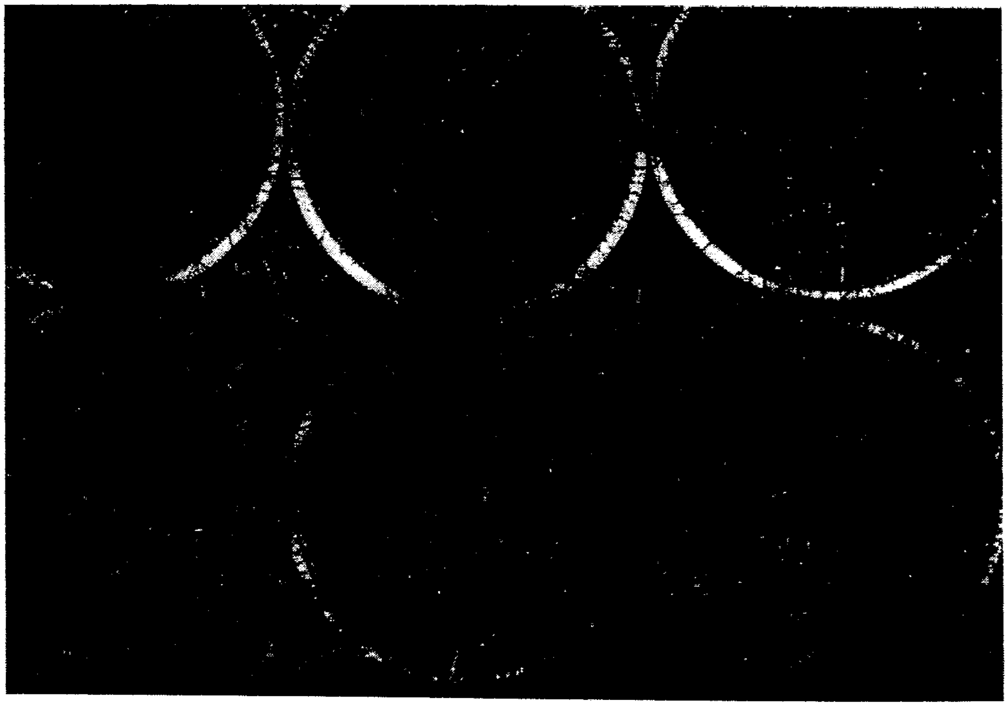


Figure 3. Results of preliminary research on resistance of chitinase-transgenic creeping bentgrass to brown patch (*Rhizoctonia solani*) disease. Upper row: control plants; Lower row: chitinase-transgenic plants.

Cultural Control, Risk Assessment, and Environmentally Responsible Management of White Grubs and Cutworms

Dr. Daniel Potter

University of Kentucky

Goals:

- *Determine factors that affect the distribution and abundance of white grubs and cutworms on golf courses.*
- *Reduce the use of insecticides by identifying methods to reduce white grub and cutworm insects through modified cultural practices.*
- *Provide better information on the effects of pesticides on natural enemies of turf-grass pests and other beneficial species that live in golf course turf.*

Cooperators:

A.J. Powell
K.F. Haynes
B.A. Crutchfield
R.C. Williamson

This research seeks better understanding of the causes of insect outbreaks on golf courses. We are also evaluating means by which superintendents can manage white grubs and cutworms with reduced use of broad-spectrum insecticides.

Field studies showed that withholding irrigation during peak flight of beetles, raising cutting height, and light application of aluminum sulfate in spring may help to reduce severity of subsequent infestations of Japanese beetle and masked chafer grubs. Grub densities were not affected by spring applications of lime or urea, but use of organic fertilizers (composted cow manure or activated sewage sludge) may increase problems with green June beetle grubs. Use of a heavy roller was not effective for curative grub control. Soil moisture seems to be the overriding factor determining distributions of root-feeding grubs in turf.

On creeping bentgrass putting greens, black cutworm (BCW) moths laid similar numbers of eggs regardless of cutting height. Nearly all eggs are laid singly, on tips of leaf blades. We found that most (75-97%) of the eggs are removed with clippings each time that greens are mowed; however, many eggs survive passage through the mower blades and will later hatch. Clippings therefore should be discarded well away from greens and tees. BCW also lay eggs in fairways and roughs, but here, most eggs are laid lower down on grass plants where they are not removed by mowing. Thus, reservoir populations may develop in high grass surrounding greens and tees. *Our work shows that cutworms may crawl as far as 70 feet in a single night, and that they often invade greens from peripheral areas.* Thus, when treating for cutworms, a 30 foot buffer zone around the putting green also should be treated.

BCW thrived when fed creeping bentgrass, perennial ryegrass, or tall fescue, but Kentucky bluegrass was highly unsuitable as food (Figure 4). Endophyte-infected cultivars did *not* provide significant resistance. Putting greens surrounded by creeping bentgrass, tall fescue, or perennial ryegrass may be at greatest risk from invasion from peripheral areas. Unfortunately, none of the 14 cultivars of creeping bentgrass that we tested showed much resistance to BCW.

BCW are most active on putting greens between midnight and just before dawn. Treatments therefore are best applied toward evening. Young cutworms feed mainly by "grazing" on the surface, whereas larger ones feed mainly from aerification holes or self-made burrows. Contrary to expectation, BCW were not attracted to aerified bentgrass, although they tend to occupy aerification holes when they are available. Sand top dressing may partially deter cutworms. Mowing at night, or an hour or so before dawn may provide substantial control by shredding.

Grubs of northern and southern masked chafers are important pests of golf courses throughout the United States. Females of both species produce a potent sex pheromone that attracts males. Interestingly, the two species are cross-attractive. In a pilot study, we tested whether grub "hot-spots" on golf courses could be located by trapping males using crude extracts of virgin female beetles. Because the beetle flights are localized, we reasoned that areas with heavy mating flights would be at highest risk from grubs. The results were promising, but the difficulty of getting virgin female beetle extract prohibits practical application. A synthetic lure is needed before this system can be fully tested on golf courses. Thus, we are collaborating with chemists at Cornell University to identify and synthesize the masked chafer sex attractant. The active chemical peak was pinpointed by gas chromatography and electro-antennogram behavioral analysis, and the compound was characterized by mass spectroscopy. A putative molecular formula has been worked out. Identification and synthesis of this potent attractant will allow its use for survey, risk assessment, and improved timing of control actions on golf courses.

Insecticides applied to golf courses can adversely affect beneficial or non-target invertebrates such as predators and earthworms. This sometimes can aggravate pest outbreaks or thatch buildup. We therefore are studying environmental side effects of two novel soil insecticides, imidacloprid (Merit®) and halofenozide (Mach 2®) as compared to conventional soil insecticides. Our work shows that both Merit and Mach 2 provide excellent control of white grubs, with low impact on beneficial and non-target species. These findings were requested by the US-EPA in support of final registration of Mach 2 for use on turf.

Finally, we initiated studies on the biodiversity and importance of predatory invertebrates in golf course habitats. The most abundant predators on Kentucky golf courses were ants, together with various mites, spiders, ground beetles, and rove beetles. More than 99 percent of the ant mounds on putting greens were made by one species, *Lasius neoniger*. When naturally deposited cutworm eggs were exposed on putting greens or aprons, 92 to 95 percent were eliminated in one night by *Lasius* workers. When cutworm or Japanese beetle eggs were exposed in fairways or roughs, predation was much higher in roughs than on fairways on both golf courses (Figure 5). Predation on eggs was closely correlated with abundance of ants. This study will reveal ant species that are most likely to cause damage to putting greens, and those that are highly beneficial predators. Ongoing work will seek ways of managing pest ants while conserving those species that are important in buffering golf courses against pest outbreaks.

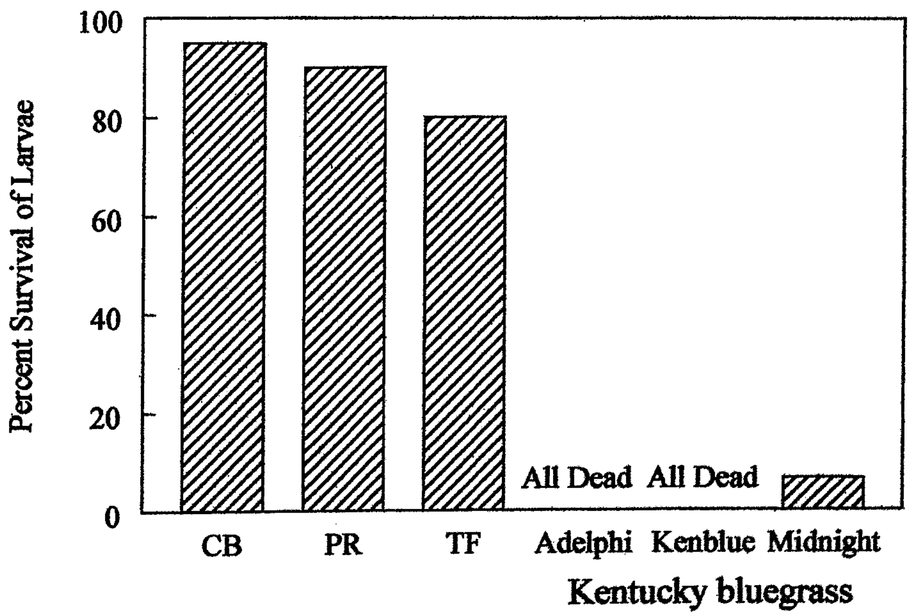
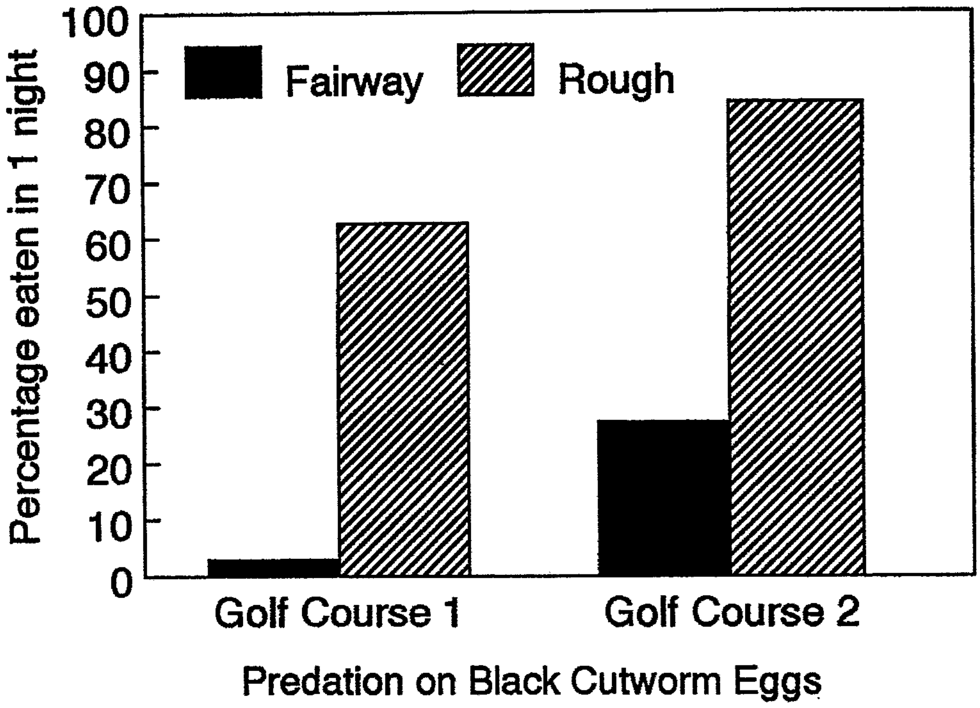


Figure 4. (last year) High survival of black cutworms reared on creeping bentgrass (CB), perennial ryegrass (PR) and tall fescue (TF), and lack of suitability of three diverse cultivars of Kentucky bluegrass.



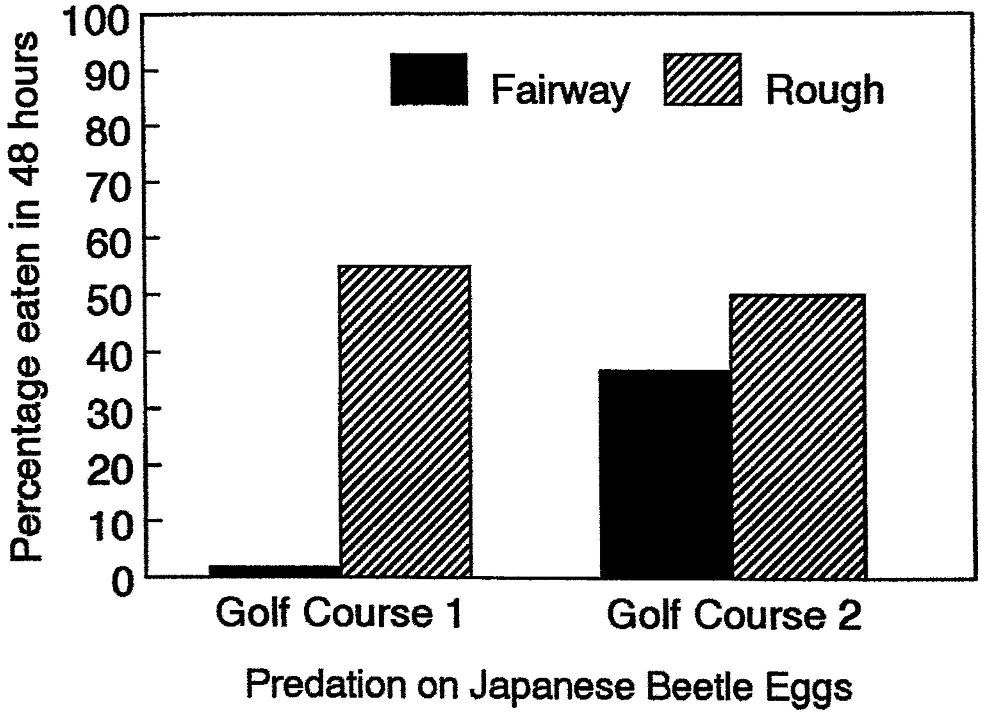


Figure 5. Natural predation on eggs of black cutworm or Japanese beetle exposed on golf courses for one night or two days, respectively. Note high rates of predation in untreated roughs, where predators were abundant, as compared to fairways. Ants were the most important predators on eggs.

Behavioral Studies of the Southern and Tawny Mole Cricket

Dr. Rick L. Brandenburg

North Carolina State University

Dr. Michael G. Villani

NY State Agricultural Experiment Station Geneva, NY

Goals:

- *Improve our understanding of tawny mole cricket and southern mole cricket behavior especially as affected by environmental conditions through radiographic studies.*
- *Isolate and determine the activity of sex, aggregation and alarm pheromones of the tawny and Southern mole crickets.*
- *Determine the behavior of tawny mole crickets in the presence of microbial and chemical insecticides.*
- *Initiate field studies to better understand tawny and southern mole cricket behavior as suggested by laboratory studies.*

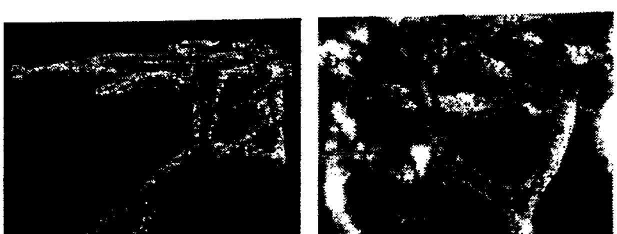


Figure 6. Examples of the use of wax castings to capture the burrowing pattern of mole crickets in large soil arenas.

The goal of this project is to develop a more effective and ecologically sound management strategy for both the tawny and southern mole cricket. The specific objectives of this proposal are to apply this new knowledge by: 1) documenting the site preference, dispersal, predation, avoidance behavior, and visible turf damage resulting from intra- and interspecific interactions between individuals in the field and through the use of radiographs, wax castings, and baits in the laboratory and in the field; 2) isolating and characterizing the biologically active compounds that may modify cricket behavior in the laboratory and in the field.

The field project at North Carolina State University has allowed us, in concert with the laboratory at Cornell University, to define factors that limit our management capabilities and identify conditions most conducive to effective mole cricket control.

Radiographic studies of mole cricket tunneling have documented stereotypic behavior of southern and tawny mole crickets. We have determined that soil physical properties, the presence of other crickets (of the same or different species), the presence of biological or chemical insecticides, and the presence of fluids from other crickets can alter this behavior. This information may help explain the variability observed when attempting to manage crickets in the field.

The use of radiography chambers that are essentially two-dimensional provides valuable insight into the subterranean activity of mole crickets. However, the actual three-dimensional components of the mole cricket's behavior are not well documented. The use of larger chambers to hold soil and preparation of a wax-based material to create casts of the tunneling structure has proven quite successful. Wax castings provide examples of the burrowing pattern of mole crickets in large soil arenas. Ordinary canning wax was heated and poured down cricket tunnels to create permanent wax castings of these tunnels. The castings allow us to view and analyze the cricket soil-burrowing behavior in response to a variety of control agents and soil conditions.

These casts document, not only the typical Y-shaped structure of the tunnel, but the development of an extensive network of tunnels useful for feeding and escape. They not only confirm radiograph findings, but allow further exploration of cricket behavior. Additionally these arenas are of a sufficient size to determine surface activity and turfgrass damage that is indicative of field damage

The use of this technique in the field during the summer and fall of 1997 has further documented the accuracy and validity of the laboratory radiographs. Field validation of tawny mole cricket tunneling behavior was conducted by creating wax castings of mole cricket tunnels on a golf course driving range that permitted complete excavation of castings. Wax castings in field tunnels and subsequent excavation of these castings have documented the Y-shaped tunnels observed in the radiographs. The consistency of these tunnels lends credibility, not only to the laboratory studies, but also to the theory that tunnel construction plays a significant role in mole cricket ecology and avoidance of control strategies.

A Masters student initiated studies on ovipositional preference, dispersal of nymphs, and the impact of the southern mole cricket on distribution on tawny mole cricket and subsequent damage during 1997. These studies have involved intensive sampling of mole crickets (both southern and tawny) over a wide range of soil types, soil textures, soil compaction, soil drainage and moisture characteristics. Data collected include ovipositional preference, nymph abundance and development, and turf damage. These data will help define high-risk areas and help target control strategies more effectively. The modification mole cricket behavior and insecticide activity using irrigation practices was inconclusive.

Studies on the impact of soil moisture on egg laying indicate the timing and intensity of oviposition can be significantly affected. This affects not only the likelihood that a mole cricket infestation will occur in a specific location, but also affects the timing of egg laying and ultimate egg hatch. Moreover, this favorable response to higher soil moisture may well serve as a risk indices for high-risk areas and thus aid in target monitoring and control strategies. Continued research on mole cricket development, as related to soil temperature and acoustic sound trap catches, add further support to previously developed population curves.

Pasteuria sp. for Biological Control of the Sting Nematode, *(Belonolaimus longicaudatus)*, in Turfgrass

Dr. Robin Giblin-Davis

University of Florida

Goals:

- *Examine bacteria ultrastructure with transmission electron microscopy and begin describing a new species of Pasteuria that was discovered parasitizing the sting nematode, Belonolaimus longicaudatus.*
- *Perform host range studies on this new Pasteuria sp.*
- *Begin studies to elucidate the population dynamics of this new Pasteuria sp. on sting nematode grown on St. Augustinegrass in laboratory pot cultures under controlled conditions.*

A new species of Pasteuria (S-1) was discovered that parasitizes the sting nematode, *Belonolaimus longicaudatus*. Host range studies with several species of soil inhabiting nematodes have demonstrated that this obligate endoparasitic bacterium only attaches to members of the genus of *Belonolaimus*. Ultrastructural and morphometric studies of mature and developing endospores with transmission and scanning electron microscopy (TEM and SEM) have shown that this *Pasteuria* is unique relative to the other described species of Pasteuria. However, different geographical isolates are morphologically and morphometrically constant.

A two-year survey of *Pasteuria* (S-1) was conducted at six different hybrid bermudagrass (fairway) sites at the Ft. Lauderdale Research and Education Center. Within these sites, *Pasteuria* (S-1) was naturally present at different levels and was monitored for its suppressive effects at three different soil depths on sting nematodes. Density dependent regulation of sting nematodes appears to be occurring in areas with *Pasteuria* (S-1). Survey locations that started with low levels of spore encumbrance showed a building trend in encumbrance levels and a corresponding decline in the numbers of sting nematodes. Locations with high spore encumbrance levels cycled and appeared to suppress sting nematode population resurgence, suggesting that *Pasteuria* (S-1) might help produce suppressive soil for the sting nematode in the turfgrass ecosystem.

An eighteen-month study was completed that compared the effects of inoculation with 900 ml of *Pasteuria* (S-1) spore-infested soil (approximately 5,000 endospores/ml) versus 900 ml of autoclaved soil in square meter *TIFDWARF* bermudagrass (putting green) plots. This study showed that a relatively small amount of Pasteuria-infested soil can be introduced into a USGA green with high numbers of sting nematodes and bring about density dependent suppression within about 12 months.

Genetic Basis of Biological Control in a Bacterium Antagonistic to Turfgrass Pathogens

Dr. Eric Nelson

Cornell University

Goals:

- *Identify and clone genes involved in fatty acid metabolism in E. cloacae strain EcCT-501.*
- *Sequence fatty acid metabolic genes.*
- *Establish relationships between fatty acid metabolism and biological control of Pythium-incited diseases on creeping.*

Cooperator:

Karin van Dijk

Enterobacter cloacae is an effective biological protectant against infection from many different soil borne plant pathogens. It is particularly effective in suppressing turfgrass diseases incited by *Pythium* species but also is effective against a number of other turfgrass pathogens including *Magneporthe poae* and *Sclerotinia homoeocarpa.*

The precise mechanisms of pathogen and disease suppression by *E. cloacae* are as yet unknown, although a number of traits have been empirically-related to the suppression of seed and seedling rots caused by *Pythium ultimum*. To date, however, no conclusive results point to one major mechanism by which *E. cloacae* suppress diseases caused by *Pythium* species.

An understanding of biological control mechanisms begins with an understanding of the host-pathogen interaction targeted for control. One of the more important aspects of *Pythium* diseases of plants is that these species respond extremely rapidly to germinating seeds and growing roots. *Pythium* spp. are highly dependent on exudate molecules to initiate infection of plants. Microbial interference with the production and activity of such stimulatory molecules could be an effective mechanism of biological control of *Pythium* diseases.

Over the past few years, we have been exploring the possibility of such a mechanism operating with *E. cloacae* and its suppression of *Pythium* diseases. Our previous research with other crop plants demonstrated that *E. cloacae,* and other seed-applied rhizobacteria, can utilize seed exudate from a variety of plant species as a sole carbon and energy source. At the same time, *E. cloacae* rapidly reduced the stimulatory activity of exudate to *P. ultimum* sporangia. Depending on the cell density, this inactivation of exudate can occur as rapidly as 2 to 4 hours.

Other previous work in our laboratory indicated that unsaturated, long-chain fatty acids (LCFA) found in plant exudates were the primary molecules responsible for the elicitation of *Pythium* responses to plants. From analysis of these exudate fatty acids, we found linoleic acid to be the most abundant unsaturated fatty acid found in exudates from a number of plant species, including creeping bentgrass and perennial ryegrass.

Few bacteria strains recovered from seeds of various plant species reduced the stimulatory activity of perennial ryegrass exudate within 24 hours to levels capable of inducing less than 30 percent *Pythium* sporangium germination. However, of those strains with activity, the majority were strains of *Enterobacter cloacae*. There also was a correlation between the ability of *E. cloacae* strains to inactivate linoleic acid and their ability to protect creeping bentgrass from *Pythium* damping-off.

We have taken a multifaceted approach involving physiological, biochemical, and molecular studies to investigate the relationship between fatty acid metabolism and biological control processes. Wild-type strains of *E. cloacae* can utilize a variety of both unsaturated and saturated LCFA as sole carbon and energy sources but grow very poorly, if at all, on medium-chain length (C_7-C_{11}) fatty acids. In addition, *E. cloacae* is capable of eliminating the stimulatory activity of unsaturated LCFA to *P. ultimum* sporangia in as little as 12 hours.

In our studies, we have used a molecular genetic approach of generating mutants deficient in fatty acid metabolism so that relationships between this function and biological control activity can be observed. We were able to generate a number of mutants of *E. cloacae* strain EcCT-501 that were no longer suppressive to *P. ultimum* in bentgrass assays. It turned out, however, that these were largely mutations in genes encoding TCA (tricarboxylic acid) and DCA (dicarboxylic) cycle enzymes.

More recently, we have been able to generate mutants specifically dysfunctional in the β-oxidation of fatty acids. The first mutant obtained (strain Ec31) fails to grow on media containing linoleic acid as a sole carbon source, but grows well on a minimal media containing succinate. This selection protocol was chosen to avoid selecting mutants with disrupted TCA and DCA cycle enzymes. This mutant is unable to reduce the stimulatory activity of linoleic acid, very slowly reduces the stimulatory activity of seed exudate, and fails to protect bentgrass seedlings from infection by *Pythium* species. Subsequent complementation and sequence analysis has revealed that the mutation in strain Ec31 is in the *fadB* gene, one of five structural genes central to the β-oxidation of fatty acids. While this mutant has debilitated linoleic acid catabolism, it is not clear whether this mutation represents deficiencies in linoleic acid transport or in linoleic acid utilization. Nonetheless, this mutant provides us with a more direct link between the two phenotypes of interest.

As a more direct approach of investigating fatty acid transport in *E. cloacae*, we have focused on the identification and mutagenesis of *fadL* genes within *E. cloacae*. We reasoned that, in such a mutant, we would see a stronger phenotypic response in the presence of linoleic acid. This mutant should allow us to more strongly implicate fatty acid metabolism in the biological control of *Pythium* damping-off of creeping bentgrass. We were successful in obtaining a *fadL* mutant of *E. cloacae* that we designated as strain EcL1. As with the *fadB* mutant (Ec31), the *fadL* mutant (EcL1) was unable to inactivate linoleic acid and seed exudate,

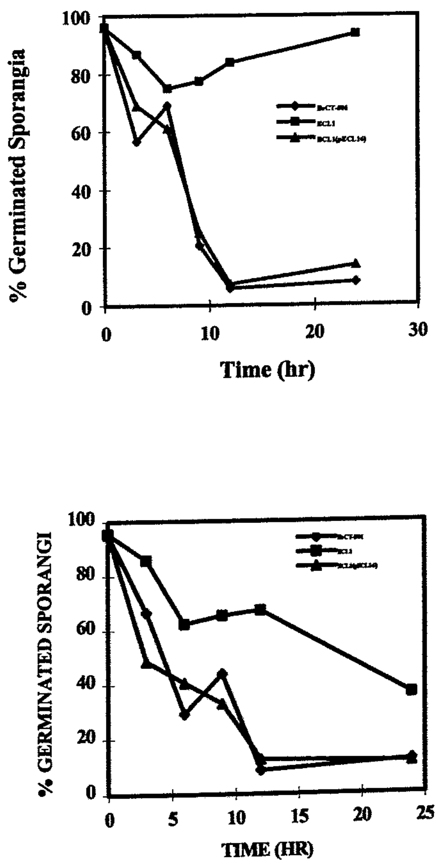


Figure 7. Inactivation of A) linoleic acid and B) seed exudate by E. cloacae strains EcCT-501, EcL1, and EcL1(pECL17).

and unable to protect seedlings from *Pythium* damping-off. Complemented strains fully restored these phenotypes.

Finally, when tested in creeping bentgrass bioassays, the mutant strain EcL1 failed to protect seedlings from damping-off (disease rating 4.5) whereas both the wild-type (EcCT-501) and the complemented strain (EcL1(pECL17)) gave similar and high levels of protection (disease ratings of 1.5 and 1.8, respectively).

Over the course of this project, we have developed strong laboratory evidence for the role of fatty acid metabolism in biological control processes with *Pythium* species on turfgrasses. This represents a novel mechanism of biological control and one that will have important implications for the further development of microbial inoculants and resistant plant germplasm for disease management in bentgrasses.

The performance of biological control agents has been unreliable and difficult to predict and manipulate, largely because of insufficient knowledge about the mechanisms by which biocontrol microbes interfere with host-pathogen interactions. Most previous studies on mechanisms involved in bacterial biological control of soil borne pathogens have focused on microbe-to-microbe interactions which result in direct fungal toxicity, such as through the production of antibiotics. This study provided convincing evidence for a biological control mechanism in which the bacterial biocontrol agent interacts directly with the plant, and only indirectly with the pathogen.

The inactivation of fatty acid germination stimulants could be an important mechanism by which bacterial biocontrol agents interfere with pathogens. This may have an influence on the screening methods for effective biocontrol organisms, since organisms best capable of inactivating stimulants could be selected. We suspect that the presence of fatty acid metabolizing bacteria such as *E. cloacae* in the spermosphere and rhizosphere of creeping bentgrasses and other grass species may actually impart disease resistance properties to those varieties. Since fatty acids are critical to the developmental biology and pathogenesis of *Pythium* species, it also is likely that breeding varieties for a low fatty acid seed content could be a favorable screening criterion for resistant germplasm. We hope to investigate these hypotheses further in the future.

Table 6. Differential protection of creeping bentgrass from infection by different *Pythium* species by wild-type, mutant, and complemented strains of *Enterobacter cloacae.*

	Disease Rating 1-5 Scale		
E. cloacae strain	*P. ultimum*	*P. graminicola*	*P. aphanidermatum*
EcCT-501 (WT)	1.8*	1.3*	2.0*
3-1	4.0	5.0	3.3*
4-1	5.0	5.0	5.0
Non-treated	5.0	5.0	5.0
Uninoculated	1.0	1.0*	1.0*

Means followed by (*) are significantly different from non-treated plants according to T-tests.
Rating scale: 1 = healthy turf and 5 = 100% unemerged or necrotic.
Ratings were determined 7 days after inoculation.

Identification of Parasitic Bacteria as Biological Control Agents against Summer Patch Disease

Dr. Donald Kobayashi

Rutgers University

Goals:

- *Isolate and identify bacteria that can colonize and parasitize the "mycelia" of Magnaporthe poae, the causal agent of summer patch disease.*
- *Screen isolated bacteria for disease control potential using controlled growth chamber and field studies.*

Cooperator:

Dr. Bruce Clarke

Summer patch disease is caused by the ectotrophic, root-feeding fungus, *Magnaporthe poae*. The disease is extremely damaging to turfgrass, affecting cool-season varieties under conditions of high soil temperature and high water potential. Disease development is enhanced by conditions that contribute to turfgrass root stress, such as low mowing heights or compacted soil. Our primary objective is to investigate the use of beneficial bacteria for control of summer patch and other diseases of turfgrass.

Stenotrophomonas (*Xanthomonas*) *maltophilia* 34S1 (Sm34S1) was previously identified as a biological control agent capable of controlling summer patch disease. Greenhouse/growth chamber studies indicated that Sm34S 1 reduced foliar symptoms on Kentucky bluegrass by as much as 70% compared to untreated disease controls. When Sm34S 1 was applied to plants on a repeated basis, summer patch was suppressed at high, sustained levels.

Colonization studies suggested that Sm34S1 populations should be established within the turfgrass rhizosphere at levels above 10^7 cfu/g sample during a two week period, and should remain above 10^5 cfu/g sample to achieve effective control. Sm34S1 was applied to pathogen-inoculated field plots located in a three-year-old Kentucky bluegrass stand that received minimal maintenance during the summer of 1995.

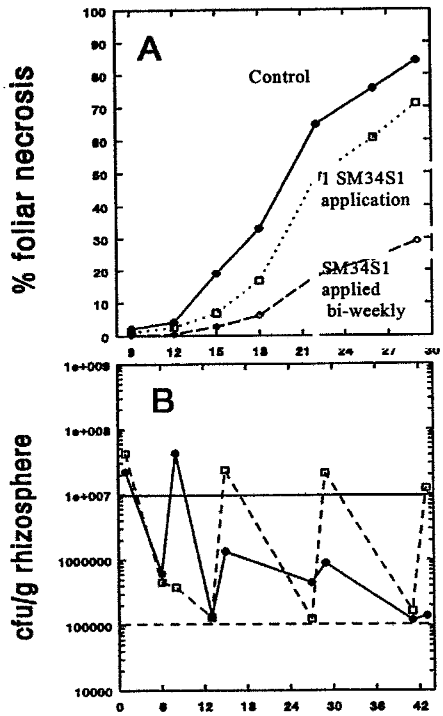


Figure 8. (A) Summer patch suppression on Kentucky bluegrass by repeated applications of SM34S1 (dashed line) in greenhouse-growth chamber studies. (B) Rhizosphere populations of SM34S1 in rootzone: solid line is one application, dashed line is bi-weekly applications.

Summer patch symptom development was not suppressed by Sm34S1during that year. Population studies indicated that Sm34S1 was maintained at levels between 10^4 and 10^7 cfu/g sample. Sm34S1 was applied to pathogen inoculated field plots in 1996 consisting of annual bluegrass/bentgrass green. Summer patch symptoms did not develop in field plots during 1996. Studies indicated that Sm34S1 populations fluctuated in the turfgrass rhizosphere over a range greater than that observed in 1995; however, on occasion, populations were established above the critically determined level of 10^7 cfu/g sample.

A single chitinase gene was cloned from Sm34S1 and the nucleotide sequence was determined. The gene encoded a single polypeptide of cat 1.6 kb, and was associated with a protein of 51.1 kdal in size. Site directed mutagenesis of the gene in 34S1 resulted in loss of chitinase activity, and a significant reduction in biocontrol of summer patch by this organism.

Chitinase activity and biocontrol of summer patch was restored when the cloned gene was reintroduced into the mutant. Studies indicated that chitinase was expressed under conditions of nutrient stress and in the presence of chitin. These studies provide strong evidence for the role of chitinase in biocontrol activity by 34S 1, and information towards understanding the conditions in which the gene is expressed.

Previously isolated biocontrol strains that appeared similar to *S. maltophilia* 34S1 were compared on a taxonomic basis. Fatty acid analysis (MIDI) and nutritional utilization (Biolog) suggested that two isolates, N4-7 and N4-15, previously recovered from the turfgrass rhizosphere and demonstrated to have summer patch suppressive abilities, were closely related *Stenotrophomonas*, *Xanthomonas* and *Xylella* species.

Serological tests using polyclonal antibodies made against N4-7 indicated relatedness to *Xylella* and N4-15, but not to *Stenotrophomonas*. Comparisons of 16s rDNA sequences confirmed the relatedness of both N4-7 and N4-15 to *Xylella* and *Stenotrophomonas*. However, N4-7 appeared most closely related to an unidentified, hydrothermal vent eubacterium.

Allelopathy vs. *Acremonium* Endophytes vs. Competition Effect on Crabgrass Suppression by 12 Perennial Ryegrasses

Dr. John King

University of Arkansas

Goals:

- *Conduct Lemna bioassays for allelopathic effects from leaf-stem and root tissue extracts from field grown plants.*
- *Conduct crabgrass seedling bioassays by overseeding crabgrass into the field plots.*
- *Evaluate crabgrass suppression by overseeding the perennial ryegrass cultivars into common bermudagrass and overseeding with crabgrass.*
- *Conduct crabgrass seedling bioassays by overseeding crabgrass into petri dishes containing the surface 1-cm of soil from a 5-cm diameter plug.*
- *Determine Acremonium endophyte content of field grown plant stems.*
- *Determine Acremonium endophyte contribution to allelopathy in the cultivar(s) showing strong allelopathic effects in the bioassays.*

Twelve (12) perennial ryegrasses that range from moderate to high stand density and zero to 95 percent endophyte infection were selected, and six replications of field plots were planted in late October, 1993. The cultivars and their expected percent endophyte infection are *LORETTA* (0), *GATOR* (0), *DERBY* (5-10), *DERBY SUPREME* (40-45), *ENVY* (40), *OMEGA II* (76), *MANHATTAN II* (50-90), *SATURN* (80), *SR4200* (80-85), *BRIGHTSTAR* (90), *ASSURE* (95), and *YORKTOWN III* (97).

Determination of *Acremonium* content showed actual infection levels different from those expected in the original and later seedlots. New seedlots were obtained for fairway overseeding trials for 1994, 1995 and 1996. All plots were maintained with good fertilizer, weed control, irrigation and 2 cm mowing practices.

One half of each original field plot was overseeded to crabgrass in spring of 1994, 1995 and 1996. Bermudagrass fairway plots were overseeded with new seedlots of the 12 cultivars in the fall of 1994 and 1995. Half of each plot was overseeded with crabgrass each spring and evaluated for crabgrass suppression. No differences in crabgrass stand could be attributed to any of the 12 cultivars. A range of crabgrass stands occurred when it was overseeded into a strip in each plot of the 99 cultivars of the NTEP Perennial Ryegrass Test.

Our basic laboratory evaluation for allelopathy is the *Lemna minor* L. (duckweed) bioassay. The *Lemna* bioassay measures allelopathic effects of extracts of plant tissues against the growth rate of duckweed fronds. Extracts from shoots are applied to duckweed cell plates at three concentrations. The amount of allelopathic inhibition (or stimulation) of duckweed varies with season of shoot tissue sample collection and extract concentration. All cultivars have affected duckweed growth, but inconsistently.

Development of a ryegrass extract-agar-crabgrass seed bioassay was attempted, but problems with fungal contamination and poor seed germination persisted. Bioassays using soil from under each cultivar, or mixing dried powdered leaf-stem tissue of each cultivar into soil in petri dishes showed inhibition of crabgrass seed germination and growth, but inconsistent results per cultivar over the tests.

We are conducting a well-rounded research approach to allelopathy in perennial ryegrasses, but inconsistencies in results over bioassays are very disappointing. Perhaps eventually, selection of ryegrass cultivars for crabgrass inhibition may become an important part of IPM programs.

Table 7. Crabgrass germination suppression by powdered tissue mixed into soil in petri dishes.

Cultivar	Tissue grams	Germination %	Sign	Cultivar	Tissue grams	Germination %	Sign
Loretta	0	51	-	Gator	0	58	-
	500	42	N		500	46	Y
	1000	43	N		1000	26	Y
	1500	41	Y		1500	24	Y
Derby	0	42	-	Derby Supreme	0	58	-
	500	40	N		500	44	Y
	1000	33	N		1000	49	N
	1500	34	N		1500	30	Y
Envy	0	34	-	Omega II	0	29	-
	500	18	Y		500	35	N
	1000	13	Y		1000	21	N
	1500	15	Y		1500	24	N
Manhattan II	0	28	-	Saturn	0	60	-
	500	15	Y		500	51	N
	1000	9	Y		1000	32	Y
	1500	9	Y		1500	31	Y
SR 4200	0	48	-	Brightstar	0	46	-
	500	44	N		500	42	N
	1000	35	N		1000	27	N
	1500	29	Y		1500	17	Y
Assure	0	33	-	Yorktown III	0	38	-
	500	32	N		500	19	Y
	1000	34	N		1000	16	Y
	1500	15	Y		1500	6	Y

Sign = significant difference at one standard deviation
Y = Significant phytotoxic effect compared to control
N = No significant phytotoxic effect compared to control

Best Management Practices

Golf courses provide beautiful green areas within our urban and suburban landscapes. However, there is public concern about the possible effects of golf courses on the environment. In response to this concern, the USGA completed a three-year research program in 1994 that examined the degradation and fate of turfgrass chemicals.

As a continuation of a responsible and scientifically based investigation of the environmental impact of golf courses, the USGA sponsored further research to understand the effects of turfgrass pest management and fertilization on water quality and the environment. To achieve this goal, three-year research projects were initiated in 1995 to focus on *Best Management Practices* and *Pesticide and Nutrient Fate.*

The purpose of the Best Management Practices research is to develop pesticide and fertilizer programs for golf courses that protect environmental quality. The current research projects focus on:

- Evaluating the effects of specific pesticides and nutrients that have a perceived environmental problem; and
- Identifying cultural practice systems that minimize pesticide and nutrient volatilization, surface runoff, and groundwater contamination.

Evaluation of Best Management Practices to Protect Surface Water from Pesticides and Fertilizer Applied to Bermudagrass Fairways

Dr. James H. Baird

Oklahoma State University

Goal:

- *Develop effective and practical management practices that protect surface water from runoff of pesticides and fertilizer applied to golf course fairways and other turf areas*

Cooperators:

Raymond Huhnke
Nicholas Basta
Gordon Johnson
Daniel Storm
Mark Payton
Michael Smolen
Dennis Martin
James Cole

The potential for runoff of pesticides and nutrients from turf, especially on golf courses, is the subject of increasing environmental concern. Consequently, a project was initiated in 1995 under the joint sponsorship of the United States Golf Association and the Oklahoma Agricultural Experiment Station. The primary objective was to evaluate the use of buffers as a best management practice for reducing pesticide and nutrient runoff from golf courses and other turf areas.

Studies were conducted in 1995 and 1996 on a three-acre sloped field of bermudagrass [*Cynodon dactylon* (L.) Pers.] located at the Oklahoma State University Agronomy in Stillwater, OK. The soil is a Kirkland silt loam. The area was surveyed to determine suitable locations for eight rainfall simulator set-ups, each containing four plots. The average slope of the plots was 6 percent. A portable rainfall simulator was used to apply controlled precipitation to a 50-foot diameter area containing the four plots (6 feet wide by 32 feet long). Each area of the plot receiving pesticide and fertilizer was 6 feet by 16 feet and mowed at 0.5 inches to represent a golf course fairway. The buffer area was considered to represent a golf course rough or the area between the treated area (fairway) and collection point (surface water). The following fertilizers and pesticides were applied to the treated area:

1. Nitrogen (N) at 1.0 lb ai 1000 ft^{-2} from urea (46% N) or S-coated urea (39% N);

2. Phosphorous (P) at 1.0 lb ai 1000 ft^{-2} from triple superphosphate (20% P);
3. Chlorpyrifos (0.5% granular or 50% wettable powder) at 2.0 lb ai A^{-1};
4. 2,4-D at 1.0 lb ai A^{-1}, mecoprop at 0.5 lb ai A^{-1}, and dicamba at 0.1 lb ai A^{-1} formulated as dimethylamine salts.

In most experiments, simulated rainfall (2.5 in h^{-1}) was applied for 75 minutes within 24 hours following application of chemicals. Start of surface runoff was recorded when a continuous trickle of water was first observed at the collection pit. Samples were collected at preset times after the start of runoff for individual plots using a nominal sampling schedule. Most plots were sampled 10 times during the simulated rainfall period. In most experiments, a single volume-weighted composite was prepared for chemical analysis from runoff samples for each plot.

In 1995, buffer length (0, 8, and 16 feet), mowing height (0.5 and 1.5 inches), and solid-tine aerification were evaluated to reduce pesticide and nutrient runoff. Soil moisture before simulated rainfall in July 1995 was low and pesticide and nutrient loss to surface runoff was less than 3 and 2 percent of applied, respectively. Highest concentrations of pesticides and nutrients in runoff water were 314 ppb for 2,4-D and 9.57 ppm for PO_4-P from the treatment containing no buffer. In August 1995, 6.5 inches of natural rainfall fell seven days before simulated rainfall. Pesticide and nutrient loss to surface runoff was increased to 15 and 10 percent of applied, respectively. Highest concentrations of pesticides and nutrients in runoff water were 174 ppb for 2,4-D and 8.14 ppm for PO_4-P from the treatment containing no buffer.

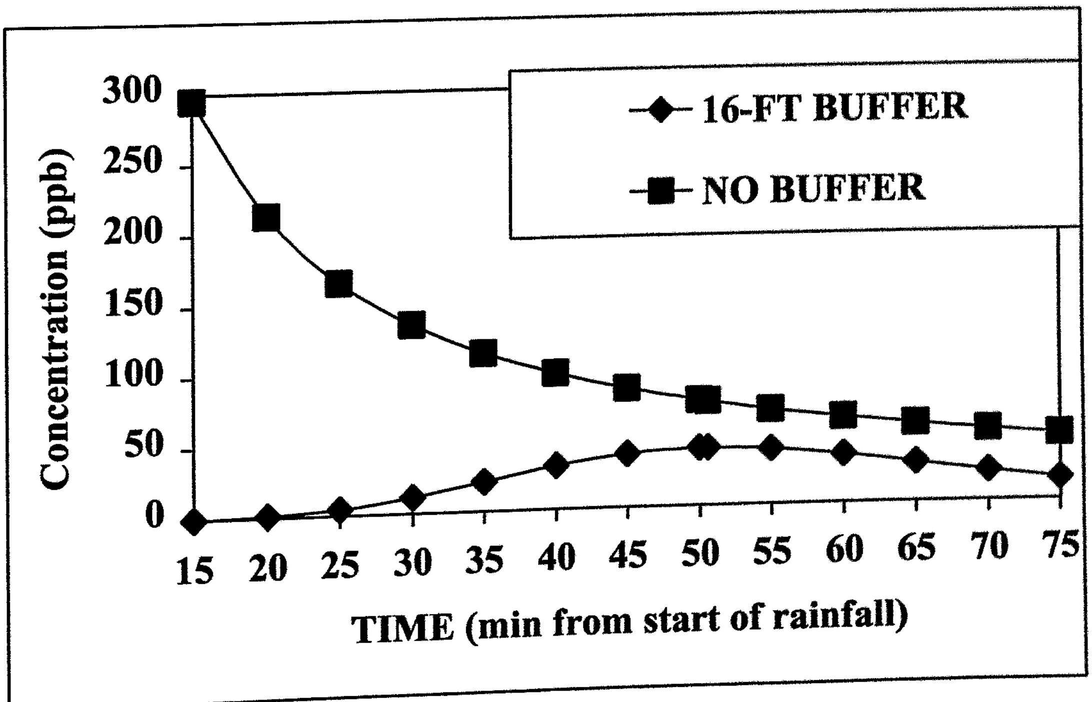


Figure 9. Plot of the predicted concentration of 2,4-D in surface runoff versus time in the 1996 buffer length experiment. *, ** Significant at alpha levels 0.05 and 0.01, respectively.

Overall, buffers were effective in reducing pesticide and nutrient runoff due, in part, to dilution. In most instances, buffer mowing height, length (8 vs. 16 ft), and aerification did not significantly affect pesticide and nutrient runoff. A paper describing research conducted in 1995 is published in the *Journal of Environmental Quality* Vol. 26 (1997).

In 1996, the portable rainfall simulator was used to evaluate the effects of: 1) buffer length (0, 4, 8, and 16 feet) at a 1.5 inches mowing height; and 2) mowing height (0.5, 1.5, and 3.0 inches) over a 16-foot long buffer on pesticide and nutrient runoff from bermudagrass turf. In the buffer length experiment, buffers reduced surface runoff losses of the pesticides and PO_4-P compared to no buffer. No differences in surface runoff were observed between buffer lengths of 4 and 8 feet. In the mowing height experiment, the buffer mowed at 3.0 inches was most effective in reducing surface runoff of pesticides and nutrients. No differences in surface runoff were observed between buffers mowed at 0.5 and 1.5 inches. Overall, effectiveness of buffers was dependent upon soil moisture content prior to simulated rainfall.

In 1995 and 1996, estimated concentrations of each contaminant for each plot were computed from a single volume-weighted composite of samples taken in a time series throughout the course of a simulated rainfall event. The focus of an ancillary investigation in 1996 was the manner in which buffers affect contaminant transport over the course of the simulation. For this purpose, samples taken in time series from no-buffer and 16-ft buffer treatments were individually analyzed for pesticide and nutrient content. Significant ratios for 2,4-D ranged from 2079 times higher for non-buffered plots at 15 min to 3 times larger at 40 minutes (see Figure 9).

Overall, the buffer was found to reduce and delay the onset of 2,4-D concentration in runoff, with a peak contamination of 41 ppb occurring approximately 51 minutes after the start of rainfall, according to the fitted model. Similar results were found for other pesticides and nutrients. For the conditions studied, significant ratios over the first half of the experiment suggest that the buffer takes an even more important role in reducing contaminant transport when rain events are expected to be shorter than 40 minutes. An analysis of estimated total runoff losses were not conclusive but suggests a buffer effect on runoff quality.

In addition to evaluating the effects of buffers on surface runoff of chemicals from turf, the time series data were used to evaluate the effectiveness of surface runoff sampling techniques for rainfall simulation studies. Volume-weighted composite samples are useful for determining if a management practice (e.g., buffer) affects the runoff quantity or quality. The data were used to predict the volume-weighted concentration of pesticides and nutrients in the surface runoff for samples taken at various times after the start of runoff. For the conditions studied, it was found that the difference in volume-weighted concentration between buffered and non-buffered plots had the lowest statistical significance 15 to 25 minutes after the start of runoff. Therefore, sampling 40 to 50 minutes after the start of runoff is recommended.

Time series data is desirable for predicting off-site environmental impacts from pesticides and nutrients in surface runoff. An optimal sampling scheme requires the smallest number of chemical analyses while still representing the actual time series accurately. For the data analyzed, the sampled data best represented the actual time series when sampling intervals were shorter at the start of runoff. The two schemes that worked best were: 1) sample every two minutes for the first 10 minutes after runoff and every 10 minutes thereafter; or 2) sample at 0, 2.5, 5, 10 minutes and every 10 minutes thereafter. The 2 to 10 minute scheme was more accurate, but requires two additional samples. Which scheme to select depends on the economics and objective of the study.

Based upon this investigation, chemical losses in surface runoff from turf can be reduced by the following:

- Install buffers between surface water and areas treated with chemicals;
- Effective buffer length is dependent upon site conditions (longer buffers are safer);
- A 3-in buffer mowing height is more effective than 0.5 or 1.5 in.;
- Avoid chemical application following heavy irrigation or rainfall events; and
- Choose pesticides and nutrients with low runoff potential.

Evaluation of Management Factors Affecting Volatile Loss and Dislodgeable Foliar Residues

Dr. John M. Clark

University of Massachusetts

Goals:

- *The role of vapor pressure and temperature will be evaluated in terms of developing a screening system for turfgrass pesticides*
- *Pesticides with possible safety concerns will be further evaluated in the context of best management practices, including the role of spray volume and adjuvants.*
- *The role of thatch accumulation on the dissipation of volatile and dislodgeable residues will be assessed.*

Cooperators:

R. Cooper, NC State University
D. Haith, Cornell University

Volatilization can be a major route of pesticide loss following application to turfgrass. Consequently, a significant proportion of applied pesticides may be available for human exposure via volatile and dislodgeable residues. Volatile residues were determined from small circular turf plots with high volume air samplers using the Theoretical Profile Shape method and dislodgeable residues were concurrently determined by wiping treated turfgrass with water-dampened cheesecloth. Inhaled doses were estimated from the volatile residues and dermal doses were estimated using the dislodgeable residues. Inhalation and dermal hazards were determined using the USEPA Hazard Quotient (HQ) method.

Our research to date has established that there are volatile and dislodgeable pesticide residues available for golfer exposure following application to turfgrass and that not all of these exposures can be deemed completely safe by the above criteria. Of the 13 pesticides examined, however, 10 were deemed safe in that their application never resulted in HQ greater than 1.0. Included in this "safe" group are the organophosphous insecticides, isofenphos, trichlorfon, chlorpyrifos; the carbamate insecticides, bendiocarb, carbaryl; the pyrethroid insecticide, cyfluthrin; and the fungicides, chlorthalonil, iprodione, propiconazole, thiophanate methyl. Application of ethoprop, isazofos and diazinon, nevertheless, did result in HQs greater than 1.0 and cannot be deemed as completely safe by the above criteria. These three pesticides are all organophosphorous insecticides that belong to the high vapor pressure group and have the lowest reference dose (i.e., highest toxicity rating) as established by the USEPA Office of Pesticide Programs. Ethoprop, isazofos and diazinon had inhalation HQs greater than 1.0 through day 3, the maximum inhalation HQs all occurred on day 1, and all were below 1.0 after day 3 following application (Table 8). Chlorpyrifos, which is in the high vapor pressure category, had a maximum inhalation HQ of 0.1 on day 2. This is due to the high reference dose of chlorpyrifos compare to the other organophosphorous insecticides. Similarly, ethoprop, isazofos and diazinon had dermal HQs greater than 1.0 on day 1 (15 min post application, Table 9). However, only ethoprop had a dermal HQ greater that 1.0 through day 1 (8 hr post application).

From these findings, we have determined that the critical vapor pressure below which no turfgrass pesticide will volatilize to the extent that it will result in an inhalation HQ greater than 1.0 to be between 3.3×10^{-6} mm Hg (i.e., isofenphos vapor pressure, Table 8) to 5.6×10^{-6} mm Hg (i.e., isazofos vapor pressure, Table 8). Similarly, we have determined the critical OPP reference dose above which no turfgrass pesticide will result in a dermal HQ greater that 1.0 to be between 0.0005 (i.e., see isofenphos, Table 9) to 0.0009 (i.e., see diazinon, Table 9).

In order to mitigate the exposure potential of the organophosphorous insecticides that have high vapor pressures and inherent high toxicity, we evaluated the practical use of spray tank adjuvants. Two adjuvants were examined as to their abilities to suppress volatile and dislodgeable residues: Aqua Gro-L, a non-ionic surfactant/penetrant; and Exhalt 800, an encapsulating spreader/sticker. Neither product resulted in significant and meaningful differences in the exposure potential of these problematic insecticides. Additionally, we determined the importance of thatch accumulation on the dissipation of volatile and dislodgeable foliar residues following the application of these problematic insecticides. Neither aeration nor dethatching of turfgrass plots resulted in significant and meaningful differences in the exposure potential of these organophoshorous insecticides.

In summary, the large majority of the turfgrass pesticides evaluated in this study were deemed safe using the USEPA Hazard Quotient method. Pesticides that were not deemed completely safe by these criteria were all organophosphorous insecticides with high vapor pressures and inherent high toxicity. Because effective organophosphorous and carbamate insecticide alternatives are available that do not share these problematic features, the use of ethoprop, isazofos and diazinon on turfgrass should be minimized and applied only when a delayed reentry period is practical.

Additionally, we have shown that some organophosphate insecticides that possess high toxicity and volatility may result in exposure situations that cannot be deemed completely safe as judged by the USEPA Hazard Quotient determination. This assessment, however, must be viewed in terms of the assumptions that were used in making these estimations. In all instances, maximum pesticide concentrations were used for the entire four hour exposure period, maximum rates for pesticide applications were used, and dermal transfer coefficients and dermal permeability factors were taken from non-turfgrass situations that are likely to exceed those that would take place on a golf course. Because of this, we view such estimates as *worst case scenarios*. To accurately predict the health implications of pesticide exposure to golfers, a relevant dosimetry evaluation of golfers, playing golf on a golf course, needs to be carried out. With more accurate exposure estimates, it is our belief that the exposure levels reported here would be found to be in excess of the true exposure to pesticides on a golf course.

Table 8. Inhalation hazard quotients (IHQs) for turfgrass pesticides in the high (i.e., vapor pressures > 1.0 x 10-5 mm Hg), intermediate (i.e., vapor pressures between 1.0 x 10-5 mm Hg and 1.0 x 10-7 mm Hg) and low (i.e., vapor pressures < 1.0) mm Hg) and low (i.e., vapor pressures < 1.0)

Pesticide	Vapor Pressure (mmHg)	OPP RFD (mg/kg/day)	Day 1 (IHQs)	Day 2 (IHQs)	Day 3 (IHQs)
High Vapor Pressure					
DDVP *	1.6 E-2	0.0005	0.06	0.04	0.02
Ethoprop	3.5 E-4	0.000015	50	26	1.2
Diazinon	9.0 E-5	0.00009	3.3	2.4	1.2
Isazofos	5.6 E-5	0.00002	8.6	6.7	3.4
Chlorpyrifos	2.0 E-5	0.003	0.09	0.1	0.04
Intermediate V.P.					
Trichlorfon	3.8 E-6	0.002	0.02	0.004	0.004
Bendiocarb	3.4 E-6	0.005	0.02	0.002	0.002
Isofenphos	3.3 E-6	0.0005	n/d	0.02	n/d
Chlorthalonil	5.7 E-7	0.015	0.001	0.001	0.0003
propiconazole	4.2 E-7	0.0125	n/d	n/d	n/d
Carbaryl	3.1 E-7	0.014	0.0005	0.0001	0.00004
Low Vapor Pressure					
Thiophanate-Methyl	7.1 E-8	0.08	n/d	n/d	n/d
Iprodione	3.8 E-9	0.061	n/d	n/d	n/d
Cyfluthrin	2.0 E-9	0.025	n/d	n/d	n/d

n/d = non - detected.
note: The IHQs reported in table 1 are the maximum daily IHQs measured on that sampling day.

Table 9. **Dermal hazard quotients (DHQs) for turfgrass pesticides listed with increasing RfDs from top to bottom through day 3 post application.**

Pesticide	OPP RfD (mg/kg/day)	Day 1 (DHQs) 15 Minutes	Day 1 (DHQs) 5 Hours	Day 1 (DHQs) 8 Hours	Day 2 (DHQs) 12:00 P.M	Day 3 (DHQs) 12:00 P.M
Ethoprop	0.000015	16.0	1.64	1.35	0.23	0.34
Isazofos	0.00002	1.05	1.17	0.97	0.16	0.21
Diazinon	0.00009	3.0	0.28	0.22	0.04	0.05
Isofenphos	0.0005	0.32	0.05	0.05	0.01	0.01
DDVP[a]	0.0005	0.06	0.003	0.003	n/d[a]	n/d[a]
Trichlorfon	0.002	0.64	0.007	0.009	0.008	0.005
Chlorpyrifos	0.003	0.17	0.02	0.016	0.003	0.004
Bendiocarb	0.005	0.31	0.006	0.01	0.006	0.0008
Propiconazole	0.00125	0.0002	0.003	0.0002	0.0005	0.0002
Carbaryl	0.0014	0.003	0.00008	0.0001	0.00006	0.000002
Cyfluthrin	0.0025	---[b]	---[b]	---[b]	---[b]	---[b]
Iprodione	0.0061	0.0004	0.0003	0.0003	0.0004	0.0003
Thiophanate-methyl	0.008	---[b]	---[b]	---[b]	---[b]	---[b]

[a] - DDVP was not applied, but is the breakdown product of trichlorfon.

[b] - Data not available.

Mobility and Persistence of Turfgrass Pesticides in a USGA Green

Dr. George H. Snyder

Dr. John L. Cisar

University of Florida, IFAS

Goals:

- *Conduct mobility (leaching and dislodgeability) and persistence studies on pesticides not examined in previous work.*
- *Monitor percolate collected on a golf course site for applied pesticides*
- *Quantify volatilization of certain pesticides applied to golf turf.*
- *Develop and document the results of using best management practices (BMPs) for fenamiphos and other pesticides that appear to have appreciable mobility, including evaluation of pesticide-adsorbing amendments.*

The mobility and persistence of the herbicides dicamba and 2,4-D were investigated in two studies conducted on a USGA green at the Ft. Lauderdale Research and Education Center that is outfitted with lysimeters for collecting percolate water. In each study, the herbicides were applied twice at one-week intervals at 58 and 6 mg a.i. m^{-2} for 2,4-D and dicamba, respectively, followed the next day by 9 mm irrigation, and by subsequent irrigation to maintain soil moisture. Samples of thatch, soil, percolate water, and clippings were analyzed for 2,4-D and dicamba.

Although the dicamba application rate was only 10 percent that of 2,4-D, the recovery of these materials (expressed as mass) in percolate water was of the same order of magnitude. Detectable levels of both herbicides were observed in thatch and soil for several months. Very little ($\leq$ 0.25 %) was recovered in clippings.

Leaching of the pesticide fenamiphos, and especially of its metabolites, has become a concern. These compounds were found in groundwater and surface waters in and around golf courses. The use of reduced irrigation for one week following fenamiphos application was studied as a means of reducing fenamiphos/metabolite leaching in a USGA green in south Florida. Leaching was reduced during the period of limited irrigation, but total leaching was equivalent for low and high irrigation treatments over a longer period that included plentiful irrigation and rainfall. It appeared that the fenamiphos and its metabolites that were not leached when irrigation was restricted eventually leached when excessive irrigation and rainfall occurred.

The percolate collection system in the USGA green at the Ft. Lauderdale Research and Education Center was expanded to include twelve lysimeters. This will permit greater numbers of replications in studies involving two or more treatments, which is very important for pesticide studies. During excavation it was noted that 7 cm of topdressing had accumulated on the green since the lysimeters were first installed. This layer appeared to hold more water than the underlying media does. It contained somewhat higher percentages of the finer sand sizes. It also had more organic matter than either the original rooting mix or the topdressing material. No movement of rootzone mix into the coarse sand layer, or of coarse sand into the underlying gravel was observed during excavation for the newly added lysimeters.

Volatilization of the organophosphate pesticides isazofos, chlorpyrifos, and fenamiphos was measured in two studies using the Theoretical Profile Shape technique. Volatilization was greatest for chlorpyrifos, and least for fenamiphos. Volatilization was less for an application that was followed by rainfall than for one followed by dry weather. Isazofos volatilization amounted to one and nine percent of that applied for the two rainfall situations, respectively.

Evaluations of pesticide dislodgeability and subsequent risk assessments were conducted in conjunction with a M.S. graduate student. The initial study was conducted on a *TIFDWARF* bermudagrass green overseeded with *Poa trivialis* to provide paired plots that were either overseeded or not overseeded. A second study was conducted with organophosphate pesticides on a bermudagrass green.

Dislodgeability methods were: cheesecloth rubbed on the treated turf surfaces, cotton and leather pressed on the turf, a golf ball putted over the turf, and a club grip rolled on the turf. The pesticides also were sprayed on the fringe of the green, and cheesecloth was rubbed on the head of a club that was swung through the turf to simulate a chipping stroke. These treatments were repeated at the end of the day, and again the next morning.

The pesticide analyses and risk assessments are incomplete at the time of this writing, although some data are available for the organophosphate pesticide study. These data demonstrate rapid decreases in dislodgeable pesticides with time after application, and particularly after irrigation.

Fenamiphos and fenamiphos metabolite adsorption by a stabilized organic polymer (SOP) was investigated in the laboratory and field. The SOP adsorbed relatively non-polar pesticides well, but the polar pesticides less well. The SOP formulation was modified to improve adsorption of less-polar pesticides. Sufficient reformulated SOP of various sand sizes has been prepared for field studies on the USGA green. The University of Florida has applied for a patent on the SOP as a soil amendment for reducing pesticide leaching without affecting the physical parameters of a USGA green, and for other uses.

Environmental Impacts of Golf Course Design, Construction and Maintenance

Mr. Mark Kuiper

Iowa State University

Goals:

- *Determine what the results of experiments concerning the fate of pesticides and fertilizers in different types of turfgrasses can tell about design, construction and management practices.*
- *Determine how to design buffer strips (natural areas) around lakes, streams and ponds.*
- *Evaluate approaches to golf course design and maintenance that can keep costs down while maintaining high environmental standards and aesthetic value.*

The purpose of this study was to synthesize current environmental research to develop a set of principles for more sustainable golf course design, construction, and management. These principles represent a synopsis of the current environmental research that has been published in a variety of journals (both refereed and non-refereed), books, and other sources.

In addition to the environmental benefits of the use of native vegetation in out-of-play areas, the research was extended to quantify the economic benefits of converting turfgrass areas to native vegetation. Prairie plants were selected for this analysis because their wide range of adaptation makes them practical for use on the widest array of golf courses. The goal of this economic analysis was to produce an estimated total cost of maintenance for golf course rough at each course. These values were then compared to the cost of establishment and management of the native vegetation on those areas to evaluate the time at which this type of turfgrass conversion could be expected to pay for itself.

The results of this study illustrate the maintenance savings available using native vegetation such as prairies. For all three of the courses studied, the conversion of turfgrass rough to prairie plants would pay for itself in reduced maintenance cost within the first two years, even using the highest priced prairie seed. In addition to making game more affordable, these areas would provide tremendous opportunities for wildlife habitat and decreased chemical, fertilizer, and water usage. These will be important characteristics of future golf courses as maintenance costs and political pressures continue to rise.

It is hoped that the results of this study will demonstrate the environmental and economic benefits of turfgrass conversion and serve as an example of a more sustainable golf course design and management strategy. A sustainable golf course would be would be capable of generating its own energy, recycling its own waste, supporting wildlife, and performing all of these functions without detrimental impacts upon the environment. Many of the principles of sustainability can be used as guidelines for providing innovative solutions for growing environmental problems, and will be helpful shaping future golf course developments. Sustainable golf course developments will include holistic, ecologically based strategies to create courses that do not impair but instead repair and restore existing ecological systems such as plant and animal communities, soils, and hydrology.

One of the key criticisms identified in this research has been water and chemical usage on golf courses. Discussion of water and chemical usage involves evaluation of a very difficult question; how much water and chemical usage is acceptable? In an effort to approach sustainability, courses of the future will be looking to decrease water and chemical usage. The research demonstrated the economic benefits of the conversion of turfgrass to native vegetation. This solution also has significant environmental benefits through the creation of wildlife habitat and the elimination of water usage, chemical usage, and labor required to maintain these areas. It is likely that there will be a continual trend towards higher water and chemical costs and corresponding increases in costs for management of golf courses. Employment of the design, construction, and management principles discussed in this research will have a large impact upon how well courses will perform economically and in protection of the environment.

Golf courses of the future will also function as multiple users of the land in their effort to approach sustainability. For example, many opportunities that exist for the conversion of damaged lands such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, and coal mines to golf courses. Development of golf courses on these degraded sites can create new habitat that supports many species of wildlife where before it was uninhabitable. The funds generated by golf courses make this conversion economically feasible. Courses also can be used to preserve urban open spaces and provide a flexible use for floodplain areas where other types of development should be avoided. Expanded use of native vegetation will provide wildlife habitat and increased biodiversity within the region and will provide educational opportunities for golfers and non-golfers alike. Effluent irrigation can be utilized on the courses, thereby creating another use for the land through waste treatment and water quality enhancement.

Continued research in the coming years will reveal more efficient irrigation systems and practices, better use of effluent for irrigation, new varieties of drought-resistant turfgrasses, and other developments that will change how golf courses are built and maintained. It is likely that mounting environmental and economic pressures related to water quality and water usage will change the way golf courses do business in the future. So far, the golf industry as a whole has been quite receptive to these changes, as demonstrated by the commitment of the United States Golf Association to fund research related to water quality, turfgrass health, and improving golf course operations. Superintendents also continue to experiment with different management practices in an effort to decrease water and chemical usage and provide wildlife habitat on their courses. It is this kind of commitment to improvement that will keep the game of golf viable in the coming years as it faces rising costs of development and other environmental concerns.

Pesticide and Nutrient Fate

Understanding and quantifying the fate of applied turfgrass pesticides and fertilizers are required for accurate prediction of the environmental impacts of golf courses. From 1991 through 1994, USGA-sponsored research demonstrated that 1) the measured nitrogen and pesticide leaching generally is minimal, 2) the turf/soil ecosystem enhances pesticide degradation, and 3) the current agricultural models need calibration/validation in order to accurately predict the fate of pesticides and fertilizers applied to turfgrasses grown under golf course conditions.

The purpose of the projects described in the following pages is to further evaluate the mobility and persistence of parent compounds and transformation products of commonly applied pesticides and fertilizers. Research results from these projects will provide information on:

- Degradation and volatilization rates for commonly used pesticides in several important turfgrass environments
- Identification of conditions that enhance microbial degradation
- Adsorption coefficients for organic and inorganic materials as a function of residence time in the turfgrass environment
- A mass balance assessment of the fate of applied pesticides that takes into account the initial distribution among volatilization, turfgrass, soil, runoff, and leachate

Nitrogen fertilizer studies include research to assess the importance of factors which influence volatilization, denitrification, mobilization, immobilization, adsorption, plant uptake, and fixation, as well as assess loss by surface runoff and leaching. Similar experimental conditions and research techniques are being used to determine the fate of phosphorous in the turfgrass environment.

Modeling Pesticide Transport in Turfgrass Thatch and Foliage

Dr. Mark Carroll

Dr. Robert Hill

University of Maryland

Goals:

- *To quantify the washoff of pesticides from bentgrass foliage as a function of time after application and pesticide formulation.*
- *To determine the effect of solution residence time on the sorption of pesticides to turfgrass thatch.*
- *To determine if the linear equilibrium form of convection/dispersion equation is able to provide accurate estimates of pesticide transport in turf.*

Cooperator:

Dr. Albert Herner
USDA Beltsville
Environmental Chemistry Laboratory

Pesticides applied to mature turf move into the soil only after being washed off the foliage and moving through the turfgrass thatch. Any attempt to predict the movement of pesticides applied to turf requires that the retention characteristics of the pesticide to foliage and thatch be known.

In 1996 and 1997, a series of sorption and transport studies were conducted to characterize the movement of 2,4-D acid in soils containing a surface layer of turfgrass thatch. The sorption studies were conducted using a device called a mechanical vacuum extractor. This device precisely controls the rate at which a solution moves through a column of porous media.

The adsorption and desorption properties of a 3.5 year old, 2.3 cm thick *SOUTHSHORE* creeping bentgrass thatch, and a 6 year old, 3.4 cm thick *MEYER* zoysiagrass thatch were compared with the soil residing below each thatch layer.

The adsorption of 2,4-D to soil was nearly instantaneous. In contrast, 2,4-D adsorption to thatch was dependent on the residence time of the solution containing this pesticide. The adsorption kinetics for thatch of the two turfgrass species was similar. The quantity of 2,4-D adsorption to thatch increased 72 percent as the solution residence time increased from 15 minutes to 24 hours. However, even at a residence time as brief as 15 minutes, 2,4-D adsorption to thatch was three times greater than to soil.

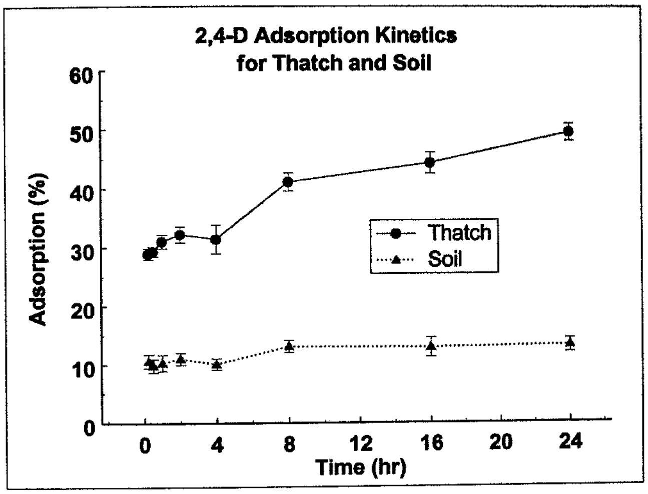


Figure 11. Adsorption kinetics of 2,4-D for thatch and soil.

Desorption losses were evaluated by subjecting columns of thatch or soil to three successive leaching events. The leaching events took place after allowing 2,4-D to adsorb to the thatch or soil for 24 hours. The quantity of 2,4-D detected in the leachate was used to determine the proportion of 2,4-D that was desorbed from the sample. The proportion of 2,4-D that was desorbed during the three leaching events was slightly less for thatch than for soil. The difference in proportional losses of 2,4-D, however, was small when compared to the total proportion of 2,4-D that was lost from each media. In a previously conducted desorption study, we found that desorption losses of dicamba were greater from soil than from thatch. Our earlier results suggest that some water-soluble pesticides may be more tightly bound to thatch than to soil.

Undisturbed cores of soil and soil plus a surface layer of thatch were used to determine the effect of thatch on the 2,4-D transport in soil. Cores having a surface layer of *SOUTHSHORE* creeping bentgrass thatch were more effective in reducing 2,4-D transport than cores having a surface layer of MEYER zoyisagrass thatch.

Bromide and 2,4-D breakthrough curves obtained from the transport study were used to evaluate the performance of linear equilibrium (LEM), two-site non-equilibrium (2SNE) and one-site kinetic non-equilibrium models to predict the transport of 2,4-D. The latter two models use non-equilibrium forms of the convection-dispersion equation to predict solute movement in porous media while the former model uses a linear equilibrium form of the equation to predict solute movement.

The bromide data did not present strong evidence of significant physical non-equilibrium or two domain flow in any core. In addition, all three models described 2,4-D transport fairly well with slightly improved fits resulting from the 2SNE model. Research in 1998 will focus on completing sorption and transport studies involving pesticides having low to moderate water solubilities.

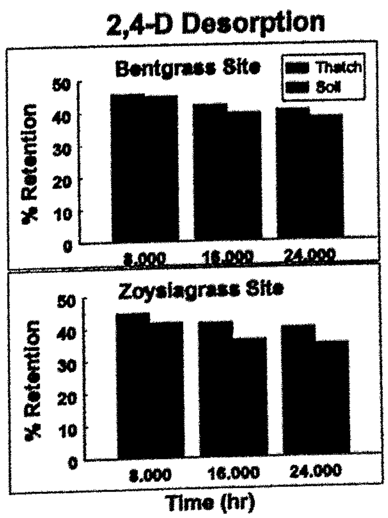


Figure 10. Cumulative proportion of 2,4-D retained to thatch following three successive 8 hour leaching events.

Measurement and Model Prediction of Pesticide Partitioning in Field-Scale Turfgrass

Dr. Marylynn Yates

Dr. Robert Green

University of California

Goals:

- *Determine the partitioning of commonly-used turfgrass pesticides among the components of a turfgrass system including the atmosphere, soil, soil-water, leachate, thatch, verdure, and clippings.*
- *Assess the ability of mathematical models, such as CHAIN_2D and PRZM2, to accurately predict pesticide movement in a field-plot-scale turfgrass system.*
- *Modify mathematical models and/or change the data collection protocol as necessary to improve the accuracy of model predictions.*
- *Test the model using independently-derived data to further assess its predictive capabilities.*
- *Conduct a sensitivity analysis of the mathematical model to determine which input parameters have the greatest effect on the model predictions and therefore should be known to the highest degree of accuracy.*

Concern over environmental contamination by pesticides has become widespread during the last several years. The United States Environmental Protection Agency has established mandatory standards for several pesticides, including 2,4-D, glyphosate and atrazine, in drinking water. In addition, several states have established regulations to limit further environmental contamination by pesticides.

Previous USGA-funded research at the University of California, Riverside (UCR) indicated that less than 0.1 percent of the applied carbaryl was lost by volatilization and leaching through the putting green plots. More of the applied 2,4-D could be accounted for: approximately 1 percent volatilized into the atmosphere, and approximately 5 percent leached through the soil. However, in both cases, more than 90 percent of the applied compound was not accounted for. In this project, we are performing more detailed analysis of the fate of pesticides in field plots to enable a determination of the mass balance.

A second area of concern is the need to predict ground-water concentrations of pesticides. It is usually not feasible to monitor ground water for the pesticides of concern, so measurements of pesticide concentrations in the near-surface soil and soil water are made. Mathematical models are then used to predict the concentration of pesticides that one might expect at deeper points in the subsurface.

The cumulative volatilization of metalaxyl was 0.08 percent of the applied mass. This was higher than predicted by the model (0%); however, it is a negligible amount. For 120 days after application, the concentration of metalaxyl in the upper 2 cm of soil decreased substantially. The concentration of metalaxyl in the leachate was negligible for the first 50 days of the experiment, and then rose to a peak at 75 days.

This is in good agreement with the model predictions, which estimated that none of the applied mass would leach during the first 30 days. The mass of metalaxyl that leached during the experiment was 0.072 percent of the applied amount. Approximately 0.139 percent of the applied mass was removed from the turfgrass clippings.

The mass of chlorothalonil that volatilized during the experiment was 0.017 percent. The model predicted that 0.6 percent of the applied mass would volatilize within 7 days of application. Detectable concentrations were seen throughout the entire soil profile by day 2 of the experiment, and measurable concentrations were detected at all depths at day 15.

The model predicted that none of the chlorothalonil would be detected in the leachate. In this experiment, detectable concentrations of the compound were found for at least 150 days. However, the concentrations were very low (less than 0.25 ppb). Only 0.0012 percent of the applied mass of chlorothalonil leached through the rootzone. The total amount of chlorothalonil removed in the clippings was 0.137 percent of the total applied.

The cumulative volatilization of chlorpyrifos was 15.7 percent of the applied mass. Essentially no chlorpyrifos was detectable in the soil below a depth of 20 cm. No discernible chlorpyrifos peak was observed in the leachate; the concentrations measured were very low, and near the analytical detection limit for the compound. A very small fraction (0.00037%) of the compound leached through the soil. Approximately 0.237 percent of the applied mass was removed from turfgrass clippings.

The mass of trichlorfon that volatilized during the experiment was 0.094 percent. Detectable concentrations were seen throughout the entire soil profile by day 2 of the experiment, and measurable concentrations were detected at all depths at day 90. Concentrations of the compound in the leachate were found for 72 days. The concentration peaked at about day 20, and moved through the system in a pulse for another few weeks. Only 0.003 percent of the applied mass of trichlorfon leached through the rootzone . The total amount of trichlorfon removed in the clippings was 0.05 percent of the total applied.

Potential Movement of Certain Pesticides Following Application to Golf Courses

Dr. Albert E. Smith

Dr. David C. Bridges

University of Georgia

Goals:

- *To obtain and develop mathematical equations for predicting the potential movement of pesticides through golf course greens constructed according to USGA guidelines.*
- *To determine the potential runoff movement of pesticides from golf course fairways on Piedmont soils and to develop management strategies for reducing the movement.*

The objectives of our research program over the past six years has been to evaluate the potential movement of pesticides and fertilizer components following application to golf courses and to develop Best Management Practices to reduce the potential for pesticide transport to potable water systems.

The initial steps for evaluating the potential movement of pesticides has been accomplished using pesticides registered for use on golf course greens and fairways on simulated greens and fairways at the Georgia Experiment Station. The facilities were constructed at the Georgia Station and analytical procedures were developed in our laboratories for this research program. Our simulation facilities were developed for the control of the environmental parameters in order to determine the potential transport of pesticides through the soil and in surface water runoff. Experimental control was necessary for defining and controlling the variable parameters that influence pesticide transport into the environment

Although, some of the recommended Best Management Practices resulting from our research program may already be in practice, there are no real data to support those practices. Additionally, there may be a concern for the choice of pesticides included in our research. Initially, we realized that the actual molecule used was not as important as to establish the characteristics of an expanse of molecular structures in the simulated greens and fairways (i.e., 2,4-D, dicamba, and mecoprop are not used on a lot of golf course greens but there is more research information available on these molecules than any other analytes). Therefore, we included 2,4-D, dicamba, and mecoprop in many of our simulated greens treatments. From these data we are developing models for predicting the potential movement of many molecules through golf course greens and from golf course fairways.

In 1995 high school student conducted research to determine the potential risk from kneeling on a green that had been treated 2,4-D, mecoprop, and dicamba (included in 1995 annual report). Additionally, in 1997 a senior from Mercer University conducted research to determine the potential risk from licking a golf ball that had been rolled across a treated green and from chewing a tee that had been placed in a treated tee box.

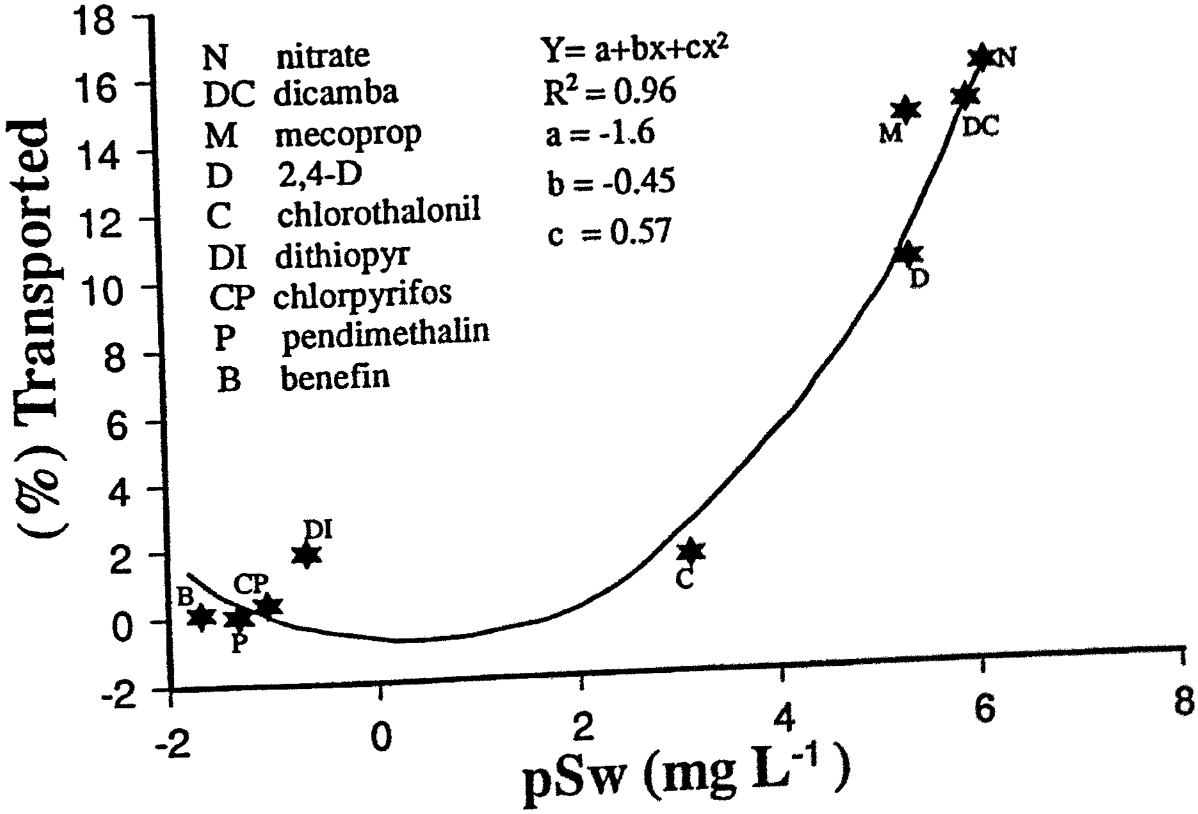


Figure 12. Fraction of the applied pesticides transported from simulated fairway plotted for the log of the water solubility (pSw) of the analyte.

Quantifying the Effect of Turf on Pesticide Fate

Bruce E. Branham

University of Illinois

Goal:

- *Quantify the ability of the turf organic matter to bind, degrade and slow the movement of a pesticide through the soil.*

This study is designed to quantify the effect of surface organic matter on the fate of pesticides applied to turf. Our goal is to relate the amount of turfgrass leaf tissue and thatch to the distribution of the applied pesticide and the retention and degradation of the pesticide amongst turfgrass leaves, thatch, and soil. Our approach is to remove thatch and leaf tissue from the turf prior to treatment with a pesticide. Using a vertical mower, we remove 0, 1/3, 2/3, and all of the turfgrass leaves and thatch from a bentgrass turf mowed at 1.25 cm.

In 1997, we repeated a study using this approach with the turfgrass fungicide cyproconazole (Sentinel). This study was initiated in July of 1997. Soil cores 20 cm in diameter and 30 cm deep were removed from the various organic matter treatments at 0, 4 8, 16, 32, 64, and 128 days following cyproconazole application. Data from this study is under analysis.

The same study was conducted in 1996. Data from that study shows the attenuating effect of surface organic matter on cyproconazole movement (Figure 13). As the amount of surface organic matter increases, the amount of cyproconazole reaching the 0-1 cm soil layer is dramatically reduced. Turfgrass leaf and thatch provide a barrier to pesticide penetration. The attenuation provided by a dense, actively growing turf is substantial, with less than 2% of the quantity of pesticide initially applied to bare soil reaching the soil of a actively growing bentgrass turf. At 4 days after cyproconazole, the concentration of

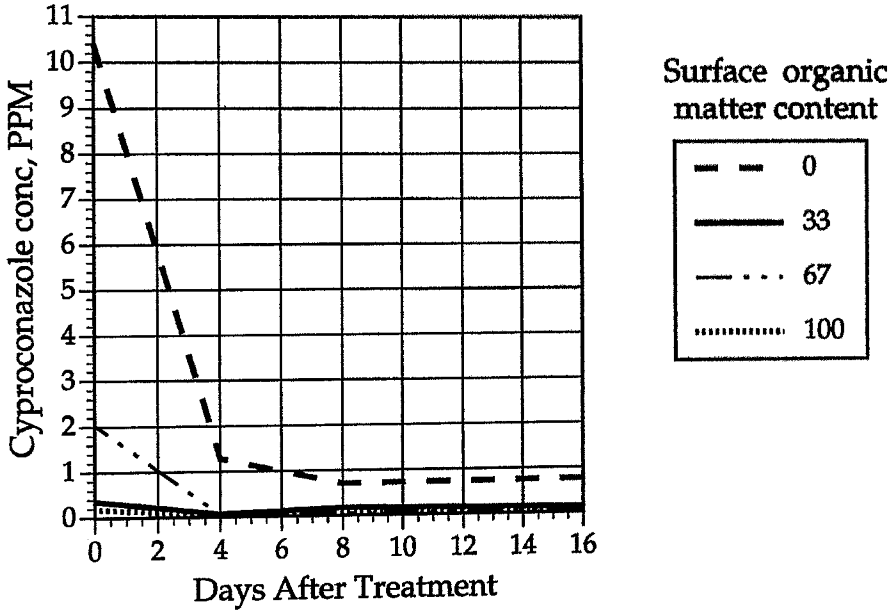


Figure 13. Cyproconazole concentration in the 0-1 cm soil layer.

cyproconazole in the 0-1 cm soil layer under full bentgrass cover was still only 2.3% of the concentration in the 0-1 cm layer of the bare soil plot.

The data on cyproconazole concentrations by soil depth also demonstrate the attenuating power of a turf cover (Figure 14). At each soil depth, the concentration of cyproconazole is higher in the bare soil treatment. However, cyproconazole degrades readily and no residues were detected below 5 cm for any cover treatment. The effect of surface organic matter on more mobile pesticides would be of interest.

The data indicate that turf has a substantial impact on the distribution and soil movement of pesticides applied to turf. As we continue to collect and analyze the samples generated in our studies, we will attempt to model the impact of various levels of surface organic matter on the initial distribution and subsequent dissipation and movement of pesticide residues. Our data will provide a quantitative assessment of the impact of turf on pesticide fate.

In 1997 a second trial was begun to determine the fate of ethofumesate (Prograss) applied to turf. This herbicide is considered likely to be mobile in soils because of its moderate soil sorption and relatively long soil half-life. Our study compares the dissipation rate for ethofumesate applied to bare soil and to a bentgrass turf. This study was initiated on September 21, 1997, the time at which ethofumesate applications are recommended by the manufacturer to begin. Soil samples for 0 to 64 days after treatment have been collected and are stored for future analysis.

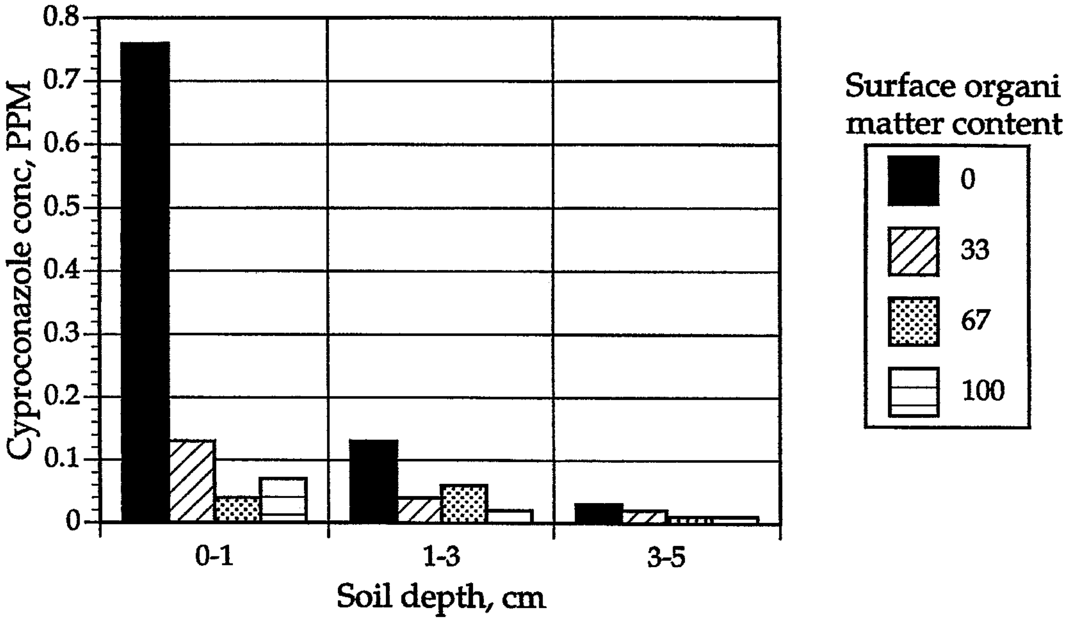


Figure 14. Effect of varying levels of surface organic matter on the cyproconazole concentration by soil depth at 16 DAT.

Degradation of Fungicides in Turfgrass Systems

Dr. Ron Turco

Purdue University

Goals:

- *Determine the character of the turfgrass leaf as a sorption material for fungicide.*
- *Determine the importance of microbial populations in controlling the degradation of fungicides on the turfgrass leaf surface.*
- *Investigate the significance of time on the fate of fungicides introduced into turfgrass ecosystems.*

Cooperators:

Clark Throssell
Zack Reiker

The study of microbial degradation of fungicides in turfgrass systems is important in order to understand the complete environmental fate of xenobiotic materials. This ongoing project investigates degradation as it may occur in the turfgrass canopy.

The turf leaf surface is an important sink for fungicides. It has been shown that a dense turf canopy can intercept over 95 percent of applied pesticides. Thus the turf canopy is a potentially important site for the degradation of xenobiotic materials including fungicides.

Review of last progress report:

Part 1. Fungicide dissipation results:

The concentration of fungicides in the extracted samples from the turf canopy was being determined using gas chromatography. Some manipulation of the samples was required in order to keep the concentrations of the detected fungicides within the limits of the standard solution concentrations. The first several samples that were going to be analyzed were those from the first and fifth two-week application cycles. These samples were chosen because they represent the first and fifth applications of fungicides that are applied every two weeks and the first and second applications of fungicides applied every eight weeks. It was thought that differences in degradation rates attributable to application frequency would most likely be observed at these sampling dates.

Part 2. Fungicide degradation results:

Oxidation of the degraded clipping samples showed that the majority (75%) of the applied radiolabeled fungicide was bound in the turfgrass leaves and probably unavailable for microbial degradation. The exact mechanism by which the fungicide became bound to the turf clippings was not clear. Determining the amount of residual parent material and metabolites formed was conducted using thin layer chromatography of ethyl acetate extracts of the degraded clippings. Because of the binding of the fungicide to the clippings, the amounts extracted from the leaf tissue was low. This kept the amount of radioactivity in the extracts spotted onto thin layer chromatography plates at a low level. Thus, plate counter-detection was impaired, and to a large extent, not useful in determining the presence of metabolite/parent compound-relationships. Few of the plate counter tracer graphs showed adequate amounts of activity that would allow for accurate quantification. This information, however, supports our conclusion that little of the fungicide is available in the environment. Most of the material appears to be retained in the leaf tissue.

Progress since May 1997

Part 1: Fungicide dissipation in the turfgrass canopy results

Analysis of the extracted fungicides showed that the dissipation rates on plots receiving fungicide applications were similar, regardless of frequency of application. Figure 15 shows the averages of all eight sampling cycles for iprodione, metalaxyl, and triadimefon. Although small changes in the dissipation rates were evident among the eight sampling cycles, the general trend of all sampling cycles was not conclusive support for the concept of

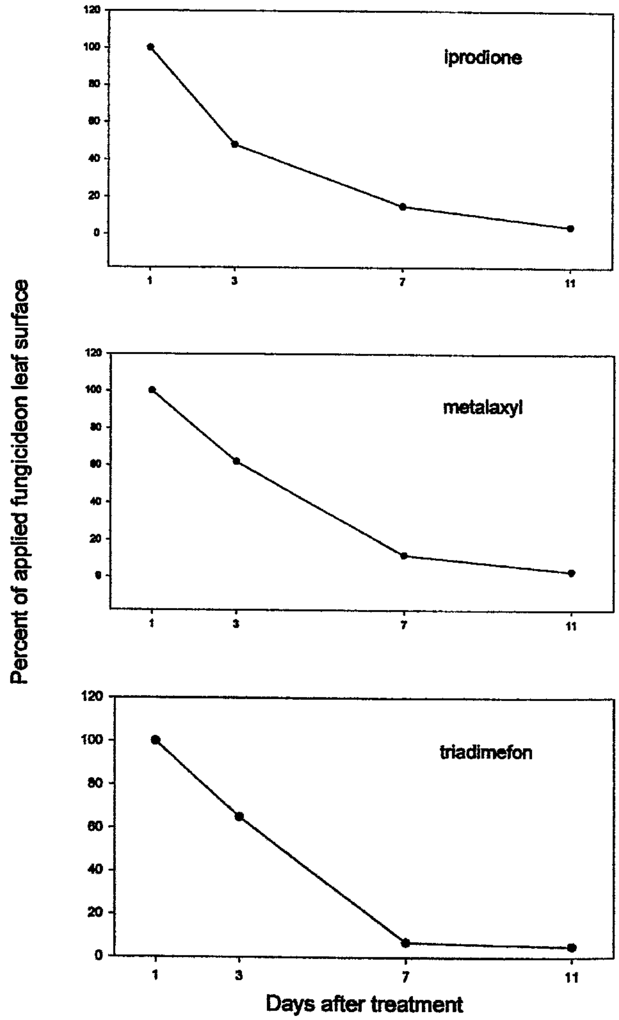


Figure 15. Averaged dissipation of iprodione, metalaxyl and triadimefon over eight application cycles.

enhanced biodegradation. The similarity of the dissipation curves suggests that little change in the loss mechanism of the fungicides is taking place.

Part 2: Fungicide degradation results:

A.) Quantifying the environmental fate of fungicides:

Table 10. Sampling cycle 5 recovery of 14C-fungicide from turfgrass clippings.

Fungicide	Pre-extraction §	Post-extraction	Extractable	Mineralized
	----------	---------- %	----------	----------
Triadimefon	100	56	42	2
Metalazyl	100	67	30	3
Iprodione	100	62	33	5

§ Data normalized to reflect pre-extraction as 100% of total fungicide amount.

An example of the mass-balance of fungicide fates is depicted in Table 10. Pre-extraction oxidation is used to determine the amount of radiolabel ("C-labeled fungicide) that is extractable from the leaf surface of the degraded clippings. After shaking with ethyl acetate to remove the extractable fungicide, a post-extraction oxidation was performed to determine the amount of fungicide that is non-extractable and thus not available for microbial degradation. Based on pre and post-oxidations, results showed that, on average, only 36 percent of the fungicide ormetabolites were extractable. This means that almost two-thirds of the applied fungicide remained bound to the leaf surface, unavailable for microbial degradation or loss into the environment. The poor extraction efficiency in addition to a presumed complexing of the fungicides with extracted plant material, such as chlorophyll, is assumed to have resulted in the limited detection and quantification of metabolites using thin layer chromatography.

B.) Short-term sorptive properties of fungicides and leaf tissue:

Results of the 48-hour sorption study are displayed in Figure 16. The two-phased nature of fungicide extractability over time suggests variability in adsorption to the leaf surface. The extractability of the three fungicides over time remained relatively unchanged for the first 24 hour. The reason for the variation in recoverable fungicide for the first 24-hour period is unknown. It is possible that either diurnal cycles of metabolism unique to the plant are at work or simply uncontrollable sampling error occurred. Changes do however occur in the extractable amounts of all three fungicides after the 24-hour sampling. In the 24 hour period between the 24-hour sampling and the 48-hour sampling, the extractable amounts of triadimefon, metalaxyl, and vinclozilin decreased by 97, 65, and 80 percent of applied amounts, respectively. Irreversible binding to the leaf surface or uptake into the leaf is thought to drive this phenomenon. The drastic immobilization of fungicide can partially explain the limited microbial mineralization that resulted from the degradation study and the inefficient extractions of the degraded clipping samples. Thus, the highly sorptive nature of turfgrass leaf tissue is important in sequestering iprodione, metalaxyl, and triadimefon and limiting the amount of free chemical in the environment. Dilution of the fungicides by the growth of the plant between samplings was determined not to effect the concentrations of the extracted fungicides.

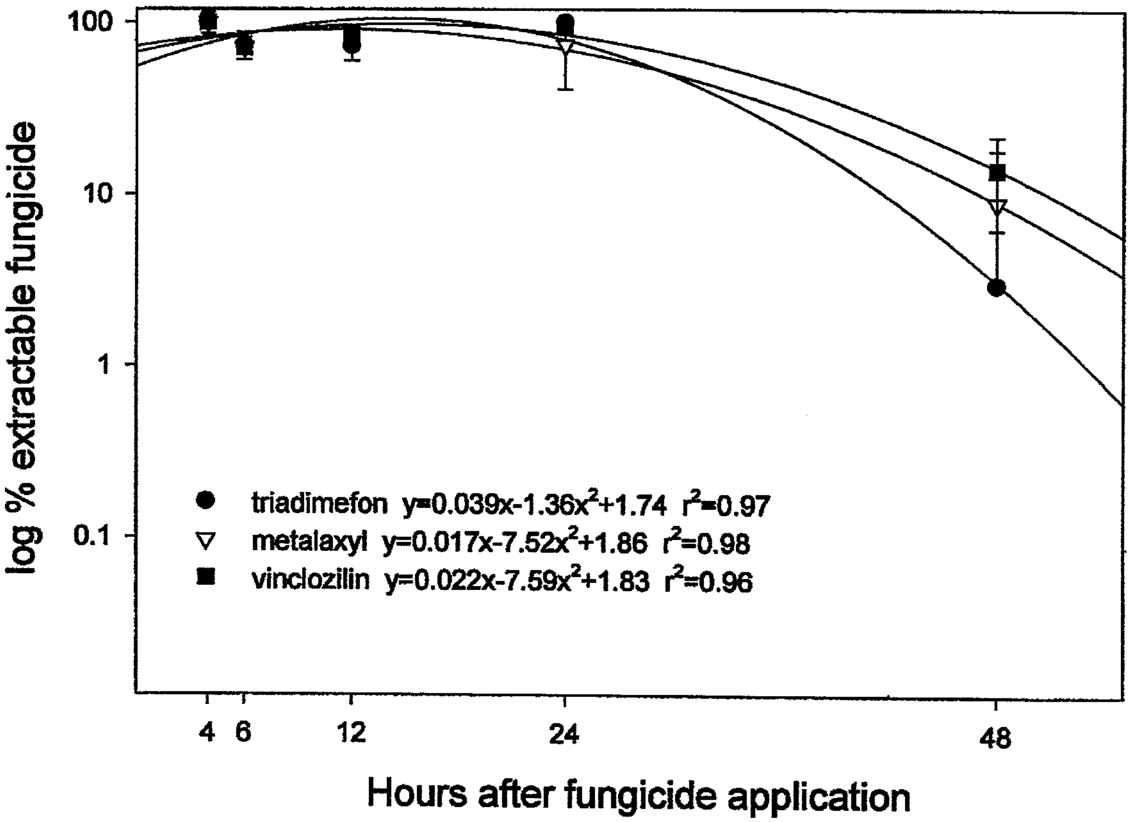


Figure 16. Percent of extractable fungicide at 4, 6, 12, 24, and 48 hours after application.

Characterization of Leaching at the Coeur d'Alene Golf Course Floating Green

W. J. Johnston

Washington State University, Pullman

Goals:

- *Quantify water flow and movement of NO_3 and NH_4 through a large-scale sand-based putting green under actual golf course conditions.*
- *Demonstrate the effect of nitrogen application regimes on sand-based putting greens to promote environmental safety and support the highest level of turfgrass quality.*
- *Determine nitrogen fate in an enclosed turfgrass environment utilizing irrigation and meteorological data.*

Cooperators:

W. L. Pan
G. K. Stahnke
C. M. Kleene

A knowledge base detailing nitrogen fate in sand-based golf greens is currently being developed through research conducted at the floating 14th green at the Coeur d'Alene Resort golf course, Coeur d'Alene, Idaho. This "signature hole" green is constructed on a concrete barge and floats on Lake Coeur d'Alene. All the irrigation water applied to the green is monitored, as well as the amount of water leaching through the green. The leachate is stored in large tanks under the green and is periodically pumped back to shore. This project is unique in that we are attempting to determine the location and form of nitrogen on an entire sand-based green under actual course playing conditions. The project aims to further open lines of communication between the golf course industry and the public by conducting research at a highly visible site.

The project to date has focused on gathering the putting green background information, equipment evaluation, and equipment purchase and setup. The design and layout of the floating green has led to a research methodology specific to this project. Site visits to the golf course have provided valuable information in regard to the experimental design.

The goal for winter 1997-1998 and spring 1998 is to complete installation of equipment and begin testing to insure accuracy and reduce possible experimental error. The majority of experimental data will be taken during 1998 and 1999.

Evaluation and Calibration of Pesticide and Nutrient Transport Prediction Models

Dr. Stuart Cohen

Environmental & Turf Services

Goals

- *Develop a questionnaire that can be administered to university researchers to help provide the site characterization data and results critical for computer modeling.*
- *Obtain pesticide leaching and runoff data from USGA-funded researchers, and fill in data gaps where necessary.*
- *Calibrate the computer simulation models PRZM and GLEAMS against the volumes of percolate water and runoff water obtained from the test plots.*
- *Calibrate the models against the pesticde leachate and runoff results.*
- *Evaluate the model performance in terms of validity and parameter sensitivity. Provide guidance on the use of the models for turf and the possible need for modifications of the models to make them more appropriate for turf.*

Cooperators:

Tom Durborow
LeJan Barnes

The purpose of this study is to evaluate the applicability of two pesticide fate models to turf. These models were developed and have been mostly used for assessing the fate of agricultural pesticides. The models are PRZM (EPA's Pesticide Root Zone Model) and GLEAMS (USDA's Ground Water Loading Effects of Agricultural Management Systems model).

First Phase (Completed)

The first phase of this project was completed last year. A comprehensive, two-volume report was issued April 12, 1996. We had good results calibrating the GLEAMS model against Dr. Al Smith's results from 12 runoff turf plots. We only had mixed success calibrating PRZM against the University of Georgia leachate data from different plots. However, we have recently received soil moisture curve data from Dr. Smith that, after clarification, will allow us to reexamine and possibly improve our previous analyses.

Second Phase (Current)

Model Selection. We are using EPA's latest version of PRZM, version 3.0, for our runoff assessment as well as our leaching assessment. This version of PRZM should become widely available within the next six months. We had previously used version 2.0 for our leaching assessment only. This version was known to overestimate pesticide runoff which was one reason why we chose GLEAMS to assess pesticide runoff in that phase. We are not using

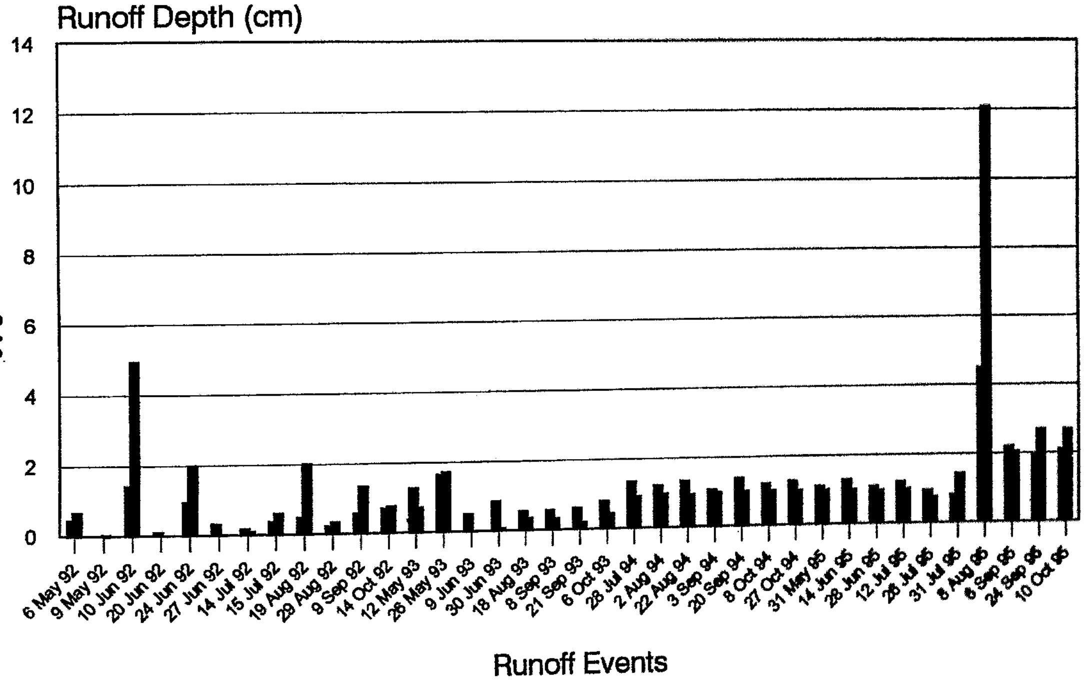


Figure 17. Plot of observed (first bar) versus predicted (second bar) using PRZM r3.0 runoff simulation model. Observed data was from the ryegrass runoff plots at Pennsylvania State University collected during 1992-1995.

GLEAMS in the current phase for two reasons: the runoff problem with PRZM has been resolved, and EPA prefers to use PRZM (although EPA will still accept GLEAMS assessments with proper documentation).

<u>Runoff.</u> We are calibrating PRZM against data generated at Pennsylvania State University. Creeping bentgrass and perennial ryegrass were maintained at three-quarter inch height. Simulated rainfall was applied at the rate of 6 inches per hour. The pesticides MCPP (mecoprop), isazofos, and triadimefon were applied and analyzed. The triadimefon metabolite triadimenol also was detected. Generally, 0.5 to10 percent of the applied pesticide ran off. There were insufficient data available on the soil properties, so we sampled the soils and had them analyzed.

We have put much effort into reproducing the hydrology (actual event-specific runoff water volumes) and we have obtained moderate success (Figure 17). More calibration work was required than desired due to one or both of the following factors.

The PRZM crop model is not as conducive to describing turf as the GLEAMS crop model. For example, GLEAMS gives the option of growing a perennial crop whereas PRZM does not. One is not able to directly model turf going dormant with PRZM. GLEAMS focuses more on the management of the crop and PRZM focuses more on the processes.

The Pennsylvania State University researchers did not measure the actual irrigation/rainfall applied to the surface. We could only estimate the actual water received by the surface based on the rainfall simulation design and the length of time the system was turned on. It is possible that a significant fraction of the fine droplets drifted off site. We have just begun to model the pesticide runoff.

Leachate. We are calibrating PRZM against the results of Dr. Garald Horst at University of Nebraska. Field turf plots (Kentucky bluegrass in a silty clay loam) were harvested for the greenhouse experiment in 1992. Porous ceramic plates were attached to the bottom of the soil cores to simulate the field environment matric potentials and to avoid creating a perched water table at the bottom of the cores.

Seven pesticides were applied to the lysimeters (soil cores) and two irrigation regimes were used. We are modeling the cores irrigated at two inches every three days, and treated with the following four pesticides: MCPP, 2,4-D, isazofos and chlorpyrifos.

Observed vs. predicted water leachate volumes on a daily basis had excellent agreement. The coefficient of variation was 10.4 percent, despite the fact that no calibration (tweaking of the model) was done. However, it should be noted that: 1) PRZM predictions are slightly to moderately high on all but three dates; and 2) the spread of observed percolate volumes was not large, thereby somewhat reducing the toughness of the test for PRZM.

Surprisingly, we are having difficulty matching predicted vs. observed pesticide leachate. We say "surprisingly" because the general rule of thumb is that successful and easy hydrology calibration usually leads to good chemical leachate (or runoff) predictions. We are continuing to examine this significant discrepancy.

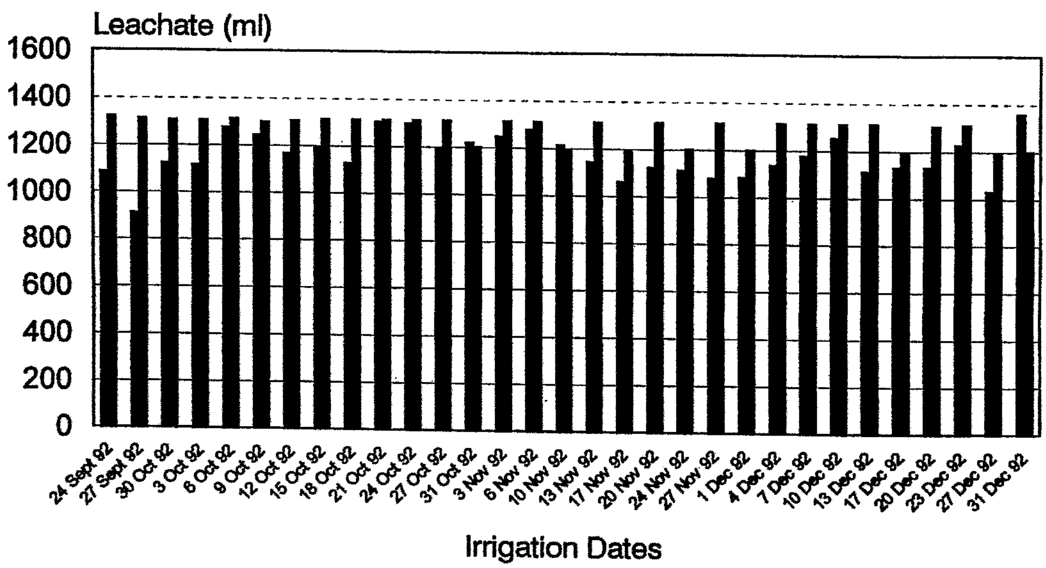


Figure 18. Observed leaching (first bar) and predicted (second bar) using PRZM r3.0 simulation model. The data was from University of Nebraska greenhouse soil cores collected during fall and winter 1992.

Mass Balance Assessment of Pesticides and Nutrients Applied to Golf Turf

A. M. Petrovic

Cornell University

Goals:

- *To develop a better understanding of the factors and conditions important in the leaching of pesticides and fertilizers applied to an experimental golf fairway following establishment.*
- *Compare two ways of evaluating the fate of N by using a traditional N source and analytical methods compared to a heavy N isotope (N15) N fertilizer source and a ratio mass spectrophotometer for quantification.*

Cooperators:

D. Lisk
J. M. Duxbury
D. S. Wilks
1. Larsson-Kovach

The objective of this project was to develop a better understanding of the factors and conditions important in the leaching of pesticides and fertilizers applied to an experimental golf fairway following establishment. The ARESTS facility was utilized for this purpose where soil types (sand, silt loam and sandy loam) and post application precipitation factors could be studied.

An additional objective was to compare two ways of evaluating the fate of N by using a traditional N source and analytical methods compared to a heavy N isotope (N^{15}) N fertilizer source and a ratio mass spectrophotometer for quantification.

The leaching of five pesticides (MCPP, triadimefon, trichlorfon, isazofos and metalaxyl) and fertilizer elements (N03-N, NH_4-N and $P0_4$-P) were evaluated under well-maintained fairway conditions and three soils types (sand, Arkport sandy loam and Hudson silt loam). Normal and extremely wet precipitation conditions were also evaluated.

Under normal precipitation-irrigation conditions, in general, pesticide leaching was very limited or near zero (with except of MCPP applied to young-thin turf) even with highly leachable pesticides. When conditions were considered "worst case" (thin-immature turf, sandy soil; heavy rainfall shortly after application or excessively wet, over-irrigated turf), pesticide leaching was substantial. The leaching of phosphorus from fertilization was zero, even for the sand. Nitrate leaching was limited and only influence by soil type (sand 9 %, silt loam 3% and sandy loam 1.5% of the amount applied) not precipitation or irrigation amount. From half (sandy loam) to over 90 percent of the applied N in the fertilizer was recovered in the clippings, while only 9 percent was recovered in the clipping from the sand lysimeters. Most of the remaining fertilizer N was found in the sod (as roots, organic matter or fertilizer). The total estimated N recovery was slightly larger than the amount applied. Generally, there was good agreement in the data between the traditional N source and analytical method and the enriched N^{15} fertilizer and mass spec analysis. The use of the traditional methods is recommended because of a lower cost unless detailed soil and atmosphere N fate is needed.

Table 11. Total amount of Nitrogen (N) recovered in clippings, soil and leachate as a percent of applied nutrient on creeping bentgrass fairway turf.

Soil	Total N in Clippings	NO_3–N + NH_4 –N in leachate	Range in total N in soil	Total N Recovered
	----------------------------	% of	applied	----------------------------
Arkport sandy loam	52*	1.5	<0	53.5
Hudson silt loam	91	3.1	<0	94.1
Sand	8	9.1	106.4 – 116.7	124 - 134

* Corrected for the amount of nitrogen recovered in unfertilized plots and amount in irrigation water.

Table 12. Total amount of phosphorous (P) recovered in clippings, soil and leachate as percent of applied nutrient on creeping bentgrass fairway turf.

Soil	Total P in clippings	Total PO-4 in leachate	Total P in soil	Total P recovered
	----------------------------	% of applied	----------------------------	
Arkport sandy loam	53	0 **	5.5	58.5
Hudson silt loam	65	0	<0	65
Sand	7.5	0	<0	7.5

** Adjusted for unfertilized plots and phosphorous in the irrigation water.

Construction and Maintenance of Greens

After years of investigation, the USGA Green Section introduced its *Specifications for a Method of Putting Green Construction* in 1960. The method utilized sand as the principal component of the rootzone mix to provide adequate drainage and resistance to compaction, and incorporated a perched water table in the profile to provide a reservoir of moisture for use by the turf. When built and maintained properly, USGA greens have provided good results over a period of many years for golf courses in most regions of the United States and the world.

During the past 10 to 15 years, changes have occurred in the way greens are maintained and in the number of products and technologies that have been developed. Play has increased, golfers have demanded closer mowing and perfection in maintenance, new grasses have been developed that have different maintenance requirements, and many more golf courses are using recycled water or poor quality water sources for irrigation. A wide array of organic and inorganic soil amendments have been introduced, and ideas for new green construction methods have been proposed. In addition to agronomic changes, the cost of golf course construction has increased dramatically, threatening to limit the growth of the game.

To take advantage of new ideas and technologies, and to address the environmental and economic challenges of the coming decades, the USGA will sponsor research studies on construction and maintenance of golf course greens. The goal of this research is to:

Identify the best combinations of construction, grow-in procedures and post-construction maintenance practices that prevent long-term problems, reduce environmental impacts, and produce high quality playing surfaces.

The reduction of maintenance costs and resource inputs, and the simplification of construction procedures were included among the research project objectives addressing this goal.

Engineering Characteristics and Maintenance of Golf Putting Greens

Dr. James Crum

Dr. John N. Rogers, III

Michigan State University

Goals:

- *Study the engineering characteristics of sands used in putting green construction to ensure a stable and agronomically sound rootzone mixture.*
- *Study post grow-in (3-7 years) changes which occur under traffic on a USGA specification putting green to two other construction methods for differences in putting green quality and speed as well as long term differences in the organic matter, rooting, edaphic and nutritional characteristics.*

Cooperators:

Thomas F. Wolff
Eldor A. Paul
Joseph M. Vargas
Fred S. Warner

Phase One: Engineering Properties

In the first phase of this research project, the primary objective is to apply engineering principles to the study of strength and stability in sand-textured root zones used for golf putting greens. In addition to completing the literature review, the second year of study allowed us to expand the types of testing. Evaluation of the properties of the six test sands which were generated in the laboratory and designed to simulate possible mix ranges found in USGA specifications was continued.

New constraints were incorporated into the testing procedures already in place. The data generated from the modified tests, along with the data previously collected, provided a more detailed picture of the properties crucial for strength and stability. The field testing portion of the study was also begun. This allowed us to compare laboratory test results with real-world turf conditions. From this we will be able to create guidelines for achieving desired soil strength.

The second year of research has allowed for extensive laboratory testing. This has made it possible to test the strengths of sands under numerous controllable parameters. Tests included the direct shear test and the California Bearing Ratio (CBR) tests. From these tests we were able to determine that although small amounts of water may cause some apparent cohesion within a sand, drier more-well compacted

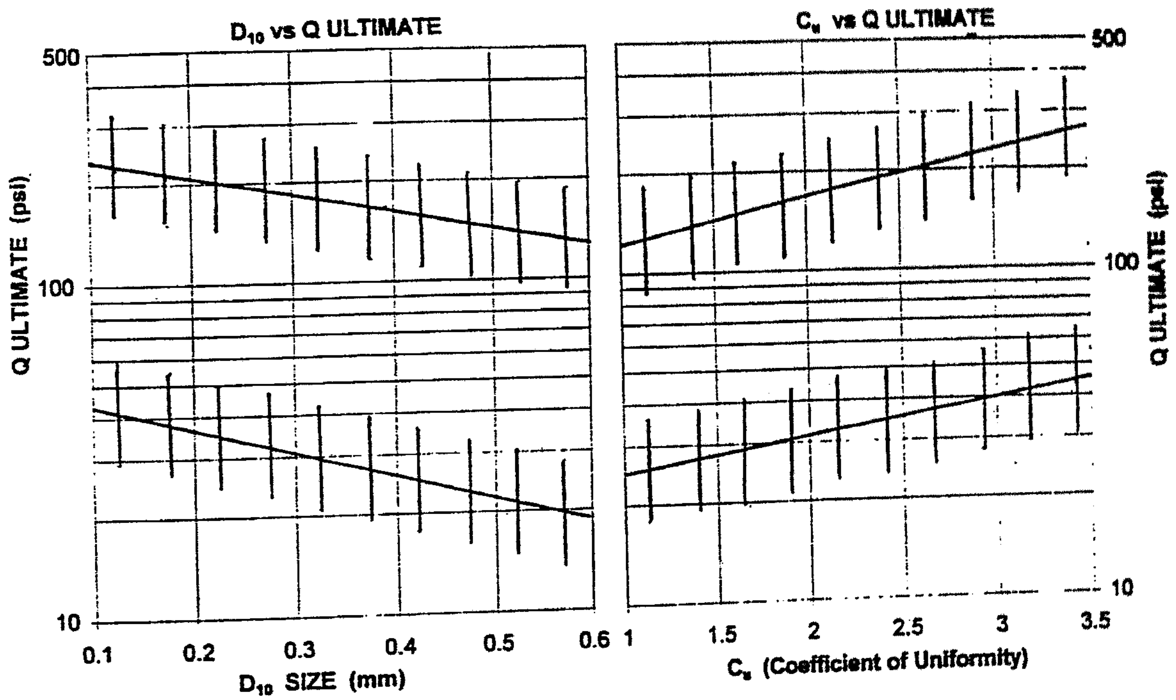


Figure 19. Trends among D10, uniformity coefficient (Cu) and ultimate bearing capacity (psi).

sands withstand a greater load before failing.

The initial phase of field testing was begun and has already produced significant amounts of information. It was possible to directly relate the field test results with the laboratory tests. The testing has shown that a rootzone will be able to carry a greater load without failure if it is comprised of particles that cover a wide range of sizes. In addition, the smaller the minimum sized particles in this wide range of sizes are, the greater load the sand will be able to carry.

For most soils within the root zone, once a large enough load has been applied to cause a given deformation, very little increase in loading is needed to cause further failure of the soil. All of this information points to the fact that significant variations in the bearing capacity and resistance to deformation can be found among similar sands even thought they are ail within USGA specifications.

The increased number of field tests that will be possible in the future will make it possible to further analyze the most crucial soil parameters for affecting strength. Once this is accomplished, guidelines will be developed so that superintendents will be able to design a sand mixture that will produce the exact results which they desire while still falling within USGA specified guidelines.

Phase Two: Maintenance

The objective of this phase is to evaluate and quantify responses of variously constructed putting greens subjected to typical maintenance practices. This five-year project has now finished its second year and all objectives are well under way. While it is somewhat unwise to draw conclusions at this point, there are trends emerging from the research.

Specific objectives of the second portion of the proposed research were:

- Evaluate three putting greens constructed by different methods and their response to sand topdressing and season long rolling (split plot) under simulated trafficked conditions for 3 to 7 years after establishment.
- Evaluate the effects of nitrogen and potassium fertility on trafficked creeping bentgrass quality and wear tolerance on three putting green construction methods with a rolling variable.
- Determine the long-term effects of plant growth regulators on putting green speed and creeping bentgrass quality on three putting green construction methods with a rolling variable.
- Monitor the long-term changes in turfgrass rooting, soil physical characteristics, nematodes, and pathogens under three putting green construction methods.
- Monitor the long-term changes in organic matter and forms of soil nitrogen among three putting green construction methods.
- Compare topdressing with crumb rubber from used tires to sands in putting green collars of the three putting green construction methods.

General Maintenance Procedures

The area was mowed six times a week with a walk mower at a cutting height of 0.157 inches. Topdressing of the entire area with sand was accomplished on a light frequent basis throughout the growing season. Irrigation was applied on a daily light-frequent practice with acceptation of dry down periods to collect data regarding localized dry spot. Pesticides were only applied on a curative basis to allow for disease, insect, and weed data collection. Core cultivation was not performed in 1997 because the formation of the black layer began to occur in the 80:10:10 root zone mix in the late fall of 1996. Core cultivation will take place in the spring of 1998 after samples are taken from all 18 greens in an attempt to quantify the effect of the black layer with gas exchange measurements.

Traffic simulator - Traffic to simulate typical wear on putting greens was applied to the plots six times per week with a triplex greens-mower modified with spiked rollers in lieu of reel units. The rollers are 60 cm long and 20 cm in diameter. 6-mm spikes are spaced at 2.5cm intervals on the unit. Front and rear 5-cm rollers level each of the three traffic simulator units.

Methods for Classifying Sand Shape and the Effects of Sand Shape on USGA Specification Rootzone Physical Properties

Dr. Charles Mancino

The Pennsylvania State University

Goals:

- *Determine if a simple, inexpensive and quantitative procedure can be used to give a reliable estimate of sand shape without having to examine individual grains.*
- *Determine the effect of sand shape on the physical properties of rootzone sands and whether particle size distributions of USGA rootzone sands should be modified to account for differences in sand shape.*

Cooperators:

P.J. Landschoot
A. McNitt

Sand shape may contribute to the physical properties of a rootzone mixture because shape can have an effect on bulk density, total porosity, air-filled and capillary porosity, and saturated hydraulic conductivity. Sand grain shape may also influence the stability of the playing surface because of its effects on how individual particles can lock together. Sand shape is currently determined by visual ratings. These ratings are difficult and quite subjective. The purpose of our project is to: 1) determine a non-subjective method for measuring sand grain shape; and 2) determine how sand shape influences rootzone mix physical properties.

Our methodology for determining sand shape involves visual and mechanical assessments of sand shape. While these visual and mechanical tests are being conducted on our sands, we also have been determining the physical properties of the sand materials as outlined by USGA specifications. At the end of this study we will be able to state if any of our methods can accurately determine shape and how shape relates to the physical properties of the rootzone mixes.

The physical properties of a round (smooth) sand and angular (rough) sand having similar sphericities have been measured alone or in various combinations with peat and/or soil. The round sand had a higher bulk density (BD), lower total porosity (TP), lower air-filled porosity (AP), higher capillary porosity (CP), and lower saturated hydraulic conductivity (Ksat) than the angular sand. This is due to the round sand grains having a tighter soil matrix because it can settle more easily than the angular sand.

These round and angular sands were tested in three-way mixes made of sand, peat and soil. To summarize these findings, shape did have an impact on the changes that occurred in bulk density, total porosity, capillary porosity, and aeration porosity when amendments were added. However, any effect of sand shape on these physical properties only resulted in minor changes in saturated hydraulic conductivity.

Mechanical methods being tested include:

- *Direct shear method - this determines the amount of sidewards force (shear force) required to cause the sand to slide over itself while a downward force is being applied. An angular material should require more shear force than a round material due to the frictional resistance of the individual grains towards sliding;*
- *Rotatable drum method - this method determines the critical angle that an uncompacted sand can reach before it begins to avalanche. A less smooth and less spherical sand should have a greater critical angle than a smooth, spherical sand;*
- *Dense soil angle of repose - In this technique the sand is compacted with a vibrator. The sand is then tilted until it fails at some critical angle. As in the rotatable drum method, the critical angle should be related to the surface characteristics of the sand; and*
- *The cone penetrometer - The force required to push a cone shaped tip into a confined sand sample is measured. A spherical, round sand should offer less resistance than a non-spherical, non-round sand.*

The direct shear method, an excepted mechanical engineering procedure for determining the strength of non-cohesive soils, has not been able to separate sands due to their shape. The procedure gives good reproducible results but angular, sub-angular, sub-rounded, and rounded sands yield approximately equal internal friction angles.

The dense soil angle of repose method gives reproducible results for separating sands after they are densified at 40 volts. Round sand strength increases as voltage increases until 80 volts is applied after which the sand can no longer be compacted. The angular, sub-angular, and sub-rounded sand mixtures have greater strength than the round sand mixture up until 50 volts. These sands then weaken. This method appears promising for the separation of differently shaped sands.

Another promising method for sand separation is cone penetrometry. In studies conducted this year we have been able to separate rounded sands from angular sands. Further work is necessary to determine if we can separate a round sand from a sub-rounded sand, or a sub-angular sand from an angular sand.

Work on the computer imaging sand shapes includes two principal software methods. Parameters include: (a) number of line segments defining the polygon perimeter, (b) polygon area, (c) average length of line segments, (d) perimeter length, (e) average angle of deviation formed by two connected line segments, and (f) major and minor axis lengths. Correlation between graphical shape parameters and sand grains of pre-determined shape class will be calculated to determine if the shape parameters can be used to effectively classify sand shape.

Layers in Golf Green Construction

Sports Turf Research Institute

Dr. Stephen Baker

Goals:

- *Examine particle migration from the rootzone layer into underlying gravels of increasing size in situations where no intermediate layer is present.*
- *Assess the effects of different intermediate and drainage layers on moisture retention in the rootzone layer*
- *Review particle size criteria for the selection of intermediate layer and drainage layer materials.*

Cooperator:

Daniel Binns

Two separate laboratory experiments have been established to examine particle migration into the underlying gravel and moisture distribution in the rootzone layer for a variety of golf green profiles.

In the first experiment, a two-layered profile is considered with the rootzone layer directly overlying the drainage layer. Two rootzones have been used, one based on an 85/15 mix with medium-coarse sand and sphagnum peat, the other being a 70/30 mix of medium-coarse sand and the same peat. Ten gravels are included, five based on rounded material and five based on angular material. The increase in size from a range where particle migration into the gravel should not occur to a size where there is a severe risk of downwards movement from the rootzone into the gravel. A total of 3000 mm of simulated rainfall is currently being applied at the rate of 100 mm per week. At the end of this period, the gravel layer will be impregnated with an araldite resin containing fluorescent dye. When the resin has hardened, the impregnated material will be sectioned so that particle migration can be examined.

Vertical changes in moisture distribution in the rootzone layer also will be measured.

In the second part of the study columns simulating a three-layered USGA golf green profile have been established. The rootzone is based on an 80:20 sand:peat mix and the gravel is a predominantly 6-9 mm material conforming to USGA requirements. The intermediate layer is, however, varied to allow for increasing proportions of medium sand (0.25-0.5 mm) and coarse sand (0.5-1.0

mm) being added to the 1-4 mm grit that forms the intermediate layer. Moisture profiles will be assessed after saturation and 48 hours gravitational drainage to establish at what point the inclusion of finer material in the intermediate layer begins to affect the suspended water table in the rootzone layer.

Table 13. Bridging factors for the combination of two rootzones and five gravel sizes.

D_{15} of gravel (mm)	Medium rootzone $D_{85} = 0.45$ mm	Medium-coarse rootzone $D_{85} = 0.60$ mm
	------------- Bridging Factor	-------------
2.2	4.9	3.7
2.8	6.2	4.7
3.5	7.8	5.8
4.4	9.8	7.3
5.6	12.4	9.3

Note: The 1993 revision of the USGA Recommendations for a Method of Putting Green requires a value of ≤ 5.

Understanding the Hydrology of Modern Putting Green Construction Methods

Dr. Edward McCoy

The Ohio State University - OARDC

Goals:

- *Examine the effects of rootzone composition and putting green construction method on water drainage and redistribution within the profile.*
- *Examine the effects of rootzone composition, soil depth and degree of water perching on turf water use and irrigation management.*
- *Examine long-term changes in physical, biochemical and microbiological properties of the rootzone; and relate these changes to the long-term hydrologic behavior of modern putting green designs.*

Cooperators:

Warren Dick
Mike Boehm

This research investigates the influence of modern putting green construction method on hydrologic processes in the root zone, including water infiltration, redistribution, and drainage. The greens construction methods under investigation are the United States Golf Association (USGA) and California (CA) specifications. Additionally, each soil profile design contained either a high or low water permeability root zone, resulting in four, soil profile/root zone composition treatments, each replicated three times. The experimental greens contained a creeping bentgrass turf maintained at a mowing height of 3/16th inches.

Of particular interest is the effect of green slope on hydrologic processes. The greens were built above ground in 4 by 24 foot boxes with slopes of 0, 2 and 4 percent adjusted by jacking and blocking the legs. The units also contained drain lines at 2 and 17 feet from the down slope end effectively yielding a 15 foot drain spacing. The root zone of each experimental green was instrumented with TDR soil moisture probes at three depths (3, 6 and 9 inches) and five locations (2, 7, 12, 17 and 22 ft from the down slope end). A tipping bucket rain gauge was connected to the outflow of the furthest down slope drain line to monitor drainage outflow rate.

Each green received simulated rainfall from a device delivering either 4.44 ±0.09 inches per hour for the high rate or 1.89 ± 0.04 inches per hour for the low rate treatment. Continuous measurements of drainage outflow and soil water contents were started at the beginning of the rainfall period. Rainfall was then applied for 3 hours to ensure a constant drainage rate. At the end of the rainfall period, the rain

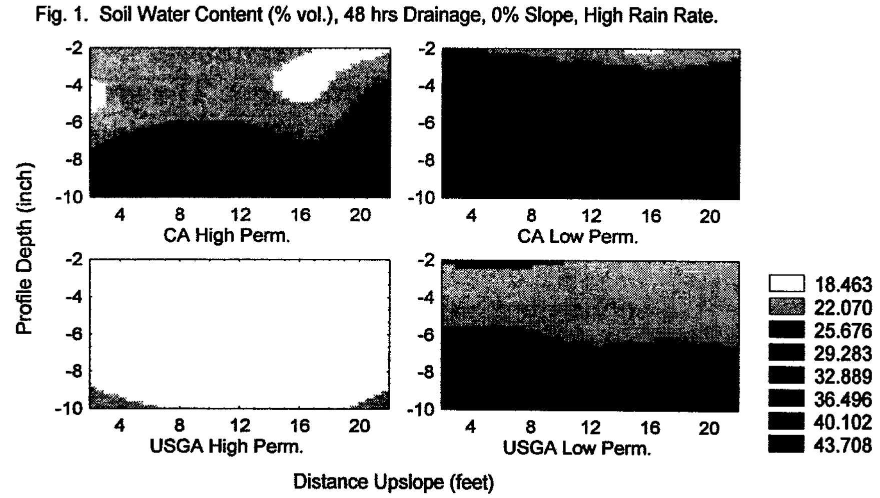


Figure 20. Root zone soil water content (% volume) after 48 hours drainage (0 % slope and high precipitation rate).

simulation device was turned off but drainage outflow and soil moisture measurements continued for an additional 48 hours.

While drainage rate is but one aspect of putting green hydrology, there is some confusion regarding which construction method should be the more rapidly drained and proponents of either system have claimed that theirs promotes faster drainage. The important understanding we demonstrated in this study is that both profile design and root zone mix permeability contributes to drainage rate. Given equal root zone mix permeability, the USGA profile yields drainage that is more rapid. Indeed, even rainfall rates of about 4.5 inches per hour failed to overwhelm drainage of the USGA profiles as evidenced by equivalent drainage rates for both the low and high permeability root zones.

Further, this same rainfall rate exceeded the drainage capacity of a CA profile containing a root zone mix initially tested to have a permeability of 20 inches per hour. For equivalent drainage performance, therefore, it seems that a CA style green would need a root zone mix permeability 10 to 20 inches per hour greater than a USGA green.

Drainage rate represents an intensity factor. The capacity factor of the drainage process, in the context of the present study, is the completeness of excess water removal from the respective root zones. Here, it is commonly thought that a USGA putting green profile would become less completely drained than a CA green. This belief results from the water perching effect in a USGA green. Our results showed that for equivalent root zone mix permeabilities the USGA green is drier after 48 hour (interpreted as more completely drained) than a CA system green (Fig. 1). This appears to be principally due to the need for water to move laterally through the root zone in a CA green before reaching a drain line. Again, for more complete drainage, a CA green would appear to need a higher root zone permeability as evidenced by the nearly equal soil water contents after 48 hours drainage in the CA high permeability profile and the USGA low permeability profile.

All greens are contoured or sloped to some degree. This contouring may be slight in hole location areas, but is more extreme between terraces or throughout links style greens. This sloping clearly has an effect on water redistribution following rainfall. Prior to this study we believed that the perched water table in a USGA green would lead to strong lateral movement of water to more down slope locations. This would suggest the possibility of 'hot spots' forming at higher elevations in a USGA green. We did not believe this would occur to a great extent in a CA green because this green construction method was thought to be more completely drained, having no perched water to migrate. The results from this study suggested that our prior beliefs were somewhat incorrect. While lateral water movement was observed in the USGA greens, it was also observed in the CA greens. Thus, for equal root zone permeabilities, there was a much greater lateral difference in water contents after 48-hour drainage in the CA greens than the USGA greens (Fig. 2).

One caveat in the results of this study is that these constructions were just one year old and had not experienced foot traffic. Our plan for the experimental greens is to simulate foot traffic and repeat this study under more natural conditions. We also have collected undisturbed soil cores in November 1996 and 1997. These cores are currently being measured for soil physical properties and changes relative to the fresh mixes. These periodic sampling and measurements will continue throughout the study.

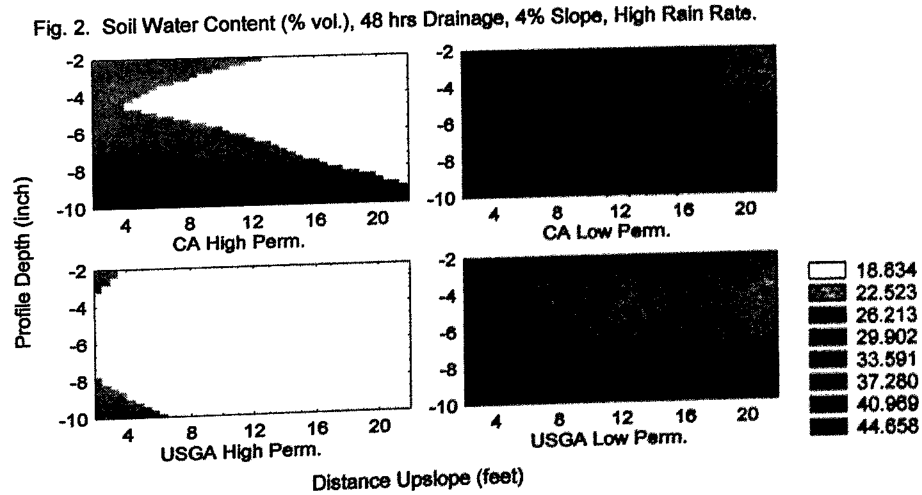


Figure 21. Root zone soil water content (% volume) after 48 hours drainage (4 % slope and high precipitation rate).

Assessing Differential Root Zone Mixes for Putting Greens Over Time Under Two Environmental Conditions

Dr. James Murphy

Rutgers/Cook College

Goals:

- *Improve recommendations for sand particle size distribution and the depth of the root zone by consideration of the microenvironment.*
- *Evaluate composts as organic additives and inorganic products for root zone mixes compared to peat sources*
- *Assess the potential of various root zone mixes to reduce management and resource inputs*
- *Monitor the physical, chemical, and biological changes that occur in root zones as greens mature for understanding factors that contribute to the success or failure of greens.*

Cooperators:

S. Murphy
J. Honig
K. Motto
B. Clarke
R. Tate

This project is designed to i) improve recommendations for sand particle size distribution and the depth of the root zone by consideration of the microenvironment, ii) evaluate composts as organic additives and inorganic products for root zone mixes compared to peat sources, iii) assess the potential of various root zone mixes to reduce management and resource inputs, and iv) monitor the physical, chemical, and biological changes that occur in root zones as greens mature for understanding factors that contribute to the success or failure of greens.

Packed cores of various sands, differing in particle size distribution, but falling within USGA specifications for greens mixes, have been characterized in terms of physical properties in the laboratory. A large number of organic and inorganic amendments added to sand mixes at various rates have been tested as to their effects on the physical properties of the sands. Organic amendments evaluated in the laboratory included Dakota peat, sphagnum peat, Irish peat, AllGro compost, Fertl-soil, sewage sludge compost, and leaf compost. Inorganic amendments evaluated in the laboratory included Greenschoice, Profile, Isolite, Axis, Zeopro, and soil.

Physical properties were frequently affected by the interaction between amendment and amendment rate. Total porosity was usually increased by amendment, and the sand size distribution and the type of amendment determined whether the increase occurred primarily in the air-filled porosity or the capillary porosity. Increases in air filled porosity did not always correspond with increased saturated hydraulic conductivity.

Root zone mixes having a range of characteristics were identified for study in the two microenvironments of the field research facility at North Brunswick, NJ. Putting green construction was begun in the spring of 1997 and completed in the late fall 1997. Organic amendments being evaluated in field plots include Dakota peat, sphagnum peat, Irish peat, AllGro compost, and Fertl-soil. Inorganic amendments being evaluated in fields trials include Axis, Greenschoice, Isolite, Kaofin, Profile, Soil, and Zeopro. Seven sands differing in particle size distribution were established in fields trials; three of the sands fell within USGA guidelines and the remaining four sands varied in the fine or very fine sand size ranges. Plots of various root zone depths were constructed using the three sands meeting USGA guidelines. The construction depths selected for each sand were based on water release curves in the laboratory. It is anticipated that the field plots will be seeded in the early spring of 1998 as weather permits.

The microbial ecology aspect of the project has progressed in a lab study and in a survey of golf greens varying in age. Differences in various microbial parameters were characterized in soil and sand amended with sphagnum moss peat, and the changes were monitored over time. The parameters used were dehydrogenase activity (which is associated with microbial respiration), estimation of viable bacteria, and metabolic diversity of the microbial population. Sand had much less microbial activity than soil. The effect of sphagnum moss peat added to soil was generally negative in terms of microbial activity, but sometimes increased activity in sand. Field samples taken from greens of different maturity and from neighboring fairways are being assessed in terms of the microbiological parameters. In 1998, the development of the micro-biological community in the constructed root zone plots will be monitored.

Evaluation of New Technologies in Construction and Maintenance of Golf Course Greens

North Carolina State University

Dr. Daniel Bowman

Goals:

- *Determine the laboratory and field physical and microbiological properties of sand amended with organic and inorganic materials.*
- *Determine creeping bentgrass morphological and physiological responses under low oxygen situations.*
- *Evaluate soil physical and plant responses of forced air injection and water evacuation.*

Cooperators:

D.K. Cassel
T.W. Rufty
A.H. Bruneau
R.J. Cooper

The initial study investigating the effects of inorganic amendments on sand-based rootzone mixes has been completed. Three very uniform sands (coarse, medium and fine) were amended with Irish sphagnum peat, Profile®, Greenschoice®, lsolite®, and Ecolite® The amendments were used at 10% and 20% by volume. PVC cylinders, 30 cm deep, were filled with the various mixes. Soil physical properties, including bulk density, saturated conductivity, air-filled pore space and water-filled pore space were determined. Moisture profiles were generated with depth of the soil columns. The results indicate that the inorganic amendments did improve soil moisture holding capacity, but much less so than did the peat. Saturated hydraulic conductivity was high in all soils, probably due to the uniform sands used.

Nutrient retention studies indicated that none of the amendments reduced nitrate leaching, but that Ecolite and profile were very efficient at retarding ammonium leaching. Rate and positioning effects of amendment on nutrient leaching is presently under investigation. These data have implications for fertility practices in new putting greens.

The field installation, consisting of 60 mini-putting greens, has been completed. Each green is equipped with its own drainage system, which will also permit application of SubAir® treatments. The plots were seeded October 3 with *L93* bentgrass.

Grow-in and Cultural Practice Inputs on USGA Putting Greens and Their Microbial Communities

Dr. Roch Gaussoin

University of Nebraska

Goals:

- *Evaluate grow-in procedure effects on putting green establishment and performance, and develop criteria and recommedations for new putting green readiness for play.*
- *Determine grow-in procedure impacts on root zone physical and chemical properties.*
- *Evaluate post grow-in cultural practice effects on putting green long-term performance.*
- *Determine temporal and spatial (by depth) patterns of rhizosphere community development in golf greens during accelerated and controlled grow-in of select root zone mixes and during long-term green maintenance.*

Cooperators:

Rhae Drijber
William Powers
Mine Aslan
Milda Vaitkus
Leonard Wit

The overall goal of this project is to develop a better understanding of the impact of grow-in procedures on putting green establishment and performance. Impacts on the physical, chemical, and microbiological factors associated with the USGA root zones and rhizosphere are emphasized in the project.

The five year project is composed of three phases, One: Construction and Grow-in, Two: Microbial Community Assessments, and Three: Grow-in Procedure Impacts on the Long-term performance of the Putting Green. Phases One and Two span three year periods, while Phase Three will involve experiments repeated over the five years of the project.

Two separate USGA-specification root zone mixtures - one composed of sand and peat (80/20 ratio) and one a combination of sand, soil, and peat (80/5/15 ratio) - were developed in 1996. Materials used for construction complied with USGA Greens recommendations for physical characteristics and organic matter content. Greens were constructed in late summer of 1996, allowed to settle over the winter, and were seeded with Providence creeping bentgrass (1.5 lbs/1000 ft^2) in the spring (May 30) of 1997.

Preliminary results from 1997 indicate the following:

Higher inputs will initially increase cover during grow-in. This increase may not translate to earlier opening for play if environmental stress conditions occur that result in damage to lush, immature turf.

A root zone mix containing soil will establish quicker and recover from environmental stress faster than a soil-less mix. A soil-containing mix also will be harder and may result in longer ball roll distance.

Addition of soil to the root zone mix will not effect water infiltration during the establishment year.

Results of microbial assessments are pending.

Organic Matter Dynamics in the Surface Zone of a USGA Green: Practices to Alleviate Problems

Dr. Robert Carrow

University of Georgia

Goals:

- *Determine the effectiveness of selected fall/spring-applied cultivation on enhancement of bentgrass root development, water infiltration, and soil oxygen status during spring and fall root development periods.*
- *Determine the effectiveness of selected summer-applied cultivation, topdressing and wetting agent practices on bentgrass root maintenance and viability, water infiltration, and soil oxygen status during the summer months when root decline occurs.*
- *The best treatments from the objectives above will be combined to develop an integrated year-round program for maximum root development and maintenance during stress periods.*

Organic matter in the surface 0 to 2 inch zone of a USGA green increases from an initial level of 1.0 to 5.0 percent (by weight) at establishment to 8 to 12 percent after two years. Organic matter accumulation occurs even under excellent management and regardless of construction method. The two proposed problems are:

I. Summer Bentgrass Decline in Response to Root Deterioration and Plugging of the Macropores that are Important for Soil O_2 and Infiltration of Water. A project was initiated in late spring 1996 to investigate the influence of treatments (summer cultivation, sand topdressing, sand substitutes, wetting agents) on maintaining infiltration, soil O_2 status, and root viability. This field study will continue until fall 1998. Observations to date are:

- Percent organic matter (OM) by weight ranged from 10.1 to 10.2 percent for the untreated control in the surface 0 to 3.0 cm zone. Core aeration with sufficient topdressing to fill the holes in March was the only treatment to reduce percent OM content (i.e., to 4.1 and 7.7%).
- High OM content in the surface 0 to 3 cm zone resulted in the following soil physical properties relative to USGA recommended specifications (in parenthesis): total porosity of 74.2 to 76.7 percent (35 to 55 percent); aeration porosity of 17.3 to 22.5 percent (15 to 30%); capillary porosity of 54.1 to 56.9 percent (15 to 25%).

- The surface zone resulted in saturated hydraulic conductivities (SHC) of 53 to 304 mm hr^{-1} for the control (minimum recommended is 120 mm hr^{-1}) and oxygen diffusion rates (ODR) of less than 0.20 μg O_2 cm^{-2} min^{-1} (threshold for O_2 stress) on all readings in 1996 for 2.5 to 26 hours after irrigation. In 1997, ODR readings were occasionally less than 0.20 for 26 to 50 hours after irrigation.
- The major effect of treatments was on SHC at 1 to 7 days and 17 to 26 days after cultivation (DAC). At 17 to 26 DAC, the most effective treatments for maintaining SHC were: HJR (Hydro-Ject run in raised position for ¼ inch diameter hole) with sand topdressing (S), wetting agent (WA), or bio-stimulant (B); (468 to 548 mm hr^{-1} versus control of 139 mm hr^{-1}). The next most effective treatments were HJL (Hydro-Ject lowered position); HJR; HJR + Sand + WA; and HJR + Sand + WA + B; (385 to 405 mm hr^{-1}).
- Treatments resulting in the greatest percentage (in parenthesis) of visual ratings greater than the control for all shoot parameters were HJL; HJR; HJR + WA; and HJR + B; (11 to 27% readings > control).

II. Inhibition of Root Development (in Spring/Fall) from the Zone of High Organic Matter Content. A second project was initiated in winter 1996 to investigate the influence of selected cultivation procedures, that are non-disruptive, on root development. Wetting agent and sand substitute treatments were also included. The goal is to determine whether better root growth/depth can be achieved by increasing macropores in the surface 0 to 3 cm zone without conducting the traditional spring/fall core aeration operation. This field project will continue through spring 1999. Observations to date are:

- High O.M. content (18.8%, wt.) in the surface 0 to 3.0 cm zone reduced aeration porosity to 8.6 to 10.5 percent and caused SHC values of 9 to 125 mm hr^{-1} (control) with lowest SHC occurring in November through May. Apparently as adventitious roots develop in the fall, surface macropores become plugged with live roots and SHC markedly declines.
- ODR values at 3 cm and 10 cm were frequently less than 0.20 μgO_2 cm^{-2} min^{-1} at 2 to 31 hrs after irrigation. ODR values at either depth were only occasionally improved by HJR or HJR + WA treatment.
- The primary treatment influence was on SHC where the most effective treatments for maintaining SHC at 24 to 41 DAC were HJR + WA; HJR; HJR + G + WA (G = 70% sand + 30% Greenschoice topdressing); AW (Aerway Greens Slicer, Fine Tines); (168 to 239 mm hr^{-1} versus 63 mm hr^{-1} control). Quad tines (solid, ¼ inch diameter) with or without G topdressing resulted in SHC values of 52 to 72 mm hr^{-1} at 24-41 DAC.
- Treatments resulting in least shoot injury (i.e., ratings similar to control) were: HJR + G; HJR; HJR + WA; HJR + G + WA.

Table 14. Bulk density, organic matter, and mineral matter content in the surface 0 to 3 cm zone in June and August 1997. University of Georgia, Griffin Experiment Station.

Treatment and Contrast‡	Bulk Density		Percent Organic Matter		Organic Matter Content§		Mineral Matter Content§	
	6 Jun	18 Aug	6 Jun	18 Aug	6 Jun	18 Aug	6 Jun	18 Aug
	---- g cm^{-3} ----		----- % (wt.)----		------- g -------		------- g -------	
Control vs.	0.51	0.62	10.2	10.1	7.5	9.3	67.5	84.4
CA (Mar)	0.70**	0.69	4.1**	7.7*	4.4*	8.8	99.1**	105.7*
HJL	0.54	0.58	9.7	10.2	7.7	9.1	69.8	81.7
HJR	0.48	0.60	11.5	11.7	8.3	10.0	62.6	75.7
HJR + Sand	0.57	0.63	9.4	10.6	7.7	9.7	74.9	82.4
HJR + Greenschoice	0.56	0.54†	7.4	10.2	5.8	9.0	73.5	79.2
HJR + WA	0.59	0.58	9.1	10.0	7.6	9.3	80.2	85.5
HJR + B	0.52	0.59	8.4	10.1	6.2	9.7	70.2	88.2
HJR + Sand + WA	0.51	0.59	10.1	11.1	7.7	9.3	68.4	75.7
HJR + Sand + WA + B	0.52	0.60	8.5	11.4	6.4	10.2	69.4	79.2
LP + Greenschoice I	0.52	0.54†	10.0	11.1	6.9	9.4	68.8	76.1
LSD (.05) =	0.12	0.10	4.3	2.2	3.0	1.3	18.9	16.8
F-test	†	0.20	†	†	0.39	0.56	*	*
CV (%)	15	11	33	14	31	10	18	14

‡ Contrast versus Control based on LSD.

**, *, † Significant difference at $P \leq 0.01, 0.05, 0.10$.

§ Weight is grams per 50 cm^2 surface area X 3.0 cm deep.

Nontarget Effects of Turfgrass Fungicides on Microbial Communities in USGA Putting Green Profiles

Dr. Gary Harmon

Cornell University

Goals:

- *Establish and microbially characterize standard and biological-augmented root zones on USGA and soil-based putting greens.*
- *Determine comparative responses of native and constructed microbial communities to fungicide applications on USGA and soil-based putting greens.*
- *Assess sensitivities of important groups of turf-associated microbes to common turfgrass fungicides.*
- *Evaluate impacts of fungicide applications on levels of biological control in native and microbially-augmented USGA and soil-based putting greens.*

Cooperators:

Eric B. Nelson
Kristen L. Ondik

This research has been designed primarily to focus on the impacts of fungicide applications on levels of biological control in native and microbial-augmented USGA and soil-based putting greens.

This is the second year of funded research. Trials were established on native (standard peat-sand) and microbially-augmented (constructed with the inclusion of composted brewery waste and with Bio-Trek 22G [containing Trichoderma harzianum] included). The following fungicides were applied at the maximum label concentration and minimum labeled time interval: chlorothalonil (Daconil Ultrex), iprodione (Chipco 26019 Flo), mefenoxam (Subdue Maxx), propiconazole (Banner Maxx), triadimefon (Bayleton), benzamide (Prostar 50WP), and cyproconazole (Sentinel). Plots were in a randomized pattern with 5 replications. At various time intervals over the summer, cores (1 X 5 cm) were taken from each plot and microbial populations were assessed by dilution plating.

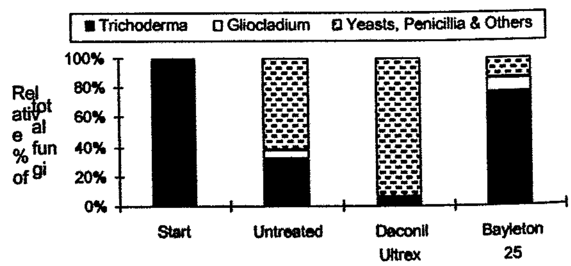


Figure 22. Relative percentages of fungi on foli after treatment with two fungicides.

The results from the 1996 field season can be summarized as follows:

- Almost no detectable differences were obtained in total or specific fungal or bacterial numbers. Similarly, assays of BIOLOG plates to determine physiological groupings of microbial populations demonstrated no detectable effect of fungicide applications.
- The only major effect of fungicide applications noted was in microbial respiration. Application of fungicides increased microbial activity.

Thus we saw few substantial effects in the 1996 trials. Therefore, we hypothesized that there were few effects on the root/soil microbes because of fungicide degradation or dilution. However, there should be effects on foliar microbes. Therefore, in 1997, we conducted similar trials on the augmented plots only, but cut each soil core into root and leaf portions by slicing the thatch layer near its upper surface with a razor blade. All of the data was compiled in the final report, but results can be summarized as follows:

- There was little long-term effect reduction of total fungi or bacteria on leaves or roots. The accompanying Figure 22 demonstrates representative results. However, application of some fungicides, especially Daconil Ultrex, may enhance development of some fungi such as yeasts on leaves and components of the fungi on leaves appear to vary as a percentage of the total.
- Two related fungi, Trichoderma harzianum and Trichoderma (Gliocladium) virens, are the principal components of the endophytic fungi on leaves, and made up nearly all fungi tested at the start of the season. At the end of the trial, these two fungi comprised about 40% of the total fungi seen, but after treatment with some fungicides, especially Daconil, their numbers dropped to only about 6% of the total. On the other hand, the percentages of these two fungi increased to nearly 90% after treatment with Bayleton.

These results suggest that effects of fungicides on resident leaf fungi are not as dramatic as we expected. The apparent differences between percentages and total populations of fungi on the two graphs is a consequence of the difference between arithmetic and log plots. The main results of the chemical applications were to alter the fungal compositions but not their total numbers. Apparently, fungal populations only are slightly or transiently affected by chemical applications. However, the shifts in populations seen in this study could substantially affect disease incidence in the absence of actual toxicity of the chemical in question to the pathogen being controlled.

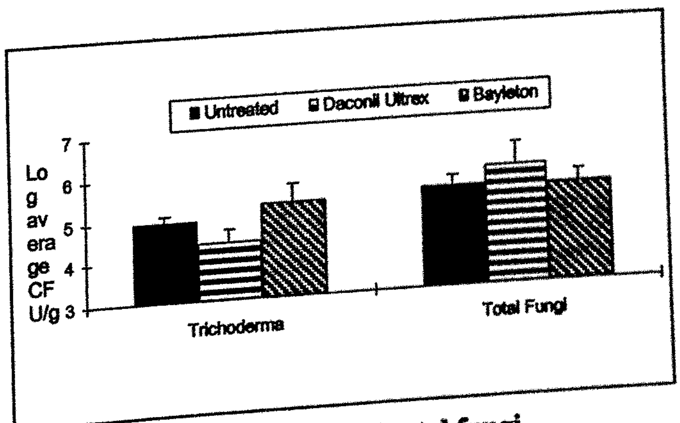


Figure 23. Trichoderma and total fungi populations after fungicide treatments.

Bacterial Populations and Diversity withing New USGA Putting Greens

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Goals:

- *Determine bacterial populations associated with putting green root-zone mix materials.*
- *Determine bacterial populations of the root-zone mixes before and after fumigation.*
- *Compare rhizosphere bacterial populations on two different turfgrasses, bentgrass and and South Carolina.*
- *Compare rhizosphere bacterial populations of bentgrass in two different locations, Alabam and South Carolina.*
- *Compare rhizosphere bacterial populations of bermudagrass in two differrent locations, southern Florida and notrthern Florida.*
- *Compare thatch development, rooting and bacterial population of bentgrass in relation to rootsone mix and nitrogen fertilization.*
- *Compare soil and rhizosphere bacterial populations of root-zone mixes containing various clay sources.*
- *Document rhizosphere bacterial population dynamics on bentgrass and bermudagrass over a four year time period.*

The overall objective of this project is to develop baseline data concerning bacterial composition (populations and diversity) of new USGA putting greens, both during and after construction. During 1996, the best methods for enumerating specific groups of bacteria were determined. These were incorporated into the research accomplished during 1997. This past year was our first attempt to enumerate bacterial groups associated with putting green construction materials, prior to and after fumigating and planting of bermudagrass sprigs.

University of Florida

Trenches were dug at the Florida Research and Extension Center (FLREC) for placement of 100-gallon size Lerio™ tree containers. These containers are 36-in square and 18-in deep. A 6-in layer of non-calcareous washed river gravel was placed in the bottom of each container. No intermediate layer was added as the gravel and root-zone mixes met USGA specifications. Two peat materials were used to make the mixes, either sphagnum peat or reed sedge peat. The Canadian sphagnum peat was mixed with the sand to obtain an 80/20 mix. The Dakota reed sedge peat was mixed with the sand to obtain a 90/10 mix. The root-zone mixes are the two main treatments. The subplots or second factor are three fumigants, methyl bromide (gas), metam sodium (liquid) and dazomet (granule). The active ingredient for both metam sodium and dazomet is MITC.

Samples were obtained for enumeration of seven different bacterial groups from: 1) individual root-zone components prior to mixing, 2) each root-zone mix after blending, 3) prior to fumigation, 4) 10 days post-fumigation, 5) 25 days post-fumigation, 6) each month after planting of bermudagrass for five months total. Samples of the bermudagrass sprigs also were obtained.

At delivery of the individual root-zone components, the sand was essentially devoid of bacteria. All bacterial groups were detected in the reed sedge peat. The fluorescent pseudomonads and *S. maltophilia* were not detected in the sphagnum peat. Similar results were obtained in the two root-zone mixes.

At 10 days post-fumigation, no or minimal fluorescent pseudomonads or *S. maltophilia* were detected from containers treated with dazomet or metam sodium. Dazomet and metam sodium break down to the same active ingredient (MITC). These bacterial groups were detected in containers treated with methyl bromide, but actinomycetes were not detected.

The bacterial groups detected 15 days after the plastic was removed were different from those detected immediately after the plastic was removed. The fluorescent pseudomonads were now isolated from all containers, regardless of fumigant used. However, actinomycetes were still not detected in containers fumigated with dazomet and metam sodium nor were they now detected in containers fumigated with methyl bromide.

All the bacterial groups were present when *TIFDWARF* bermudagrass was sampled prior to planting. All groups continued to be detected on plant material and in the root-zone mix throughout the next five months of sampling. By the fourth month, there appeared to be few differences among treatments.

Table 15. Bacterial groups present prior to fumigation and 10 days after fumigation.

	Colony forming units per gram dry weight[x]							
	Pre-fumigation		Dazomet		Metam sodium		Methyl bromide	
Bacterial Group	S.P.[y]	R.S.P.[z]	S.P.	R.S.P.	S.P.	R.S.P.	S.P.	R.S.P.
Total	6.4	7.4	4.0	5.5	3.4	5.1	4.6	5.6
Fl. pseudomonads	<2.0	3.7	ND	ND	ND	ND	2.7	3.0
S. maltophilia	2.8	4.0	ND	ND	<2.0	ND	<2.0	<2.0
Gram positive	4.1	5.5	<2.0	2.8	ND	<2.0	3.4	3.2
Gram negative	4.8	5.9	ND	3.1	<2.0	<2.0	<2.0	3.8
Actinomycetes	3.0	5.9	2.8	4.8	2.7	4.8	ND	ND
Heat tolerant	3.2	5.4	3.3	5.1	3.2	4.2	2.5	2.8

[x]Values are mean of twelve replicate samples for pre-fumigation and four replicate samples for post-fumigation.
ND, not detected
[y]S.P., sphagnum peat root-zone mix
[z]R.S.P., reed sedge peat root-zone mix

Table 16. Bacterial groups present prior to fumigation and 25 days after fumigation.

	Colony forming units per gram dry weight[x]							
	Pre-fumigation		Dazomet		Metam sodium		Methyl bromide	
Bacterial Group	S.P.[y]	R.S.P.[z]	S.P.	R.S.P.	S.P.	R.S.P.	S.P.	R.S.P.
Total	6.4	7.4	4.0	4.5	7.0	7.4	6.6	6.9
Fl. pseudomonads	<2.0	3.7	<2.0	3.5	5.5	4.8	5.7	5.4
S. maltophilia	2.8	4.0	ND	<2.0	5.7	4.3	4.8	4.2
Gram positive	4.1	5.5	<2.0	<2.0	2.6	5.4	5.1	5.4
Gram negative	4.8	5.9	<2.0	4.1	6.4	6.5	6.2	6.4
Actinomycetes	3.0	5.9	ND	ND	ND	<2.0	ND	ND
Heat tolerant	3.2	5.4	2.3	3.6	6.0	5.6	5.7	5.4

[x]Values are mean of twelve replicate samples for pre-fumigation and four replicate samples for post-fumigation. ND, not detected

[y]S.P., sphagnum peat root-zone mix

[z]R.S.P., reed sedge peat root-zone mix

Auburn University

Conducted in cooperation with Clemson University (H.D. Skipper) and the University of Florida (M.L. Elliott) this study evaluates bacterial species and their population fluxes in the soil and rhizosphere during the establishment and maintenance of putting greens. Treatments in this study include grass type (bent or bermudagrass), organic construction material (sphagnum vs. reed sedge), fumigants (methyl bromide, metam sodium or dazomet) and N fertility regimes (x vs 2x normal). At Auburn University, treatments are N rate (1 x or 2x normal rate) and construction materials (pure sand putting green or 80/20 sand/peat mix). Sixteen containerized greens were constructed at the Auburn University Turfgrass Research Unit, four replications of each fertility/soil mix combination. Greens were sodded in January 1997 with washed bentgrass sod (*CRENSHAW*). Greens are 1 m long x 0.5 m wide, and each drains to an individual collection chamber. Total leachate from each green is collected as needed, volume recorded and a subsample is analyzed for NO_3-N and NH_4-N concentration. In February, May, August and November of each year root and soil samples (0-4 inch depth) are collected from each green. These samples are shipped to the University of Florida, where they are subject to dilution plating and identification. Selected isolates are returned to Auburn University, where identification at the species level is conducted via GC FAME analysis. Nitrogen rates applied at the Auburn University site were originally 1 or 2 lbs N per 1000 ft^2 month (granular fertilizer source). Excessive loss of N through leachate and burning of turf at application resulted in a shift of application times and amounts to 1/5 or 1 /10 lb N per 1000 ft^2 per week applied via a CO_2-backpack sprayer. These N application rates were initiated on 25 August, 1997 and will likely continue for the rest of the study unless grass health indicates a need for more N.

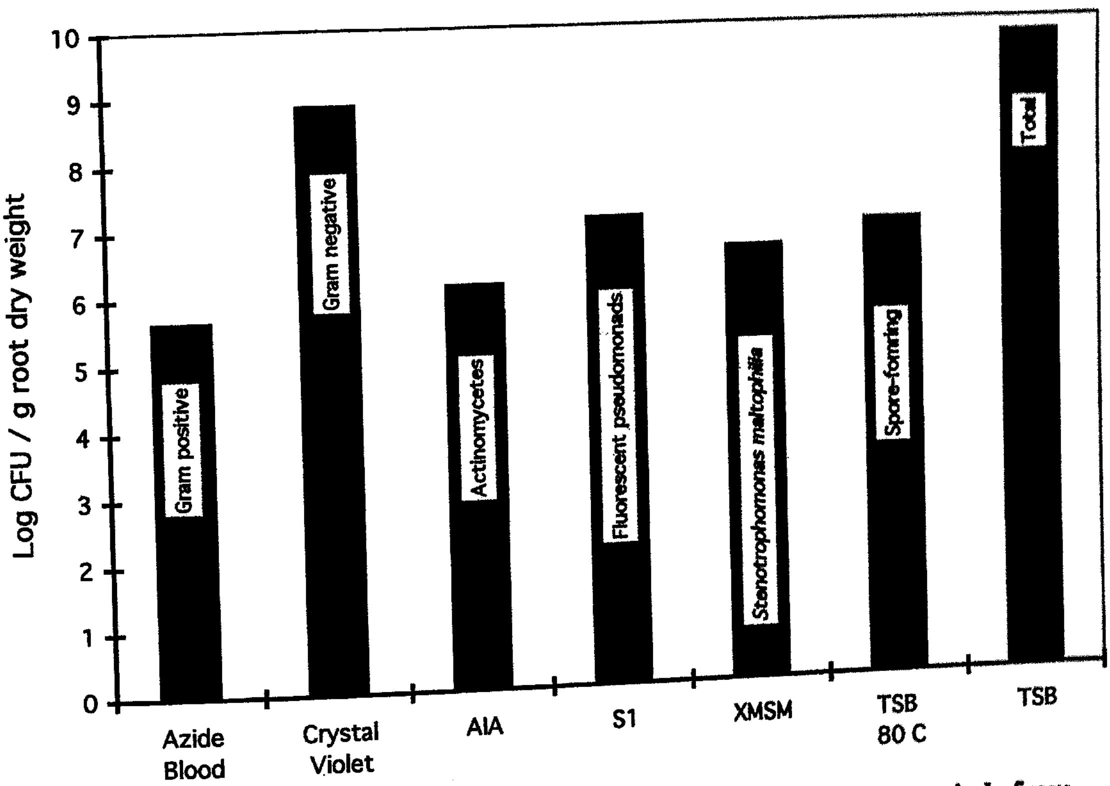

Figure 24. Rhizobacteria populations were averaged over four sampling periods from bentgrass greens. Samples were collected from December 1996 to September 1997 from Charlotte Country Club Golf Course, NC.

Clemson

Rhizobacteria are being evaluated for promotion of plant growth and for biological control of weeds, insects, diseases, and nematodes in a number of ecosystems. A critical research need in putting greens management is to understand the bacterial interactions in the rhizosphere of turfgrasses. Development of a database on turfgrass rhizobacteria from newly constructed bentgrass putting greens has been initiated. Each quarter, 160 randomly selected bacterial isolates on tryptic-soy broth agar (TSBA) were isolated. They now are being identified by FAME analyses. Broad classes of rhizobacteria populations were successfully separated on selective media. Preliminary numerical differences of rhizobacteria populations in bentgrass rhizosphere were observed (Figure 24). In the samples of December 1996, isolates identified from bentgrass rhizosphere belonged to 23 genera and 34 species and 76 percent were Gram negative. *Acidovorax, Burkholderia,* and *Pseudomonas* were the major genera. However, in the samples of Mar-1997, isolates identified from bentgrass rhizosphere belonged to 25 genera and 40 species and 78 percent were Gram negative. *Pseudomonas, Comanonas, Cytophaga,* and *Arthrobacter* were the major genera.