Turfgrass and Environmental Research Online

Using Science to Benefit Golf

The 2011 USGA Turfgrass and Environmental Research Summary is an annual compilation of projects currently funded by the USGA Turfgrass and Environmental Research Program.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 450 projects at a cost of $31 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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2011 USGA Turfgrass and Environmental Research Summary

Jeff L. Nus, Ph.D.
Editor

Since 1983, the United States Golf Association has funded more than 450 university research projects at 39 universities at a cost of over $34 million. The Turfgrass and Environmental Research Program provides direction to these institutions and employs **science as the foundation to benefit golf** in the areas of turfgrass and resource management, sustainable development, and environmental protection. At the end of each year, the USGA provides a summary of the research conducted under this important national program and this report summarizes the results from 2011.

There are two primary goals of the research program. The first is to develop turfgrasses and cultural systems with better stress tolerance and reduced water requirements and pesticide use. To address the USGA's first research goal, 24 research projects were funded in integrated turfgrass management, physiology, breeding, genetics, and course construction practices. The second goal is to investigate environmental issues and sustainable resource management for golf courses. Three of the research projects investigate the environmental impact of golf courses.

The research program actively coordinates and supports research, associated educational programs, and other partnerships to benefit golf, the environment, and people. For example, the USGA, GCSAA, and the National Turfgrass Evaluation Program (NTEP) together have developed turfgrass variety testing programs conducted on golf courses throughout the United States. In addition, the USGA works with state research foundations and superintendent chapters to fund applied research through the Grant-in-Aid Research Program. Seven research projects in this report are funded by the Grant-in-Aid Research Program. This summary also includes four reports in the Product Testing category of the USGA Turfgrass and Environmental Research Program.

The United States Golf Association Turfgrass and Environmental Research Program

Vision

Use science as the foundation to benefit golf in the areas of turfgrass and resource management, sustainable development and environmental protection.

Mission

Coordinate and support research, associated educational programs, and partnerships to benefit golf, the environment, and people.

Goals

Develop turfgrasses and cultural systems with enhanced stress tolerance and reduced supplemental water requirements, pesticide use and costs.

- *Course Construction Practices*
- *Integrated Turfgrass Management*
- *Breeding, Genetics, and Physiology*

Investigate environmental issues and sustainable resource management for golf courses.

- *Environmental Impact of Golf Courses*
- *Wildlife and Habitat Management*·

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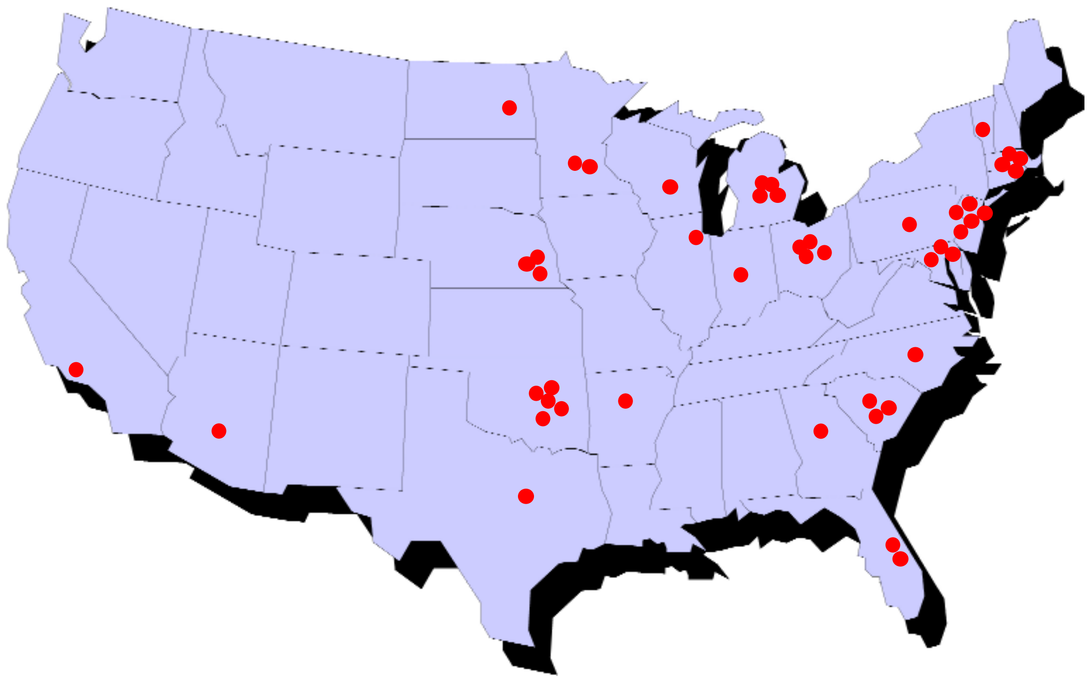
Location of 2011 projects funded by the USGA Turfgrass and Environmental Research Program



USGA Green Section Turfgrass and Environmental Research Project Grants in 2011

Project Area	Number	Grant $	% of Total
Integrated Turfgrass Management	**15**	**235,994**	**32.8%**
Sustainable Management	6	110,112	15.3%
Pathology	9	125,882	17.5%
Breeding, Genetics, and Physiology	**13**	**284,232**	**39.6 %**
Cool-season Grasses	5	101,064	14.1%
Warm-season Grasses	4	89,765	12.5%
New or Native Grasses	4	93,403	13.0%
Environmental Impact	**2**	**120,000**	**16.7%**
Fate and Transport	1	20,000	2.8 %
Wildlife	1	100,000	13.9%
Outreach Programs	**14**	**77,800**	**10.9%**
Grant-in-Aid Research Program	8	33,000	4.6%
Product Testing	4	37,800	5.3%
Cooperative Research-Allied Assoc.s	2	7,000	1.0%
Total	**44**	**$ 718,026**	**100.0 %**

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Integrated Turfgrass Management

Improved turfgrasses developed for use on golf courses require management practices that provide quality playing surfaces while conserving natural resources and protecting the environment. A series of research projects are being funded with the aim of conserving natural resources by reducing the use of water, pesticides, and fertilizers. These studies will focus on the following objectives:

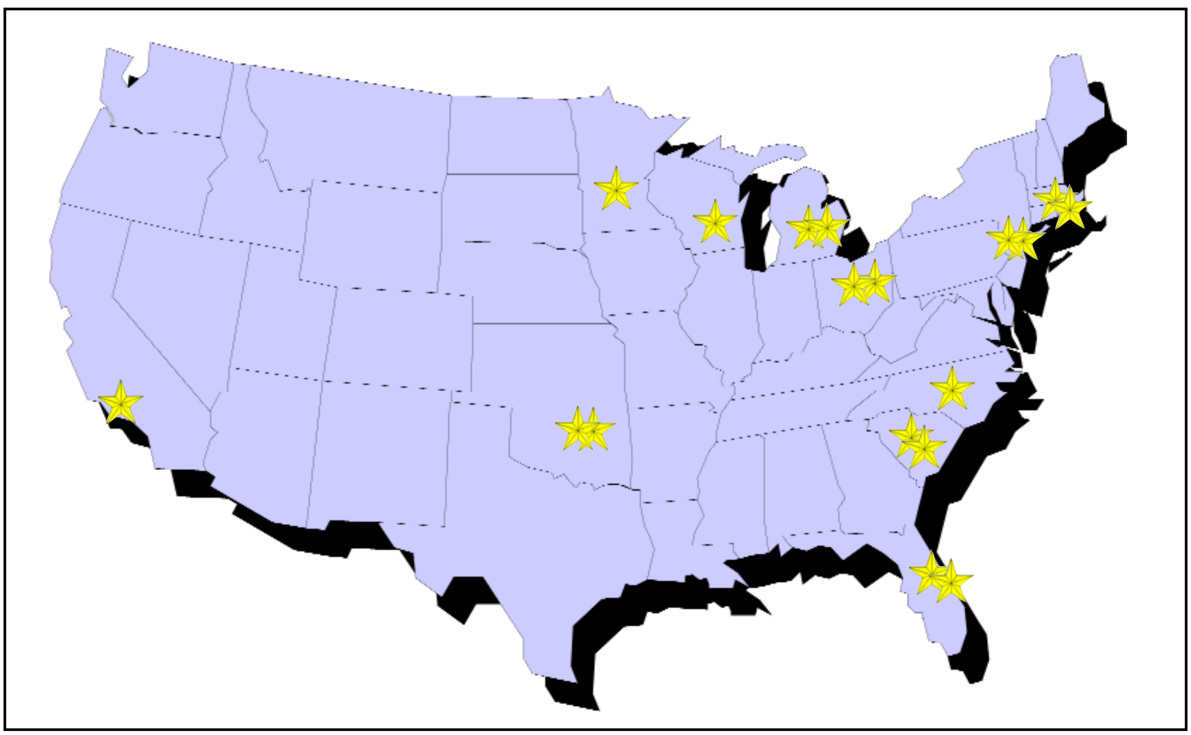
1. Develop cultural practices that allow efficient turfgrass management under unique conditions, such as poor quality soils, shade, and marginal quality water.

2. Determine the range of adaptability and stress tolerance of turfgrasses.

3. Evaluate direct and interacting effects of two or three cultural practices like mowing, irrigation, fertilization, cultivation, compost utilization, and develop programs to control pests and organic matter accumulation (thatch).

4. Investigate pest management practices such as biological, cultural, and mechanical controls, application of turf management practices utilizing IPM and reduced inputs, and pest modeling and forecasting.

The results of these studies should lead to the development of turfgrass management programs that conserve our natural resources and reduce costs, with minimal impairment of playing quality conditions or aesthetic appeal. We encourage regional cooperation among researchers where similar climactic and soil conditions exist.



Location of projects funded in 2011 by the USGA Turfgrass and Environmental Research Program under the category of Integrated Turfgrass Management

Developing Best Management Practices for Anthracnose Disease on Annual Bluegrass Putting Green Turf

James A. Murphy, Bruce B. Clarke, Charles J. Schmid, James W. Hempfling, and Ruying Wang
Rutgers University

Objectives:

The objectives of this research were initially organized into four field studies on annual bluegrass (ABG) putting green turf that were designed to evaluate the impact of cultural practices including: 1) nitrogen source, 2) rate of nitrogen fertilization during summer, 3) sand topdressing programming, and 4) mid-season cultivation on anthracnose severity.

Start Date: 2011
Project Duration: 3 years
Total Funding: $60,000

Anthracnose, caused by *Colletotrichum cereale*, is a destructive disease of annual bluegrass putting green turf. The frequency and severity of anthracnose outbreaks on putting greens have been attributed, in part, to management practices employed to improve playability on putting greens. A trial to determine the effect of soluble-N sources on anthracnose severity was initiated in the summer of 2010. Five soluble-N sources (ammonium nitrate, ammonium sulfate, calcium nitrate, potassium nitrate, urea) were applied at 0.1 lb per 1,000 ft^2 every week or biweekly for 12 and 16 weeks in 2010 and 2011, respectively.

Nitrogen applied every week reduced disease severity 9 to 26 % on 7 out of the 9 rating dates in 2010 and 2011 compared to biweekly applications. Interaction data from 2011 indicated that weekly applications of potassium nitrate reduced disease severity compared to all other N sources; whereas, weekly applications of ammonium sulfate increased disease severity. Two additional trials were initiated in 2011 to identify the mechanisms involved with N-source effects. These trials were designed to determine whether potassium nutrition or soil pH have effects on anthracnose severity.

A trial was initiated in 2009 to determine the optimum rate of summer soluble-N fertilization to suppress anthracnose severity and whether excessive rates may enhance disease. N fertilization rates of 0.4 lb per 1,000 ft^2 every 7 days consistently produced the lowest anthracnose severity during the first half of the season.

However, from mid-July to late-August, theses rates enhanced anthracnose severity compared to 0.2 lb per 1,000 ft^2 every 7 days which provided the greatest reduction in disease severity. Over the three year study, a cumulative soluble-N rate of 3.4 to 3.9 lb N per 1,000 ft^2 during the summer (12 weeks) provided the greatest overall reduction in disease severity.

Spring topdressing at 8 ft^3 per 1,000 ft^2 provided the greatest suppression of disease (all dates).

A three-factor trial was initiated in 2010 to determine whether autumn topdressing (medium sand) interacts with the effects of either spring or summer topdressing on anthracnose severity. The first year of data indicated that autumn topdressing at 4 ft^3 per 1,000 ft^2 lessened disease severity on 5 of 12 rating dates, whereas topdressing at 8 ft^3 per1,000 ft^2 provided a greater reduction in disease (10 of 12 dates).

Spring topdressing at 4 ft^3 per 1,000 ft^2 had a stronger and more consistent effect than autumn topdressing, reducing disease severity on 9 of 12 rating dates. Spring topdressing at 8 ft^3 per 1,000 ft^2 provided the greatest suppression of disease (all dates). Biweekly topdressing at either ¼- or ½ ft^3 per 1,000 ft^2 during the summer did not affect anthracnose severity during 2011.

Mechanical injury from cultivation practices during the summer did not influence anthracnose severity. One trial examined the effect of scarification depth (0, 0.05, or 0.3 in) on anthracnose severity and indicated that scarification, regardless of depth, had no effect on the disease. A second trial investigated whether the apparent increase in anthracnose severity observed after verticutting in a previous trial was an artifact of defoliation or was due to an actual increase in disease.

Trials evaluating a fifth objective, the effect of important factors on anthracnose fungicide efficacy, will be initiated in spring of 2012. Potential factors to be investigated in these trials include: N fertility, topdressing, and mowing height. These factors will be combined with fungicide factors such as application timing (calendar vs. threshold applications) and application sequence (rotation vs. limited-rotation strategies) to determine the impact of best management practices on fungicide requirements for the control of anthracnose on annual bluegrass turf.

Summary Points

- Potassium nitrate applications suppressed anthracnose severity compared to all other N sources; whereas, ammonium sulfate applications resulted in the greatest disease severity. Potassium nutrition and soil pH are being investigated as possible mechanisms involved in these N source effects.
- Three years of trial work indicate that a soluble-N rate of 0.2 lb per 1,000 ft^2 every 7 days applied during late spring and summer was optimal for suppressing anthracnose severity. Greater rates of N (0.4 and 0.5 lb per 1,000 ft^2 every 7 days) initially reduced disease severity better than lower rates but resulted in the greatest disease severity by the end of each season.
- Spring topdressing was more effective than autumn topdressing at reducing anthracnose severity. Spring topdressing at 8 ft^3 per 1,000 ft^2 provided the greatest suppression of disease, regardless of autumn topdressing.
- Mechanical injury from verticutting does not appear to increase anthracnose severity. Thus, superintendents should continue to use verticutting to manage surface organic matter accumulation without concern of intensifying the severity of this disease.

Infection and Colonization of Bermudagrass by Ophiosphaerella *Species, the Causal Agents of Spring Dead Spot*

Nathan R. Walker, Stephen M. Marek, Yanqi Wu, and Damon Smith
Oklahoma State University

Thomas K. Mitchell
Ohio State University

Objectives:

1. Transform *Ophiosphaerella korrae* to express green (GFP) and red fluorescent (tdTom) proteins.
2. Compare and contrast infection and colonization of roots and stolons/rhizomes of resistant and susceptible inter-specific hybrid, common, and African bermudagrasses by *O. herpotricha* and *O. korrae* that express fluorescent proteins.

Start Date: 2010
Project Duration: 3 years
Total Funding: $57,657

The green or red fluorescing O. korrae *transformants are currently being used to study growth and colonization on several different bermudagrass varieties that differ in their tolerance to the disease.*

Bermudagrasses in the transition region will undergo cool-temperature induced dormancy during winter months. In this region, spring dead spot is the most devastating and important disease of bermudagrass. The disease is caused by any one of three fungal species in the genus *Ophiosphaerella* (*O. herpotricha, O. korrae, or O. narmari*). The disease results in unsightly dead patches in the spring on bermudagrass fairways, tees, and greens and the patches can persist for months.

A critical limitation to the study of turfgrass diseases that occur on roots, stolons, and crowns in the soil, such as spring dead spot, is the inability of researchers to rapidly and easily study the plant-fungus disease interaction. This is a result of the interaction occurring below ground and often inside of plant organs. The overall goal of this study is to enhance our understanding of the interaction between *Ophiosphaerella* species and different bermudagrass hosts and to reduce the impact of this disease to bermudagrass in the transition zone.

Spring dead spot is the most devastating and important disease of bermudagrass in the transition zone.

To genetically transform *O. korrae* to express fluorescent protein genes, an *Agrobacterium tumefaciens*-mediated transformation system that we previously optimized for *O. herpotricha* was utilized. A gene for green fluorescent protein (GFP) under the control of the ToxA constitutive promoter with a hygromycin-selectable marker gene was moved into the genome of the fungus. A second cassette encoding the red fluorescent protein gene, tdTomato also driven by the ToxA promoter, was used to generate red transformants.

Colonization of bermudagrass roots by the transformant fungi was compared to the wild-type to verify comparable phenotypes. The green or red fluorescing *O. korrae* transformants are currently being used to study growth and colonization on several different bermudagrass varieties that differ in their tolerance to the disease. Studies are also being conducted to determine if there are differences in these events between *O. herpotricha* and *O. korrae* and their interactions with the various bermudagrasses.

The studies with *O. korrae* are in their early stages and ongoing. However, to date no significant differences have been observed for root colonization between the two fungal species. We will also examine the interaction using the confocal microscopy which permits examination of the fungal colonization not possible through traditional microscopy. With the fungal transformants we have also begun examining the release of reactive oxygen by the plants in response to fungal colonization. This response is part of the plants' defense against fungal invasion.

This basic information on how the cultivars react to the fungus will improve our ability to enhance and deploy host-plant resistance through traditional breeding efforts at Oklahoma State University.

Summary Points

- Transformants of *O. korrae* have been generated and are being use to study growth and colonization on several different bermudagrass varieties.
- Confocal microscopy has revealed details of plant-fungal interactions not obtainable through tradition microscopy approaches.
- This information will be used to enhance host-plant resistance through traditional breeding efforts at Oklahoma State University.

Correlation and Calibration of the Illinois Soil Nitrogen Test for Use as a Nitrogen Fertility Management Tool

David Gardner
The Ohio State University

Brian Horgan
University of Minnesota

Kevin Frank
Michigan State University

Objectives:

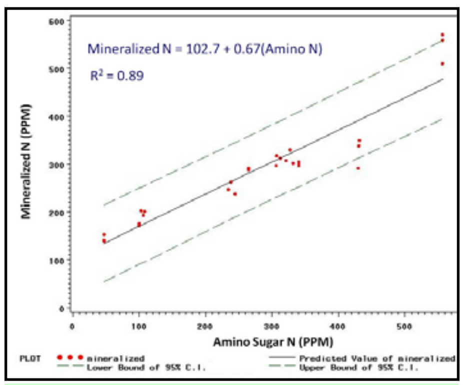
1. Evaluate the production of mineral N during incubation of soils differing in N fertilizer responsiveness.
2. Refine the critical amino sugar-N levels for turfgrass quality responsiveness.
3. Determine the impact of long-term fertility management practices on soil amino sugar-N values and nitrate leaching potential and to evaluate amino sugar-N concentration changes over time using the long-term N leaching plots at Michigan State University.

Start Date: 2010 (current cycle)
Project Duration: 2 years
Total Funding: $46,962

A USGA report "Nitrogen and phosphorus fate in a 10-year-old Kentucky bluegrass turf" authored by Frank (2005) has found leaching of ^{15}N labeled urea from a 10-year-old Kentucky bluegrass turf. This and other recent studies suggest that over time mineralization of N may exceed immobilization on fertilized turf which may increase the potential for nitrate leaching.

The Illinois Soil Nitrogen Test (ISNT) was developed to identify sites in production agriculture that are non-responsive to N fertilizer inputs. The test measures amino sugar-N fractions that supply the plant N through mineralization. This fraction is relatively stable compared to NO_3^- and NH_4^+, and thus may provide an accurate measure of potential nitrogen fertility on managed turfgrass. Our goal is to determine if the ISNT has any utility in predicting turfgrass response to nitrogen fertilizer. If the ISNT could be used to determine soil nitrogen status in turfgrass, this might allow superintendents to reduce excess time and money spent on unnecessary fertilizer applications. More importantly, this test may predict the impact of our fertility practices and could reduce environmental contamination associated with NO_3^- leaching.

In order to evaluate the production of mineral N during incubation of soils differing in N-fertilizer responsiveness, soils have been collected from North Dakota, Illinois, Indiana, Ohio, Michigan, Wisconsin, and Minnesota. Soils were incubated at 25°C for 12 weeks. Mineralization tests were conducted at weeks 0, 1, 2, 4, 8, and 12. Incubations to determine mineralization rates developed from procedures described in Mulvaney et al., 2001. Extracts and leachates were then analyzed for NH_4-N and (NO_3 + NO_2)-N by accelerated diffusion methods. We determined that there is a strong correlation between the level of amino sugar-N in the soil and the amount of N that mineralizes from the soil.



Results show a strong relationship between the amount of amino sugar nitrogen as determined by the Illinois Soil Nitrogen Test and the amount of potentially mineralizing nitrogen in the soil.

We have conducted several experiments during 2010 and 2011 to investigate the yield response of turfgrass (clipping yields, as well as quality and color responses) to added nitrogen in soils with various amino sugar-N levels. Results of these trials suggest turfgrass response to added nitrogen may be lower on soils with higher amino sugar-N levels. However, the results are not as conclusive as what has been found in production agriculture.

Part of our hypothesis is that as amino sugar-N levels increase in soil, the N needs of the turf are increasingly met by mineralized organic N. Therefore, on high amino-N soils there may be an increased chance that added fertilizer nitrogen would be more susceptible to leaching. If true, then the ISNT may be useful as a tool to identify sites that are prone to contribute to nitrate contamination of groundwater due to added fertilizer. In order to test this hypothesis, soil samples have been gathered from microplot lysimeters at Michigan State University for the years 2000-2010. Our goal with the analysis of these samples is to determine if the nitrate leaching events observed on the lysimeters at Michigan State can be correlated to changes in the amino-nitrogen level in the soil.

We expect to develop sampling procedure guidelines and interpretation of the ISNT results based on amino sugar-N and mineralization rates in order to make fertility reduction management recommendations on golf courses. We also expect to demonstrate that the ISNT can be utilized to explain nitrate leaching events. Since Frank (2005) reports that a 50% reduction in added fertilizer effectively eliminates nitrate leaching potential, we believe the ISNT may serve as an appropriate test to assist superintendents in reducing nitrate leaching from golf courses.

Summary Points

- Laboratory experiments have showed that the Illinois Soil Nitrogen Test value can be correlated to the amount of potentially mineralizing nitrogen in the soil.
- Our field studies suggest that the relationship between amino sugar-N and response of turfgrass to added fertilizer nitrogen is not as consistent as what has been reported in production agriculture. Additional studies are being conducted to analyze if a relationship between amino sugar-N levels and turfgrass fertility response exists.
- Analysis of soils gathered from lysimeters at Michigan State University from 2000-2010 will determine if the ISNT has any utility for predicting soils with the potential to leach nitrate due to fertilizer nitrogen.

Integrated Pest Management of Plant-Parasitic Sting Nematodes on Bermudagrass

William T. Crow and Kevin E. Kenworthy
University of Florida

Objectives:

1. Determine if one or more biopesticide programs can be used to replace or reduce reliance on 1,3-dichloropropene.
2. To verify if sting-nematode resistant/tolerant bermudagrass genotypes identified in greenhouse screening are more resistant/tolerant in the field than 'Tifway'.
3. To determine if the above genotypes require less frequent nematicide use than 'Tifway'.
4. To determine if a biopesticide program combined with use of resistant/tolerant bermudagrass genotype is sufficient to manage sting nematodes without the use of a conventional nematicide.

Start Date: 2011
Project Duration: 3 years
Total Funding: $60,000

This research is combining the use of tolerant cultivars with new nematode management tactics to develop IPM strategies for management of sting nematode.

The majority of golf courses in Florida experience damage from plant-parasitic nematodes. With limited nematicides available and 87% of golf courses in Florida at risk for nematode related damage, the superintendents need enhanced options for effective management. Options to be investigated by this research as components of an IPM plan for sting nematode management include the use of several biopesticides and tolerant or resistant bermudagrass genotypes.

Comparisons will be made with the conventional nematicide (Curfew; 1,3-dichloropropene) and to a conventional bermudagrass cultivar ('Tifway'). Earlier USGA- and Florida Turfgrass Association-funded experiments identified two types of tolerance to sting nematode in bermudagrass: 1) Cultivars that do not suffer as much root loss from sting nematode as standard cultivars, and 2) cultivars that, due to having exceptionally vigorous root growth, can have an adequate root system despite suffering significant root loss.

Also, University of Florida research has identified three new nematicide/bionematicide products available in 2012 (Nortica, Multiguard Protect, and MustGro Invest) that have shown some degree of efficacy against sting nematode. This research will combine use of tolerant cultivars with new nematode management tactics to develop IPM strategies for management of sting nematode.

The experimental design is split-plot with 5 replications. Whole plots are grass cultivars and the sub-plots are nematode treatments. Five different bermudagrasses will be planted in the field, including a standard susceptible cultivar ('Tifway') and a commercial cultivar and experimental accession each exhibiting one of the two types of tolerance. The first type of tolerance is exhibited by 'TifSport' and PI 291590, the second by 'Celebration' and BA 132.

The nematode treatments will be 1) untreated control; 2) Curfew applied annually in May or June; 3) maximum calendar-based alternative nematicide program including Nortica in February, MustGro Invest in April, and three sequential Multiguard Protect treatments starting in May; and 4) monitoring-based program where the three new nematicides will be used as needed based on nematode populations.

In August 2011 we assigned this project to a new Ph.D. student, Sudarshan Aryal. He grew nematode-free sprigs of each of the five grasses for planting in the field. While the sprigs were rooting, a sting nematode infested field at the University of Florida Agronomy Breeding facility in Hague, FL was identified and prepped for planting. All the grasses were planted in the field in fall 2011. The nematode treatments will begin in spring of 2012.

While the sprigs were rooting, a sting nematode infested field at the University of Florida Agronomy Breeding facility in Hague, FL was identified and prepped for planting. All the grasses were planted in the field in fall 2011.

Summary Points

- To date there are no results to report other than 'Tifway' having the least vigorous growth among the different grasses planted.

Efficient Irrigation of Golf Turf in the Cool-Humid New England Region: Evapotranspiration and Crop Coefficients

Scott Ebdon and Michelle DaCosta
University of Massachusetts

Objectives:

Develop research-based crop coefficients (K_c) for efficient irrigation practices in recreational turf (golf and sports) under maintenance and climatic conditions typical of the New England region.

Start Date: 2011
Project Duration: 3 years
Total Funding: $57,304

Scheduling irrigation according to actual turfgrass evapotranspiration rates (ET_a) reduces waste and increases irrigation efficiency. Landscape and crop coefficients (K_c values) are used in association with weather station reference ET (ET_0) to accurately predict ET_a. Experimentally derived K_c values need to be developed at the local level to ensure optimum turf function and effective irrigation efficiency specific to the region. Specifications developed by the US EPA have been drafted to restrict irrigation to only 60 to 80% of ET_0. These EPA guidelines may severely impact turf function in the cool-humid New England region because EPA K_c recommendations are based on California data.

Compared ET_a and K_c values for a golf turf species (creeping bentgrass, CBG) maintained as green and fairway, and 2 sports grass species (Kentucky bluegrass, KBG, and perennial ryegrass, PRG) using the standard reference ET_0 values computed using the UN Food and Agricultural Organization report 56 (FAO 56 equation). Studies were initiated in 2011 at the Joseph Troll Turf Research Facility, South Deerfield, MA. Pure stands measuring 5 by 10 ft of "Exacta" PRG and "Touchdown" KBG were established to represent sports grass while 'Memorial' CBG was used as green and fairway turf. Sports grass height of cut was maintained at 1.25 and 2.5 inches while CBG plots were maintained at 0.125 and 0.375 inches. All treatment plots received either 2 or 4 lbs N 1,000 ft^{-2} yr^{-1}.

Twenty-four daily ET_a (using weighing lysimeters) and ET_0 (using FAO 56 equation) measurements were used to derive K_c values (calculated as ET_a/ET_0) during the summer months beginning June 21 and ending August 31, 2011. Reference ET values derived using the FAO 56 equation were correlated with ET_a ($r = 0.78$, $P \leq 0.001$) and therefore ET_0 was effective in predicting actual daily ET rates.

Within a species, height of cut and N fertilization rate had no significant effect on ET_a and K_c values. However, taller grass species typical of sports turf exhibited significantly higher ET_a and K_c values than short grass fairway and putting green turf. Biweekly K_c values during the summer irrigation season for KBG ranged from 1.15 to 1.30. Perennial ryegrass biweekly K_c values ranged from 1.05 to 1.20. Creeping bentgrass ranged from 0.90 to 1.05 in biweekly K_c values in 2011. Averages for the 2011 irrigation season showed that KBG exhibited the highest seasonal K_c (1.28) and CBG the lowest seasonal K_c (0.98), with PRG statistically intermediate in seasonal K_c (1.13).

First-year results indicate that a lower K_c value may be more appropriate for golf fairway and green turf compared to taller grass. Short-cut golf turf offers potential water savings and, in turn, K_c values that are 25 to 30% lower compared to sports turf. Short-cut CBG exhibited significantly slower leaf growth rates and lower leaf area components, which contributed to this species lower ET_a and K_c. Implementation of specifications of 60 to 80% of reference ET may severely under estimate actual cool-season turf water use for the cool-humid New England region.

Twenty-four daily ET_a (using weighing lysimeters) and ET_0 (using FAO 56 equation) measurements were used to derive K_c values (calculated as ET_a/ET_0) during the summer months beginning June 21 and ending August 31, 2011.

Summary Points

- Species such as KBG and PRG maintained under tall HOC as sports turf used 25 to 30% more water as ET_a than short grass CBG maintained as putting green and fairway turfs.
- K_c values derived as the ratio of ET_a to ET_0 were significantly lower for golf turf compared to sports grass. CBG exhibited 15% lower K_c values than PRG, and 30% lower K_c values than KBG turf.
- Seasonal K_c values during the 2011 summer irrigation season ranged from 0.98 for CBG to as high as 1.28 for KBG, with biweekly K_c values for CBG ranging from 0.90 to 1.05.
- Effects of N and HOC within the species on ET_a and K_c values were not statistically significant.
- US EPA WaterSense proposed K_c values of 60 to 80% of reference ET_0 may severely under estimate irrigation requirements for cool-season turfgrass species in the cool-humid New England region.

Water-Use Efficiency and Carbon Sequestration Influenced by Turfgrass Species and Management Practices

Darrel Jenerette and James Baird
University of California

Objectives:

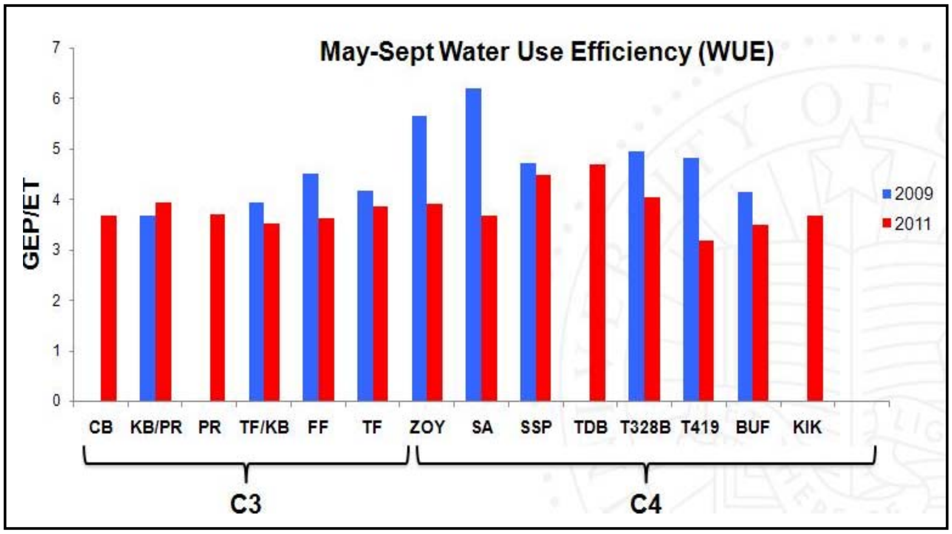
1. Estimate carbon balance of golf course carbon flux and soil carbon pools.
2. Determine associations between water use efficiency and carbon dynamics within turfgrass system.
3. Identify effects of reduced water and nutrient inputs.

Start Date: 2011
Project Duration: 3 years
Total Funding: $17,734

Our study addresses a need for improved data and understanding of turfgrass carbon dynamics, especially under reduced inputs of water, nutrients, and light. We use this approach to examine annual dynamics of seven cool-season and six warm-season turfgrass species and various cultivars of each in a field experiment, surveys of turf in common land management, regional patterns along a strong coastal to inland gradient, and high resolution sensing and modeling to describe physiological responses to drying and wetting events.

Beginning in 2011 we established a varietal experiment to evaluate turfgrass sensitivity to irrigation deficit. The experimental design was similar to one we used in 2009 to study turfgrass under optimal management conditions. In combination with these direct gas exchange measurements we measured carbon dynamics through a soil inventory approach. To initiate soil inventory we collected cores from the experimental plots and through representative sampling of turfgrass under different conditions throughout the region and at multiple depths. We are preparing the samples for chemical analysis. Our project uses new field monitoring systems to describe turf ecosystem carbon fluxes, water fluxes, and water use efficiencies.

Beginning in the summer of 2011, bi-weekly measurements were initiated on the different species and cultivars under deficit irrigation according to physiology (C_3 vs. C_4).



Differences in species water use efficiency (Gross Ecosystem Production / EvapoTranspiration) between optimal watering (2009) and deficit irrigation over the summer period. Water use efficiency general declined between species and there were large species differences.

Beginning in the summer of 2011 and building upon our preliminary research in 2009-2010, we commenced biweekly measurements on the different species and cultivars under deficit irrigation according to physiology (C3 vs. C4). Baseline measurements of gas exchange and soil properties were collected in late spring before the hot and dry summer conditions.

Irrigation ranged from 5-25% below established crop coefficients for cool-season and warm-season turfgrasses (deficit irrigation was based on a percentage of historical crop coefficients). Hand irrigation was used to maintain highest level distribution uniformity. Our measurements were conducted shortly after watering and accurately documents plant condition in response to deficit irrigation.

We found a decrease in water use efficiency associated with deficit irrigation that progressed in intensity throughout the season. Species exhibited significant differences in their sensitivity to deficit irrigation. In a study conducted throughout the day following an irrigation period, we observed a lower water use efficiency in the afternoon than in the morning.

We plan to continue the deficit irrigation measurements throughout the winter. In the following summer we will incorporate nutrient reductions into the experimental design. This work will evaluate how reduced nutrients influence water use efficiency under optimal and deficit irrigation. We also plan to expand regional sampling of turf soils from golf courses through collection across a climate gradient extending from moderate coastal to desert inland.

Summary Points

- Deficit irrigation reduces maximum water use efficiency across all turfgrass species.
- Species varied significantly in sensitivity to deficit irrigation.
- More severe effects of deficit irrigation were observed following extended deficit irrigation.
- Water use efficiency decreased following irrigation events – such measurements may help improve irrigation frequency plans.

Validation of a Logistic Regression Model for Prediction of Dollar Spot of Amenity Turfgrasses

Damon L. Smith
Oklahoma State University

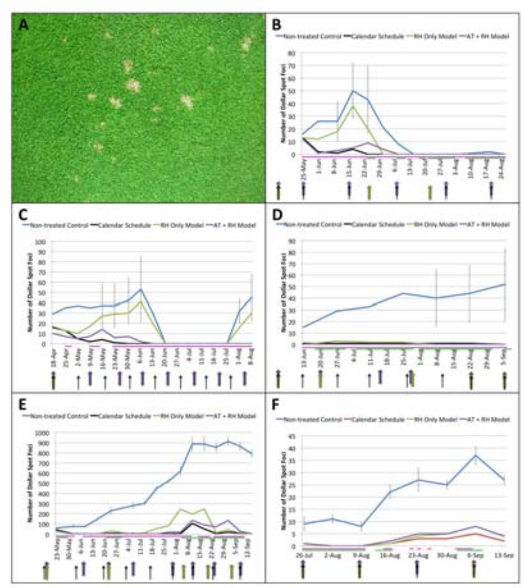
Objectives:

To validate new dollar spot prediction models for accuracy in predicting dollar spot epidemics so that preventative fungicide applications can be precisely applied in diverse locations of the United States.

Start Date: 2011
Project Duration: 2 years
Total $29,188

Dollar spot (*Sclerotinia homoeocarpa*) is the most economically important turfgrass disease in North America. The disease is frequently found on golf greens and fairways where it can be quite destructive. In the northern U.S., golf courses routinely spend 60-75 % of their pesticide budget to manage dollar spot and the fungicide applications are often conducted even if they are not required for disease control. An improved dollar spot prediction model for making fungicide application decisions would promote targeted use of fungicides for control of dollar spot.

This research focused on validating two new dollar spot prediction models. Models used in the validation were previously constructed using logistic regression. In 2011, all validation was conducted on creeping bentgrass (*Agrostis stolonifera*) putting greens with four treatments and a minimum of four replications. Treatments included a non-fungicide treated control, fungicide applied using a standard calendar-based application where the spray interval was 14 to 28 days (depending on location), fungicide applied using the newly developed air temperature and relative humidity (AT+RH) model, and fungicide applied based on a relative humidity (RH) only model.



Depending on the location, models differed in their accuracy to predict dollar spot. In the "deep south" and "transition zone" states (Figs. B, C, and D) the models were less accurate than in the "northern" states (Figs. E and F).

ZedX, Inc. supplied weather data (interpolated weather), which served as inputs for the models. Each location was provided a unique subscription (based on GPS coordinates) where cooperators received from ZedX, Inc. weather information along with spraying recommendations based on the models each morning via email. Sprays were applied for the model treatments only if fungicide protection had lapsed (e.g. fungicide was applied more than 14 – 28 days before) using established probability thresholds for each model. If fungicide protection had not lapsed, then no action was required by the user.

The number of dollar spot foci were recorded for each plot on a weekly basis throughout the growing season. Data were analyzed using standard analysis of variance, disease progress curves were developed for each treatment at each location, area under the disease progress curves (AUDPC) were determined, and separation of means were calculated using Fisher's test of protected least significant difference.

For all locations, fungicide applications based on the models provided a reduction in dollar spot compared to not treating. Depending on the location, models differed in their accuracy to predict dollar spot. In the "deep south" and "transition zone" states (Figs. B, C, and D) the models were less accurate than in the "northern" states (Figs. E and F).

At the Mississippi and Oklahoma locations, applying fungicide according to the AT+RH model provided control of dollar spot that was comparable to the calendar-based treatment and significantly less (AUDPC; $P<0.05$) than the non-treated control, however, the number of fungicide applications were the same for the two application strategies.

The RH only model prevented the need for three applications at the Mississippi location and seven at the Oklahoma location, but control was not significantly different from the non-treated control. At all other locations, spraying according to both models provided a significant reduction in the amount of dollar spot compared to the non-treated controls, and was comparable to the calendar-based treatment. The reduction in fungicide applications using the AT+RH model ranged from zero to two at these locations while using the RH model ranged from one to four. The AT+RH model resulted in a slight over-prediction of dollar spot while the RH model often resulted in an under-prediction. Data suggest that there might be different models, or probability thresholds, required for each region of the U.S.

Summary Points

- The AT + RH model provided control of dollar spot, which was comparable to the calendar-based treatments while providing an average reduction of one-fungicide application.
- The RH only model averaged a four-spray reduction versus the calendar based applications with improved control over not-treating for dollar spot; however, it consistently under-predicted dollar spot epidemics, which resulted in high levels of disease compared to the calendar-based treatment in two locations.
- The AT + RH model tended to over-predict fungicide applications by one spray vs. the RH only model which tended to under-predict fungicide application by at least two sprays.
- To improve the accuracy of the models, 2012 research will focus on tailoring action thresholds and also specific models to each "zone" of the U.S. where the models are tested.

How Does Irrigation Water Quality Affect Soil Chemistry of Sand-Based Rootzones?

Douglas J. Soldat, Glen R. Obear, Phillip Barak, and William Bleam
University of Wisconsin

Objectives:

1. Determine if accumulation of calcium carbonate results in a detectable decrease in porosity or air permeability under different fertility regimes.
2. Determine the pedogenic distribution of calcium carbonate in sand-based rootzones of various ages across different regions of the USA.
3. Determine how various base cation saturation percentages affect saturated hydraulic conductivity and soil solution composition of sand mixed with various rootzone amendments.

Start Date: 2011
Project Duration: 2 years
Total Funding: $41,243

The use of alternative, non-potable water sources for irrigating golf courses is becoming more common as pressure increases on water resources. These water sources and the associated agronomic challenges that arise from using these waters have traditionally been restricted to the arid southwestern U.S., but are now expanding throughout the country.

It is a widely held belief that water high in bicarbonate can result in calcium carbonate precipitation in the soil, sealing of soil pores, and decreases in water infiltration rates. However, very little research has been done to examine carbonate precipitation in soils, especially as it relates to soil physical properties.

Sand-based profiles (10 cm diameter, 30 cm length) were built to USGA-specifications in PVC columns. Cores were seeded with creeping bentgrass (*Agrostis stolonifera* L.) in August 2011 and are being irrigated at approximately 90% of evapotranspiration by the weighing method. The water sources used are calcium carbonate saturated, calcium-magnesium carbonate saturated, and deionized water. The carbonate waters are enriched with ^{13}C-bicarbonate in order to accurately track carbonate accumulation. Cores are fertilized at 0.6 lbs N/M/month with either an acidifying or a basic fertilizer.

Sand-based profiles (10 cm diameter, 30 cm length) were built to USGA-specifications in PVC columns.

Air permeability is measured biweekly to determine whether there is a decrease in porosity or air infiltration rate due to accumulation of carbonate. After 12 months, the cores will be sliced into 2-cm sections and analyzed for total carbonate and ^{13}C content. These results will help to determine the effects of carbonate accumulation on physical properties of sand-based rootzones.

Water samples and full-profile soil samples have been collected from golf course putting greens throughout the U.S. and are being analyzed for carbonate content. This information will lead to a better understanding of the pedogenic distribution of carbonate in different regions throughout the U.S. Sample collection and analysis will continue through summer of 2012 with the goal of collecting samples from at least 35 golf courses.

During winter of 2011/12, USGA-recommendation rootzone mixtures (10 cm diameter, 10 cm length) will be amended with calcined clay, sphagnum peat, zeolite, and silt loam soil. The profiles will be saturated in different solutions of increasing sodium and varying base cation saturation percentages.

Hydraulic conductivity will be measured using an automated falling head permeameter, and soil solution composition will be analyzed using both immiscible liquid displacement and saturated paste extraction. These results will help to determine the effects of various base cation saturation percentages on soil physical and chemical properties.

The results from this experiment will provide a better understanding of the effects of irrigation water quality on the chemical and physical properties of sand-based rootzones. This information could ultimately serve to provide better recommendations to golf course superintendents who are using alternative, non-potable water sources

Hydraulic conductivity will be measured using an automated falling head permeameter.

Summary Points

- The findings of the study will help to determine the effects of calcium carbonate accumulation on the chemical and physical properties of sand-based rootzones and the natural distribution of calcium carbonate in sand-based rootzones across the U.S.
- The results will help to determine the effects of differing base cation saturation percentages on chemical and physical properties of sand-based rootzones.
- The findings of the study are expected to result in improved recommendations to golf course superintendents who are using alternative, non-potable water sources.

Promotion of Turf Health through Early Pathogen Detection: Development of a Turf PathoCHIP

Ning Zhang and Bruce B. Clarke
Rutgers University

Francis Wong
Bayer Environmental Science

Philip F. Harmon
University of Florida

S. Bruce Martin
Clemson University

Objectives:

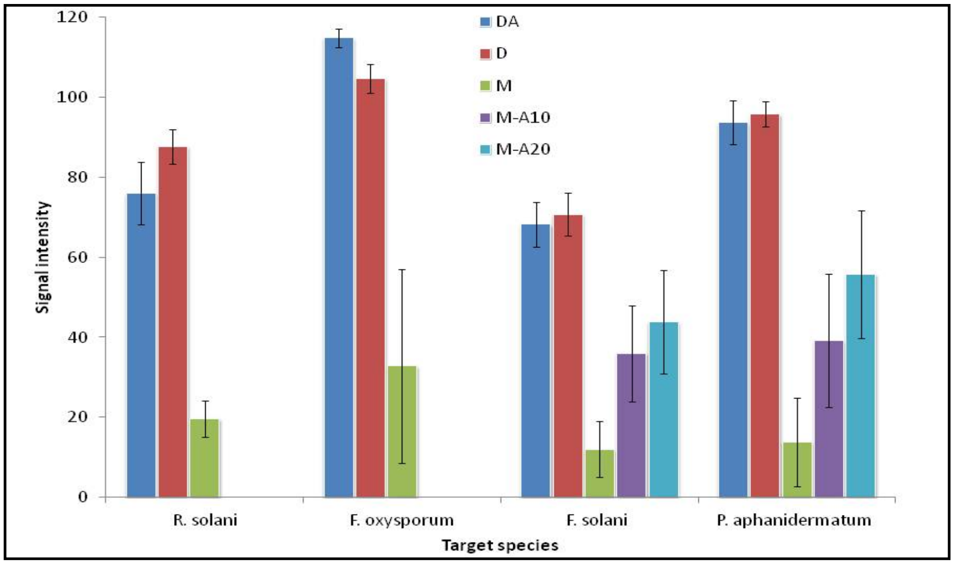
To develop and implement a highly sensitive DNA macroarray system,"Turf PathoCHIP", for rapid detection of known and emerging turfgrass pathogens based on the internal transcribed spacer sequences of the rRNA genes that are used for DNA barcoding of fungi.

Start Date: 2011
Project Duration: 3 years
Total Funding: $60,000

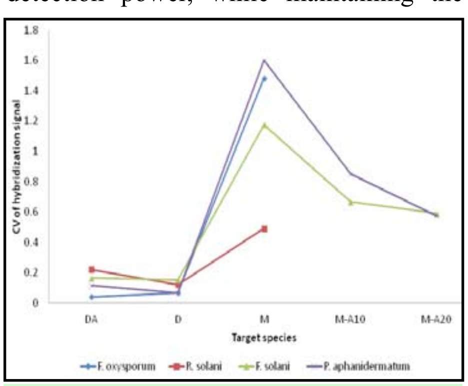
Early detection and rapid pathogen identification is essential for turf disease management. Fungi constitute the majority of pathogens that infect and damage turfgrasses. Over two hundreds fungal and fungus-like species have been recognized as turf pathogens, many of which are understudied. Identification of turfgrass pathogens poses a challenge because different pathogens may infect the same host concurrently and may produce similar symptoms. Traditionally, turfgrass diagnosticians use direct observations or culturing of pathogens from diseased plant samples to make a diagnosis.

DNA PathoCHIP is molecular technique that offers a fast, culture-independent alternative for the diagnosis of turf pathogens from field samples. The advantage of the technique is its remarkably high throughput compared to other detection methods. Hundreds of different pathogens can be simultaneously detected with one array in one reaction within a few hours.

We initiated a study in 2009 to optimize the technique for use in detection of turfgrass pathogens. The goal was to develop a novel technical approach that could increase the sensitivity of a PathoCHIP to enhance its early pathogen detection power, while maintaining the detection specificity to ensure accurate pathogen identification. Probes tested in a pilot study were based on four important pathogens of turfgrass and other plants: *Rhizoctonia solani* (basidiomycete), *Pythium aphanidermatum* (oomycete), *Fusarium solani* (ascomycete) and *F. oxysporum* (ascomycete) that cause brown patch, Pythium blight, root and vascular diseases, respectively.



Signal intensity comparison of different oligonucleotide probe types for the four species tested. The data are means ±SD (n =12) except F. oxysporum *where n=6.*



Coefficient of variation of hybridization signal intensity among different probe types for the four target species.

The dimeric oligonucleotide probes provided a low measurement variation and superior signal intensity. The new technique was remarkable in detecting low quantities of pathogen, which was a thousand times more sensitive than the PCR detection technique. The method was also successfully validated with target species infected turfgrass or soil materials vis-à-vis disease free materials.

We also embarked on a sample collection exercise for important diseases of turfgrass and microbes co-inhabiting in turfgrass. Great progress has been made in this area. We have collected over 200 pathogen and pathogen strains, sequenced the ITS region of the rRNA gene (for probe design) and fully identified the pathogen to species and subspecies level. The purpose of this exercise is to use the ITS sequence to design sequence specific probes for all important pathogens infecting turfgrass.

Starting 2011, different methods (bioinformatics software based and direct visualization) are being devised on how to detect the signature probes. This process requires all known related species sequence to be aligned and compared with sequences of target pathogen.

Pathogen specific probes will be designed and printed into an array (PathoCHIP) and thereafter validated for use by means of non-target pathogen, symptomatic and symptom-free target plants. The process will also be validated with microscopy, culturing, and real-time PCR.

Summary Points

- A database of more than 200 turfgrass pathogenic fungal strains have been built. All pathogens have ITS region sequence and have been preserved in various forms.
- Design of probes specific to target pathogens of turfgrass is underway.
- The PathoCHIP (array) system has been optimized for sensitivity.

Bacteria Associated with Creeping Bentgrass Disease Syndrome in the Southern and Southeastern United States During the Summer of 2010

Bruce Martin and Hanafy Fouly
Clemson University

Objective:

To identify the causal agents associated with creeping bentgrass disease syndrome in southeastern U.S. golf courses.

Start Date: 2010
Project Duration: 1 year
Total Funding: $5,000

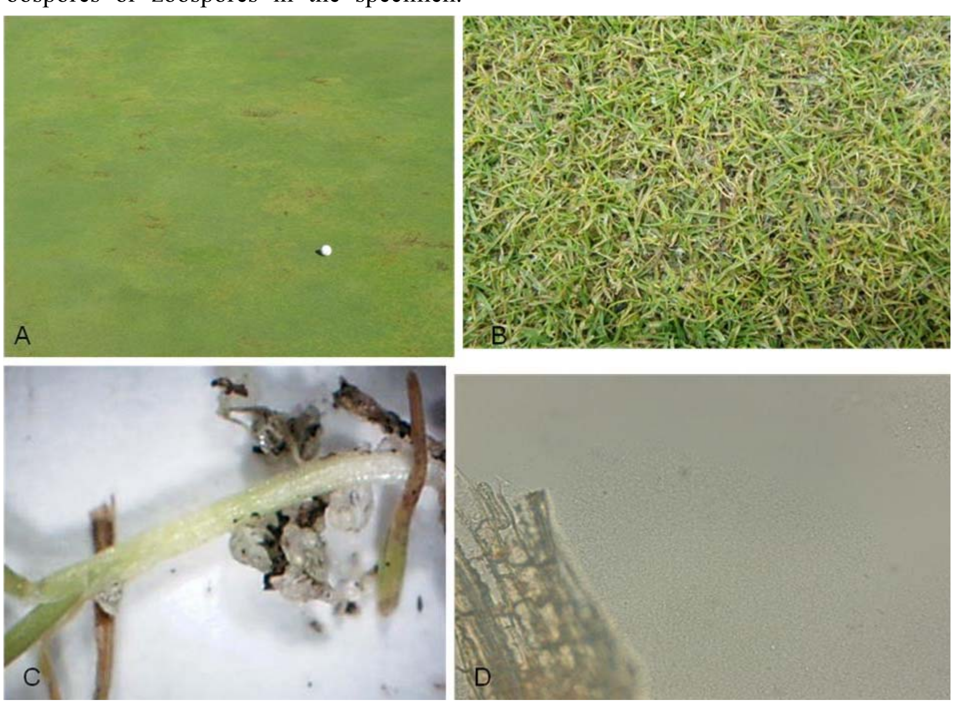
During the summer of 2010, the Clemson University Commercial Turfgrass clinic received samples of bentgrass (*Agrostis stolonifera* L.) on putting greens from 15 golf courses in the southern and southeastern United States. The samples were submitted on suspicion of Pythium blight or Pythium root dysfunction.

Additional samples were received and described as healthy turf. On the samples suspected of having disease, symptoms varied from yellowing of lower leaves to wilt and dessication of entire plants. Microscopic observations revealed streaming of bacteria from infected yellow leaves and from newly emerging leaves. In addition, there was no evidence of Pythium oospores or zoospores in the specimen. Following surface disinfestation, bacteria were isolated by maceration of infected leaves in nutrient broth and streaking the suspension on nutrient agar.

Pathogenicity tests of Acidovorax avenae *isolates; 18 and 19 on bentgrass (cone assay).*

Pure cultures of predominant bacterial colonies growing on plates from serial dilutions were transferred to nutrient agar medium. Samples from individual colonies growing on nutrient agar were used to establish pure cultures. Based on color, morphology, and appearance of bacteria on several media including yeast dextrose calcium carbonate, we were able to distinguish 16 different bacterial morphologies. Pathogenicity testing of each culture was conducted on creeping bentgrass (*Agrostis stolonifera* L.) cv. Penn G-2.

There were 11 pathogenic isolates belonging to 10 different bacterial morphologies. Sequence analysis of 16S rDNA of pathogenic bacteria revealed the highest similarity (>98%) to *Xanthomonas translucens* pv *poae*, *Acidovorax avenae* subsp. *avenae*, and a similarity of (> 93%) to *X. campestris* pv *campestris* and *X. oryzae* pv *oryzae* for all the 11 pathogenic isolates.



Symptoms of bentgrass disease syndrome caused by Xanthomonas translucens *and* Acidovorax avenae. *(A) Symptoms and incidence of the disease in putting greens; (B) close up of yellowing plants; (C) elongation of infected plants; (D) bacteria streaming from infected tissues.*

Summary Points

- During the summer of 2010, we at the Clemson University commercial turfgrass clinic isolated several bacterial isolates from diseased bentgrass.
- Two of those isolates were tentatively identified as *Xanthomonas translucens* and *Acidovorax avenae* based on morphology and DNA sequence of their 16 SrRNA. Pathogenicity tests have shown that those two bacteria are pathogenic to bentgrass.

Biology and Management of Acidovorax avenae

Nathaniel Mitkowski
University of Rhode Island

Objectives:

1. Determine the distribution of *Acidovorax* and *Xanthomonas* species associated with declining creeping bentgrass putting greens.
2. Conduct growth chamber and field tests to confirm the pathogenicity of bacterial species and closely define the symptoms induced by those that are pathogenic.
3. Determine the specific environmental conditions and cultural practices that are conducive to infection of creeping bentgrass by bacterial pathogens.
4. Identify effective cultural and chemical practices for management of bacterial diseases in creeping bentgrass.

Start Date: 2011
Project Duration: undetermined
Total Funding: $5,000

Bacterial wilt of creeping bentgrass was extremely severe throughout the eastern half of the United States in 2010 as a result of the unprecedented summer heat and humidity. The disease caused significant damage to creeping bentgrass greens from Maine to South Carolina. In 2011, conditions were less severe in the Northeast, but southern and midwestern courses continued to experience a dramatic decline in turf quality as the disease progressed into the summer months. There are no chemical pesticides labeled for the control of the disease.

During the summer and fall of 2010, 14 different *Acidovorax avena* isolates were collected at the University of Rhode Island from Connecticut, Massachusetts, Rhode Island, New York, New Jersey, Pennsylvania, Ohio, Illinois, and Virginia. The bacteria were subjected to ELISA and PCR testing, both of which uniformly identified the isolated bacteria as *Acidovorax avenae*.

Once identified, three of the isolates were then inoculated onto grasses in the growth chamber setting to determine pathogenicity. The bacteria were fully pathogenic on the following bentgrass varieties: 'PennA4', 'South Shore', 'Crenshaw', ''Providence', 'Mackenzie', 'L93', 'Cato', 'SR1150', 'Penncross', 'Pennlinks', 'Penneagle','SR7200' (velvet bentgrass), 'Exeter' (colonial bentgrass), and 'Alistar' (colonial bentgrass). The isolates were moderately pathogenic on annual ryegrass and non-pathogenic on *Poa annua*, Kentucky Bluegrass (variety 'Nuglade'), perennial rye (variety 'Turf Star'), tall fescue (variety 'Pixie') and fine fescue (variety 'Cindy Lou').

The most promising material for control of the disease is currently Actigard (acibenzolar-S-methyl), which is currently marketed for turf in combination with chlorothalonil and is being called Daconil Action. During the summer of 2011 we ran a number trials in the growth chamber to measure the effect of both this product and Primo Maxx (trinexapac-ethyl) on disease progression.

Growth chamber trials are of limited utility because the turf is under few stresses and often grows out of the disease quickly.

While anecdotal information has suggested that Actigard could lessen disease symptoms, other information suggested that Primo could exacerbate symptoms. Unfortunately, *Acidovorax avenae* appears to be a relatively mild pathogen when plants are in good health (that is, when they are cut at ½" or higher, receive no traffic, are not cut regularly and are well fertilized and watered). When plants are infected in the growth chamber, our experience has been that infected leaves die back quickly, but uninfected leaves quickly replace them, resulting in short-lived symptoms and quick recovery. This limits the utility of growth chamber studies.

No field trials were conducted at URI in 2011 as a result of much milder environmental conditions and the lack of disease expression in general. The results of the growth chamber studies indicated that Daconil Action could dramatically reduce symptoms to very low levels, (less than 15% symptoms compared to 65% in the controls) when applied preventatively. Unfortunately, curative trials failed to show a difference between the control and Daconil Action-treated plants because all plants recovered within 2 weeks of inoculation.

Observations of golf courses that used Daconil Action curatively during the summer of 2011 did demonstrate noticeable improvement on greens that were infected with the pathogen. Growth chamber experiments with Primo Maxx did not demonstrate any increase in disease symptoms, yet superintendents continue to report a correlation between Primo use and bacterial wilt symptom development.

Summary Points

- Bacterial wilt of bentgrass is caused by *Acidovorax avenae* (presumably variety *avenae*) and is widely distributed throughout the United States, where it causes a wilt and decline of creeping bentgrass.
- The pathogen can attack any variety of creeping bentgrass but does appear to be more aggressive on selected clones when it occurs in the field.
- The pathogen does not attack annual bluegrass or other turf type grasses.
- Disease is highly dependent upon prevailing weather conditions and health of the turf. Highly stressed turf under high temperature is most likely to see damage.
- Growth chamber trials are of limited utility because the turf is under few stresses and often grows out of the disease quickly.
- Daconil Action is highly effective at limiting disease symptoms when applied preventatively, and Primo Maxx does not appear to increase disease symptoms.

Identification of Bacteria Associated with Etiolated Bentgrass and Evaluation of Management Factors that Influence Its Development

Lane Tredway
North Carolina State University

Objectives:

Identify bacteria associated with etiolated bentgrass and evaluate chemical control options for suppression of bentgrass etiolation.

Start Date: 2011
Project Duration: 1 year
Total Funding: $5,000

The disease caused significant damage to creeping bentgrass greens from Maine to South Carolina. In some cases, golf courses were forced to close for weeks at a time to allow for turf recovery.

Bacteria were isolated from creeping bentgrass samples submitted to the Turf Diagnostics Lab at NC State that exhibited etiolation symptoms or foliar decline combined with bacterial streaming from cut leaves or leaf sheaths. Fifty samples were received between June 1 and September 1 that fit these criteria. Symptoms observed in each sample were described and photo-documented. Repre-sentatives of each colony type were selected from nutrient agar isolation plates, photo-documented, and transferred to separate plates for identification using DNA sequencing and morphological characteristics.

Acidovorax avenae was isolated from 9 of the 50 samples. The symptoms observed in samples containing *A. avenae* were variable, ranging from chlorosis and etiolation to minor dieback of older leaf tips. *Xanthomonas translucens* was isolated from 6 of the 50 creeping bentgrass samples, and again the symptoms were variable and ranged from chlorosis and etiolation to dieback and water-soaking of older leaves. Neither *A. avenae* nor *X. translucens* were isolated from several creeping bentgrass samples showing prominent chlorosis and etiolation. In addition to *A. avenae* and *X. translucens*, bacteria from at least 10 other genera were also isolated from the 50 samples.

Growth chamber inoculation studies are underway with the isolated bacteria to determine if they are pathogenic to creeping bentgrass. Based on the fact that no single bacterial species is consistently associated with etiolated bentgrass, we suspect that either bacteria are not a cause of the problem or that more than one bacterial species is capable of inducing these symptoms.

Field research was conducted in 5 locations in North Carolina (3 in Raleigh and 1 each in Greensboro and Charlotte) to evaluate chemical control options for suppression of bentgrass etiolation. Evaluated products included Mycoshield, FireWall, Agrimycin 17, FireLine, Zerotol, Consan 20, Greenshield, SA-20, Junction, Camelot, Copper-Count-N, Signature, Daconil Action, Kasumin, and an experimental formulation of fluazinam.

Mycoshield was phytotoxic to creeping bentgrass after 1 application at rates of 10 lbs. product per acre or higher, and Agrimycin 17 was phytotoxic at rates of 20 lbs. product per acre or higher. No chemical treatments consistently reduced the expression of etiolation and thinning symptoms in our studies, and in fact in some cases treatments with antibiotics or copper compounds exacerbated the problem, presumably due to phytotoxic reactions.

We are investigating the influence of growth regulators and biostimulants, either alone or in combination, on the severity of bentgrass etiolation. Preliminary data collected in the fall during relatively cool weather showed that biostimulants neither increased or reduced the severity of the problem, while trinexapac-ethyl treatments significantly reduced the symptoms.

Summary Points

- Field research was conducted in 5 locations in North Carolinato evaluate chemical control options for suppression of bentgrass etiolation.
- Mycoshield was phytotoxic to creeping bentgrass after 1 application at rates of 10 lbs product per acre or higher.
- Agrimycin 17 was phytotoxic at rates of 20 lbs product per acre or higher.
- No chemical treatments consistently reduced the expression of etiolation and thinning symptoms in our studies, and in fact in some cases treatments with antibiotics or copper compounds exacerbated the problem, presumably due to phytotoxic reactions.

Occurrence and Identification of an Emerging Bacterial Pathogen of Creeping Bentgrass

Joseph M. Vargas, Jr., Paul R. Giordano, A. Ronald Detweiler, and Nancy M. Dykema

Michigan State University

Objectives:

Evaluate problems associated with *Acidovoarx avenae* subsp. *avenae* bacterial infection of creeping bentgrass on golf courses across the United States. This will be accomplished through field, greenhouse, and laboratory studies elucidating detection, infection, and control of the disease.

Start Date: 2011
Project Duration: 3 years
Total Funding: $59,608

Creeping bentgrass putting greens battling summer stress have been found to be heavily colonized by a bacterium identified in 2009 as *Acidovorax avenae* subsp. *avenae* (Aaa). Initially isolated from an *Agrostis stolonifera* cv. 'Penn-G2'/'Penn-A4' golf course putting green in North Carolina, the bacterium has now been isolated out of numerous samples from golf courses located in and around the transition zone. Symptoms include yellowing and etiolation of bentgrass plants in small (5-7 cm) to medium (7-15 cm) patches. Affected areas grow faster than surrounding areas and begin to thin after sustained periods of heat and humidity.

Research conducted has confirmed pathogenicity of the isolated bacterium on creeping bentgrass by the completion of Koch's postulates. Electron microscopy indicates a colonization of the bacterium in the vascular bundle of the naturally affected creeping bentgrass. Recently, several *Agrostis stolonifera* cultivars ('Penncross', '007', 'Bengal', 'Penn-A4', 'Penn-G2', 'Tyee', and 'Declaration') were screened for susceptibility under growth chamber conditions (33 C, 210 mE, 12-hr photoperiod, 75% RH). Results indicate the bacterium is virulent on all cultivars tested.

A collection of isolates from around the country is ongoing. Samples suspected of being affected are thoroughly diagnosed via microscopy, and upon detection of significant bacterial populations, isolations are conducted and strains stored for later use and identification.

Thus far, 16s rDNA molecular identification has verified Aaa in 7 of the 14 suspected samples from 2010. These include isolates from IN, MA, MD, NC, and TX. In 2011, a collection of 10 more suspected samples from infected creeping bentgrass putting greens have been isolated and stored for molecular analysis.

Additional to the standard 16s rDNA primers, a subset of primers have been obtained that are currently being evaluated for specificity to Aaa. Once the specificity of primers has been confirmed on a subspecies level, probes will be designed for quantitative PCR assays. This technique should allow for better diagnosis and population evaluations with regard to symptom development and disease progression.

Field work in 2011 at The Michigan State University Hancock Turfgrass Research Center was carried out from June-September. Weekly inoculations of Aaa bacterial suspensions on a 297-m^2 creeping bentgrass putting green were administered with a backpack sprayer after 3 days of bacterial growth in a nutrient rich broth. Mowing took place immediately after inoculations to encourage infection.

Inoculated (left) vs. non-inoculated (right) cups of 1 month-old creeping bentgrass. Inoculated with *A. avenae* subsp. *avenae* and incubated at 33 C for 10 days.

Treatments included products such as antibiotics and anecdotal treatments suspected to have affects on disease symptoms (Table 1). Minimal disease infection occurred on field plots as a result of the numerous inoculations. Sustained temperatures did not reach optimal levels for disease occurrence. However, valuable information could be obtained regarding quality and phytotoxicity of some of the non-turfgrass labeled products.

Greenhouse-grown plants will be subjected to treatments and inoculations before growth chamber incubation in order to test product efficacy in a controlled environment. Additionally, collaborative work has been set up with The Moraine Country Club in Dayton Ohio in order to conduct on-site product testing at a golf course with confirmed Aaa infection.

Treatment	Rate	Interval
Urea	0.10 # N/M	14 days
PK Fight (phosphite)	3 oz /M	14 days
Insignia (pyraclastrobin)	0.54 oz/M	14 days
Streptomycin sulfate	200 ppm	14 Days
Mycoshield (oxytetracycline)	200 ppm	14 days
Actiguard (Acibenzolar-S-methyl)	0.75 oz/acre	14 days
Reserve (Triticonazole+chlorothalonil)	3.6 oz/M	14 days
Primo (Trinexapac-ethyl)	0.12 oz/M	14 days
Reserve +Primo	3.6 oz/M + 0.12 oz/M	14 days
Sonnet Biofungicide (*Bacillus subtillus*)	0.75 oz/M	10 days
Control		

Table 1. *Treatment list for field study at MSU during 2010 for Aaa bacterial etiolation suppression.*

Summary Points

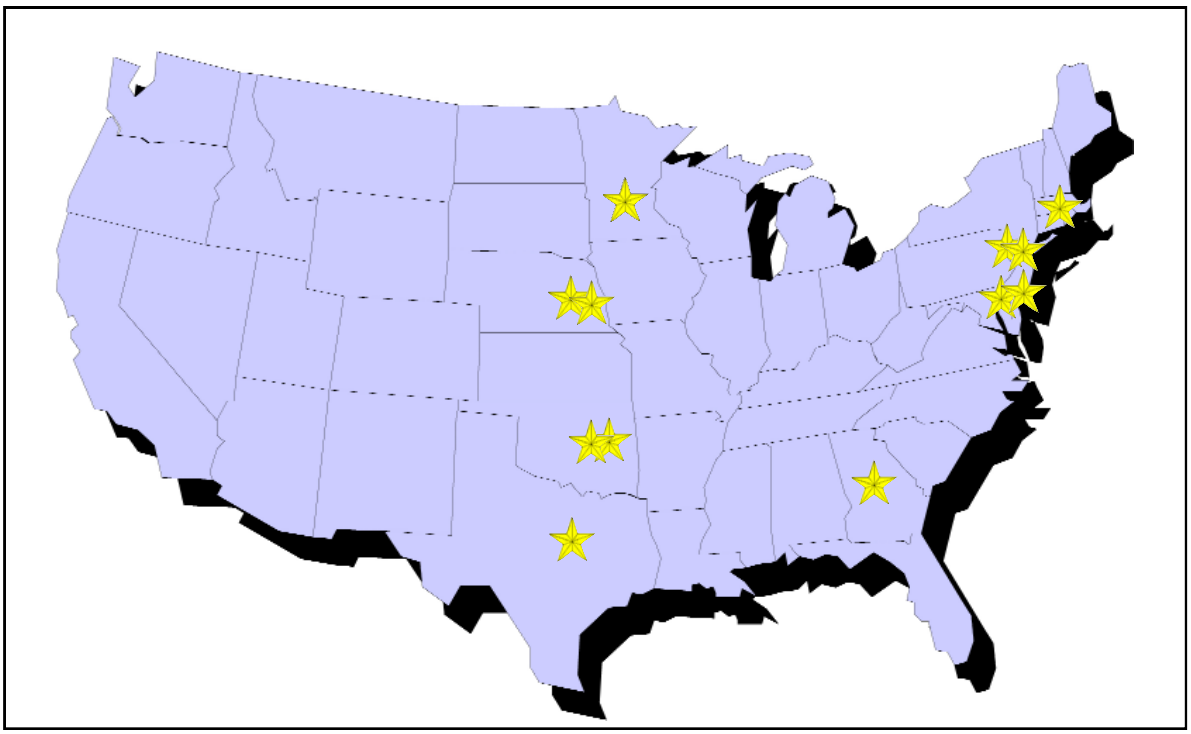
- Temperature and infection studies have determined pathogenicity of *Acidovoarx avenae* subsp. *avenae* on many creeping bentgrass cultivars.
- Continued progress has been made with obtaining samples and isolates from creeping bentgrass affected with *Acidovoarx avenae* subsp. *avenae*.
- Ongoing work to identify Aaa specific diagnostic PCR primers and probes.
- Continued field work with collaborators.

Breeding, Genetics, and Physiology

The quality and stress tolerance of turf is a product of the environment, management practices, and genetic potential of the grass plant. In many cases, major limitations to turf quality are stress effects, many of which can be modified or controlled through plant improvement. Projects are directed toward the development of turf cultivars that conserve natural resources by requiring less water, pesticides and fertilizers. Research projects that apply new biotechnological methods toward turfgrass improvement are considered. Among the characteristics most desirable in the new turfgrasses are:

1. Reduced need for pesticides by increasing resistance to disease, insects, nematodes, and weed encroachment
2. Increased shade tolerance
3. Reduced requirements for mowing, irrigation, and fertilization
4. Tolerance of non-potable water
5. Ability to survive high- and low-temperature extremes
6. Increased drought tolerance
7. Tolerance of intensive traffic
8. Tolerance of poor quality soils.

Research in the fields of biotechnology, genetics, cytogenetics, cytology, entomology, genetics, microbiology, nematology, pathology, physiology, and other sciences that support the project objectives and provide improved techniques for improving golf turf species will be considered.



Locations of projects funded in 2011 by the USGA Turfgrass and Environmental Research Program under the category of Breeding, Genetics, and Physiology

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

William A. Meyer and Stacy A. Bonos
Rutgers University

Objectives:

1. Collect and evaluate potentially useful turfgrass germplasm and associated endophytes.
2. Continue population improvement programs to develop improved cool-season turfgrass cultivars and breeding synthetics.
3. Develop and utilize advanced technologies to make current breeding programs more effective.

Start Date: 1982
Project Duration: Continuous
Total Funding: $10,000 per year

As of October 30, 2011, over 1,500 promising turfgrasses and associated endophytes were collected in Turkey, Italy, and the United Kingdom. These have had seed produced in The Netherlands and will be evaluated in New Jersey. Over 9,531 new turf evaluation plots, 74,856 spaced-plant nurseries and 8,000 mowed single-clone selections were established in 2011.

Over 236,000 seedlings from intra and inter-specific crosses of Kentucky bluegrass were screened for promising hybrids under winter greenhouse conditions and the superior plants were put into spaced-plant nurseries in the spring. Over 20,000 tall fescues, 16,416 Chewings fescues, 21,024 hard fescues, 50,000 perennial ryegrasses, and 10,000 bentgrasses were also screened during the winter in greenhouses and superior plants were put in spaced-plant nurseries. Over 393 new inter- and intra-specific Kentucky bluegrasses were harvested in 2011.

The following crossing blocks were moved in the spring of 2011: 5 hard fescues (203 plants), 2 Chewings fescues (82 plants), 8 perennial ryegrasses (358 plants), 3 strong creeping red fescues (71 plants), 8 tall fescues (332 plants), 2 velvet bentgrasses (37 plants) 5 creeping bentgrasses (60 plants) and 4 colonial bentgrasses (78 plants).

To enhance our breeding for resistance to gray leaf spot, an early July 15, 2011 planting of 200 perennial ryegrasses were seeded along with the 2010 NTEP perennial ryegrass test. Excellent *Pythium* blight control was attained and a good gray leaf spot epidemic occurred. This data will be used to select future varieties of perennial ryegrass. Over 14,000 perennial ryegrasses were planted in the spring of 2011 as spaced-plants. They were allowed to develop seedheads in the late spring and selections were made for stem and crown rust resistance.

Over 20,000 tall fescues, 16,416 Chewings fescues, 21,024 hard fescues, 50,000 perennial ryegrasses and 10,000 bentgrasses were also screened during the winter in greenhouses and superior plants were put in spaced-plant nurseries.

The breeding program continues to make progress breeding for disease resistance and improved turf performance. New promising varieties named and released in 2011 were 'Aramada' Kentucky bluegrass; 'Shenandoah Elite', 'Trerrano', and 'Penn RK-4' tall fescues; 'Shademater III', 'Contender', 'Parkbench', and 'Navigator II' strong creeping red fescues; 'Radar' Chewings fescue; and 'Barracuda' creeping bentgrass.

To enhance breeding for resistance to gray leaf spot, an early July 15, 2011 planting of 200 perennial ryegrasses were seeded along with the 2010 NTEP perennial ryegrass test.

Summary Points

- Continued progress was made in obtaining new sources of turfgrass germplasm. These sources are being used to enhance the Rutgers breeding program.
- Modified population backcrossing and continued cycles of phenotypic and genotypic selection combined with increasing sources of genetic diversity in turfgrass germplasm. This has resulted in the continued development and release of top performing varieties in the NTEP
- Three new tall fescues and 6 fine fescues were released in 2011.
- Published or have in press over 9 referred journal articles in 2010.

Breeding and Evaluation of Turf Bermudagrass Varieties

Yanqi Wu and Dennis L. Martin
Oklahoma State University

Objectives:

1. Assemble, evaluate, and maintain *Cynodon* germplasm with potential for contributing to the breeding of improved turf cultivars.
2. Develop and use simple sequence repeat molecular markers.
3. Improve bermudagrass germplasm for seed production potential, cold tolerance, leaf-firing resistance, and other traits that influence turf performance.
4. Develop, evaluate, and release seeded and vegetatively propagated turf bermudagrass varieties.

Start Date: 2010 (current cycle)
Project Duration: 3 years
Total Funding: $90,000

A large clonal selection nursery of about 1,500 putative F1 progeny plants (*Cybnodon dactylon* x *C. transvaalensis*) was established at the Agronomy Research Station of OSU in the summer of 2011. The clonal progeny were derived from 15 interspecific crosses between selected parental plants of common bermudagrass (*C. dactylon* var. *dactylon*) genotypes and African bermudagrass (*C. transvaalensis*). Seed of the crosses was harvested in 2010. Seedlings prepared in a greenhouse were individually space planted on 7-feet centers. Plants in the nursery will be evaluated for establishment, winter color retention, spring greenup, winterkill, foliage color, texture, sod density, seedhead abundance, and overall turf quality for two years .

Several common bermudagrass populations were subject to phenotypic selection. Two populations established at the Agronomy Research Station of OSU were evaluated primarily for seed yield components, i.e., seed set percentage and inflorescence prolificacy. Some plants in the two nurseries had an exceptional seed set in 2011. This was probably in part due to the weather conditions during bermudagrass flowering and seed maturing stages in June and July of last summer.

Two OSU bermudagrass populations established in 2009 at the turf research center of University Illinois, Urbana-Champaign, IL were evaluated for winter survival. Some plants in the nurseries survived the last two winters. Approximately 100 selections from the best of the survival plants were selected and brought back to be planted in a replicated nursery for further evaluation for turf performance, seed yield and related traits. This characterization research has been designed to be part of a graduate thesis of Ms. Yuanwen Guo.

Two superior clones, OKC 1119 and OKC 1134, were released as new cultivars in 2010 and were licensed to Sod Solutions, Inc. in 2011. Sod Solutions in close cooperation with OSU have named these cultivars 'Latitude 36' and 'NorthBridge', respectively. The two cultivars are clonally propagated F1 hybrids of *Cynodon dactylon* x *C. transvaalensis*. Last year data published online in the 2007-2012 NTEP National Bermudagrass Test (http://www.ntep.org/) indicated the two new cultivars continued to demonstrate exceptional turf quality and many other desirable traits. As of October 2011, six sod producers have been licensed by Sod Solutions, Inc. to produce sod of the two new cultivars.

Twenty-five high quality experimental interspecific hybrid bermudagrass lines planted in 2010 were evaluated for sod tensile strength and handling quality in October 2011.

One experiment was conducted to develop and characterize genomic SSR markers in bermudagrass. Five libraries enriched in core SSR CA-, GA-, ATG-, AAC- and CAG-sequences were constructed using the pUC19 plasmid. The SSR-enriched DNA inserts were sequenced at the Oklahoma State University Core Facility. The software program 'SSR Locator' was used to identify SSR sequences and to design SSR primers. The total of non-redundant highly amplified markers from all 5 libraries was 1,003.

Twenty-five high quality experimental interspecific hybrid bermudagrass lines planted in 2010 were evaluated for sod tensile strength and handling quality in October 2011. Nineteen of the 25 genotypes scored very good (rating 4) to excellent (rating 5) for handling quality where 3 is minimally commercially acceptable. These 19 clones will undergo more intensive field testing by MS candidate Chrissie Segars for visual performance traits as well as divot recovery and traffic tolerance/recovery rate in 2012.

Following eight years of low maintenance on a sand putting green at 0.188 to 0.25 inches, six interspecific hybrid plants from a total of 30 candidates were selected for intense final stage testing at 0.125 and 0.156 inches of mowing height, beginning in summer 2012 by MS Candidate Wenwen Liu. All final stage selections had survived winters at Stillwater, OK without greens covers, under conditions that eliminated 'Tifgreen', 'Champion', and 'TifEagle' bermudagrasses on the trial putting green during the period 2003- 2011.

Summary Points

- OKC 1119 and OKC 1134 were released as new clonal turf bermudagrass cultivars by OAES in 2010.
- A set of 10 superior clonal bermudagrass putative hybrids were selected in 2010 from a screening nursery for next-step in-house comprehensive evaluation.
- A large set of SSR markers were developed from bermudagrass EST sequences and pre-existing sorghum SSR markers.
- Eleven polymorphic SSR markers were selected to amplify 32 clonal turf bermudagrass cultivars.

Buffalograss Germplasm Improvement and Management

Keenan L. Amundsen and Robert (Bob) Shearman
University of Nebraska

Objectives:

1. Breed, select, and evaluate seeded and vegetative genotypes with improved turfgrass quality, pest resistance, and stress tolerance.
2. Improve our basic knowledge of the genetics of buffalograss through modern molecular marker technologies.
3. Expand understanding and use of efficient management practices for best genotypic performance.
4. Develop protocols for best turfgrass establishment.

Start Date: 2006
Project Duration: Continuous
Total Funding: $30,000 annually

Bur yield is a limiting factor to more widespread availability of seeded buffalograss. Buffalograss is dioecious having separate male and female plants. Increasing the ratio of females to males in production fields will significantly improve bur yields. In 2008, breeder fields were established with a seed mixture from a polycross. In these breeder fields and in natural populations, gender expression segregates approximately one to one. In 2010, a breeder field was established vegetatively, maintaining a ratio of eight females to two males. During the 2011 harvest, the vegetatively planted field yielded 2.5 times more burs per acre.

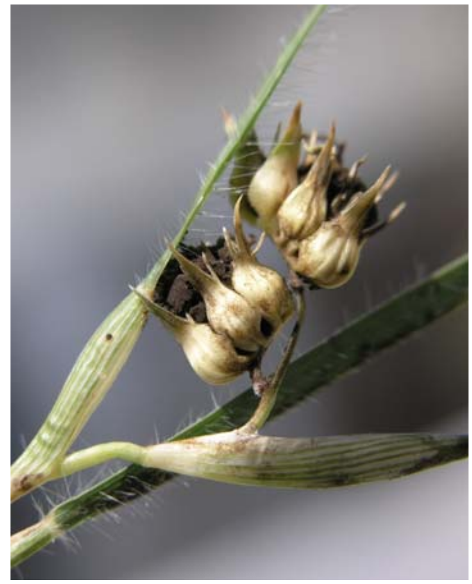
False smut, caused by the imperfect fungus *Cercospora seminalis*, inhibits seed production by infecting the unfertilized female flowers and preventing seed development. During the 2011 growing season, *C. seminalis* was cultured from infected burs isolated from 4 distinct seed production fields. Sixty female plants with promising turf quality and seed production characteristics were collected from genotypic evaluation plots. A suspension culture of *C. seminalis* will be applied to these plants over the winter in the greenhouse to determine host-resistance levels. The same plants will be evaluated under field conditions to identify resistant germplasm. Sources of host resistance will be incorporated into future cultivars.

Controlling gender expression in breeder fields through vegetative establishment.

Seed dormancy is an issue in buffalograss production and is typically broken by a KNO_3 treatment. This practice adds an estimated $0.50 per pound of seed. Eight distinct seed lots were screened for genotypes that germinate in the absence of a seed treatment. Germination percentage was determined 21 days after sowing 500 seeds from each seed lot. The germination percentage ranged from 0.8 to 17.4. Early germinating genotypes will be inter-mated following a recurrent selection breeding strategy in an attempt to overcome seed dormancy.

Progeny used in the development of a diploid genetic linkage map have been screened for western chinch bug resistance. Of the 94 progeny tested, one was considered highly resistant, 78 were moderately resistant, 13 were moderately susceptible, and two were highly susceptible. The variation in the progeny suggests improvements can be made through genotypic selection.

Using Next Generation Sequence data generated as part of the USGA supported project Molecular Characterization of Chinch Bug-Resistant Buffalograss, more than 28,000 EST sequences from the cultivar 'Prestige' were identified having simple sequence repeats (SSRs). Enough sequence information was available to design flanking PCR primers to 6,286 SSRs. A subset of these EST-SSRs along with amplified fragment length polymorphic (AFLP) markers will be used to increase the marker density and expand the coverage of the diploid buffalograss genetic linkage map. These SSRs are a valuable tool for studying the buffalograss genome.



Cercospora seminalis, *causing false smut was cultured from infected burs.*

A major and ongoing focus of our research is in collecting new material and evaluating our buffalograss germplasm collection for biotic and abiotic stress tolerance, timing of spring green-up and fall dormancy, density, quality, genetic color, mowing tolerance, sod characteristics, production traits, and mating compatibility. The genetic resources developed by this research complement our germplasm evaluation efforts and improve the efficiency of selecting new buffalograss germplasm with desirable traits.

Summary Points

- Vegetatively planted breeder fields produced significantly more seed than seeded fields.
- Cultures of *C. seminalis* were made to identify sources of host resistance.
- Started research to address seed dormancy of buffalograss
- Phenotypic evaluations for western chinch bug in an experimental mapping population segregated for resistance.

Genetic Improvement of Prairie Junegrass

Eric Watkins
University of Minnesota

Objective:

Determine the genetic potential of native prairie junegrass (*Koeleria macrantha*) germplasm for use as low-input turfgrass.

Start Date: 2007
Project Duration: 5 years
Total Funding: $50,000

Prairie junegrass (*Koeleria macrantha*), which is native to the Great Plains of the United States, has shown the potential to be successfully used as a turfgrass in low-input environments. The species is widely distributed throughout much of the western United States and can also be found throughout much of Europe and Asia.

Prairie junegrass has several attributes that would make it a useful low-input turfgrass in Minnesota including tolerance of droughty and alkaline soils, tolerance of sandy areas, survival of low and high temperature extremes, and reduced vertical growth rate. 'Barkoel' was the first cultivar of this species specifically developed for use as a turfgrass. However, this cultivar was developed with ecotypes from Europe. We are proposing the development of a cultivar primarily derived from germplasm native to North America.

Developing a high quality turfgrass is not, by itself, adequate. In order to be used by consumers, an economically viable turfgrass cultivar must be able to produce sufficient quantities of seed. Non-selected populations of the species can produce seed for 4-5 years. Evaluations of natural ecotypes made since 2005 suggest that individual genotypes may possess the ability to be highly productive. In order for a cultivar of this species to be used on a wide scale, two criteria must be met: 1) the cultivar must possess adequate turfgrass quality in a medium to low maintenance management situation, and 2) the cultivar must possess adequate seed production traits so that a sufficient supply of seed can be produced at a reasonable cost.

Evaluating native Koeleria macrantha *germplasm for seed production potential in Roseau, MN (photo credit: Donn Vellekson).*

We have collected native prairie junegrass germplasm from Minnesota, South Dakota, North Dakota, Colorado, and Nebraska. These germplasm collections have been established in breeding nurseries, and in some cases, experienced one cycle of selection. We have evaluated this material in spaced-plant seed production trials, mowed spaced-plant evaluations, and low-input turfgrass trials.

In addition to evaluating native material, we have done extensive evaluation of germplasm from other countries that are available from the USDA National Plant Germplasm Resources Network (NPGS). Taken together, these numerous evaluations have indicated that the greatest potential for a successful low-input prairie junegrass cultivar for golf course roughs and other landscapes is possible. However, the best opportunity for advancement will be through a combination of native and non-native material.

It has become clear that cultivars developed with European germplasm, most prominently 'Barkoel' and 'Barleria', have many of the traits necessary to produce a slow growing, winter hardy, stress-tolerant turfgrass for use throughout the northern United States. These cultivars maintain attractive green color and slow vertical growth rate throughout summer stress periods without any inputs.

The barriers that have kept these cultivars from establishing a market presence are primarily inconsistent seed production and issues with seed quality and germination. Fortunately, the native germplasm that we have been evaluating and advancing can contribute higher seed production potential, and we have also seen improved seed quality and germination in our populations.

Turf plot evaluations of Koeleria macrantha *accessions and breeding material in St. Paul, MN showing high turfgrass quality of European cultivars.*

We have initiated a project to make crosses between the European populations and our native populations. Due to differences in ploidy levels (the best European germplasm is tetraploid while most native germplasm we have collected is diploid), and anecdotal hybridization obstacles, this effort may take some time. Nevertheless, we are hopeful that this will lead to the development of an economically viable cultivar.

Combining the higher turfgrass quality of the non-native collections with the superior seed production potential of the native germplasm should result in a cultivar that can be used effectively throughout the northern United States on low-input turf areas such as golf course roughs.

Summary Points

- Non-native germplasm generally exhibits superior turfgrass quality but has lower seed production potential.
- Integration of traits from diverse germplasm should be effective in the development of a low-input cultivar.
- Research to initiate crosses between diploid and tetraploid populations has begun.

Selection of Bermudagrass Germplasm that Exhibits Potential Shade Tolerance and Identification of Techniques for Rapid Selection of Potential Shade-Tolerant Cultivars

Gregory E. Bell and Yanqi Wu
Oklahoma State University

Objectives:

1. Cross bermudagrass selections screened for shade tolerance and fine turf qualities over the past three years.
2. Establish progeny from seed and evaluate the progeny for shade tolerance, seed yield, and fine turf qualities.
3. Develop shade-tolerant seeded bermudagrass cultivar(s).
4. Study techniques with potential for rapid selection of shade resistant bermudagrasses

Start Date: 2011
Project Duration: 3 years
Total Funding: $60,000

Bermudagrass has good drought, heat, and salt tolerance and is resistant to many pests but does not tolerate shade nearly as well as most grasses. The development of a shade-resistant bermudagrass, especially a seed propagated type, suitable for both golf course fairways and rough would make a substantial contribution to the turfgrass industry.

A research site was planted using greenhouse-grown bermudagrass plugs on June 22, 2007 at the OSU Turfgrass Research Center, Stillwater, OK. The research site receives mid- to late-afternoon shade, depending on season, from a dense, mature evergreen canopy on the west side of the site. In 2010 we increased the length of the shade period to 89% of each day by adding 75% black woven shade cloth above the research block. Shade cloth was added over the identical block previously used as a full sun block in 2011 to provide moderate shade and a third block established in June 2009 became the full-sun block.

Through the growing seasons in 2008, 2009, 2010, and 2011, the study consisted of 45 bermudagrass selections and four vegetatively propagated standards: ‘Celebration’, ‘Patriot’, ‘TifGrand’, and ‘Tifton10’. Each bermudagrass was replicated five times. Visual turf quality (TQ) and Normalized Difference Vegetative Index (NDVI) were assessed every two weeks in 2008 through 2011. Photosynthesis was measured in the 5 best performing selections (2008 and 2009 data), 5 worst selections and 4 standards in spring, summer and fall 2010 and 2011 with a LI-6400 (LiCor, Lincoln, NE) portable gas exchange system. Internode length and density were measured monthly in 2010 and 2011.

The research block in the foreground was established in 2009 and was used as the full sun block in 2011. The original full sun block (background) was covered with a strip of shade cloth and considered moderate shade. The deep shade plot is not displayed but is just to the left of the moderate shade block.

Photosynthesis data obtained in 2010 and 2011 did not suggest a relationship between the rate of photosynthesis in shade or in sun with bermudagrass performance.

Longer internode in shade was a consistent occurrence in the best performing selections but was not a consistent occurrence in the poorest performing selections. For that reason, internode length may have some promise for rapid selection of shade-tolerant species.

The most dense bermudagrass selections in sun were not necessarily the most dense in shade limiting density as a factor for determining grasses in full sun that may have potential for strong performance in shade.

A single cross of two best performing selections was attempted in 2009-10 but was unsuccessful due to poorly matched physical characteristics. In 2011, selected clonal plants, 013, 023, 024, 028, 034, 035, 079, 116, and 118 were used in polycrosses. One single cross between 118 (shade tolerant) and 083 (shade sensitive) was field established. Seed from the polycrosses may be available for planting and testing as early as July, 2012.

Summary Points

- In 2011, selections were made from the shade study and planted for polycrossing and potential seed harvest in 2012.
- Photosynthesis was greater in summer than in spring and fall but did not correlate well with bermudagrass shade performance.
- Selections that performed well in shade had longer internodes in shade than in full sun; poor performing selections did not necessarily exhibit this trait.
- Bermudagrass density in full sun was not consistently related with its density in shade.

Genetic Enhancement of Turfgrass Germplasm for Reduced-Input Sustainability

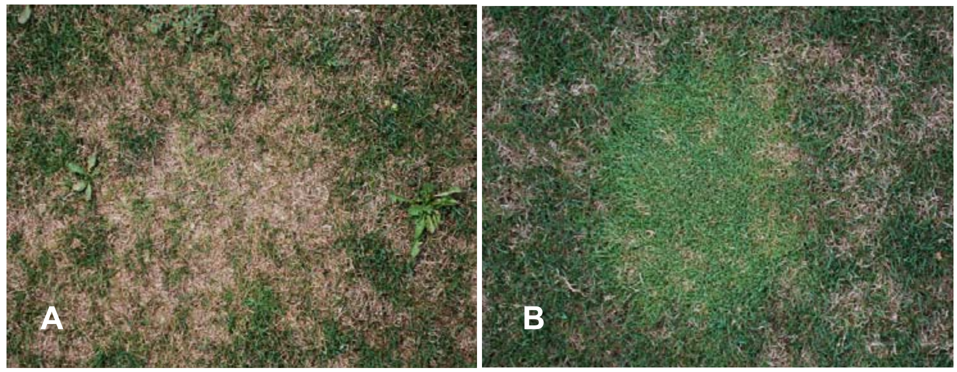
Kevin Morris
National Turfgrass Federation, Inc.

Scott Warnke
USDA-ARS

Objectives:

1. Use genetic and biotechnology approaches to identify and develop turfgrass germplasm with improved biotic and abiotic stress resistance.
2. Identify molecular markers associated with desirable traits and to combine useful traits into germplasm able to grow with reduced inputs.

Start Date: 2010
Project Duration: 3 years
Total Funding: $60,000



Susceptible creeping bentgrass clone showing low levels of dollar spot resistance (A) and creeping bentgrass clone showing resistance to dollar spot infection (B) in Maryland.

Bentgrasses (*Agrostis* spp.) are an important group of turfgrasses widely used on golf courses throughout the world. Although bentgrasses are highly diverse, much of the genetic diversity present in the species can be lost during the process of cultivar development. ARS researchers in Beltsville, MD are using new DNA marker technologies to understand the relationships between bentgrass species and develop new strategies for transferring important stress and disease tolerance genes between species.

A major effort is being done to improve dollar spot (*Sclerotinia homoeocarpa*) and brown patch (*Rhizoctonia solani*) disease resistance, as well as drought and heat tolerance. Dollar spot and brown patch are the most widespread fungal diseases of highly managed turfgrass species such as creeping bentgrass (*A. stolonifera*). In addition, irrigation of golf courses is under intense scrutiny, as potable water availability is increasingly restricted or limited. The identification of the genes providing disease and stress tolerance has the potential to significantly reduce the amount of fungicides and/or water needed to maintain healthy golf course turf.

Field and greenhouse data from 2008 and 2009 was used to search for chromosome locations influencing drought and heat tolerance in bentgrass. The analysis identified several important chromosomal regions governing stress tolerance traits in bentgrass species. The importance of these chromosomes in tolerance to multiple stresses may be most useful in future studies for the development of marker-assisted selection for both heat- and drought-tolerant creeping bentgrass cultivars.

Plant tissue of creeping bentgrass inoculated with both dollar spot and brown patch was collected and is being prepared for study using high-throughput DNA sequencing. Gene expression differences that occur during infection may provide clues to the methods of resistance to these two important turfgrass pathogens. The goal of this work is to develop more efficient methods of selecting disease resistant grass that will lead to a reduction in fungicide applications to turfgrasses.

Newly developed genetic markers were used to study the genetic diversity of both diploid and tetraploid creeping bentgrass germplasm. The analysis with these markers identified important relationships between bentgrass species and will allow us to develop strategies to transfer important traits such as heat and drought resistance and disease resistance from closely related bentgrass germplasm.

The analysis also indicates that during the process of creeping bentgrass cultivar development, significant reductions in genetic diversity have occurred. Reduced genetic diversity can lead to critical crop vulnerabilities to disease and stress that could result in sudden crop losses. Knowledge gained from this research will be used to enhance the genetic diversity of creeping bentgrass.

*A major effort is to improve dollar spot (*Sclerotinia homoeocarpa*, shown above) and brown patch (*Rhizoctonia solani*) disease resistance, as well as drought and heat tolerance.*

Summary Points

- Several important chromosomal regions were identified that are believed to govern stress tolerance traits in bentgrass species
- High-throughput DNA sequencing is being utilized to develop more efficient methods of selecting disease-resistant bentgrasses.
- Newly developed genetic markers indicate that during the process of creeping bentgrass cultivar development, significant reductions in genetic diversity have occurred .

Confirmation and Utilization of Candidate Gene Markers for the Selection of Heat-Tolerant Bentgrass

Bingru Huang, Yan Zhang, Faith Belanger, and Stacy Bonos
Rutgers University

Scott Warnke
USDA-ARS

Objectives:

1. Develop PCR-based markers from heat-responsive genes.
2. Map heat-responsive candidate genes on the present bentgrass genetic linkage maps.
3. Test for co-localization of candidate genes with mapped heat-tolerance QTLs.
4. Confirm candidate gene markers for use in marker-assisted breeding of creeping bentgrass for improved heat tolerance.

Start Date: 2010
Project Duration: 3 years
Total Funding: $89,713

Plants exposed to 20 days of heat stress (38º C), showing genetic variations in heat tolerance.

Summer bentgrass decline is a major issue affecting many turf areas during the warmer summer months. Insufficient heat tolerance in current bentgrass lines leads to major quality decline during periods of prolonged heat. By identifying important genes used for heat tolerance and then developing markers to assist in selection, the severity of summer bentgrass decline could be significantly reduced.

Several potentially important genes playing a role in heat tolerance have been identified using proteomic profiling and suppressive subtractive hybridization. Potential markers for these candidate genes are being tested in a hybrid mapping population which consist of a creeping x colonial hybrid (TH15) crossed with another creeping line (9188).

To date, markers have been tested for 18 candidate genes: catalase, chlorophyll a/b binding protein, cysteine protease, expansin, fructose 1,6-bisphosphate aldolase, glutathione S-transferase, glyceraldehyde 3-phosphate dehydrogenase, heat shock proteins (HSP 16, 26 70, 90, 90-1, 100, 101), phenylalanine ammonia-lyase, protein disulfide isomerase, Rubisco activase, and superoxide dismutase.

Several methods of developing useful markers to detect polymorphisms are being employed including using EST sequences in the NCBI database to create allele-specific PCR-based markers, as well as cleavage-amplified polymorphism (CAPs) markers which employ the use of restriction enzymes. Of the tested markers, eight have shown segregation in the mapping population they are being tested in, and of those eight, six have been added onto the existing linkage map which had previously been created using the mapping population. The six which have been mapped are catalase, cysteine protease, expansin, and heat shock proteins 26, 70, and 101 kDa.

Phenotypic variations in heat tolerance in the creeping colonial hybrid x creeping population were tested through the evaluation of turf quality, green leaf biomass, chlorophyll fluorescence, chlorophyll content, and electrolyte leakage. These parameters revealed large range of variations for heat tolerance present within the population. For example, turf quality ranged from 1 to 7 under heat stress (38º C). This confirms the appropriateness of using this population, as well as gives valuable information about the population which can be used for later analyses, such as QTLs analyses.

We are continuing to search for genes of potential importance based on current proteomic and metabolic research and testing associated markers. A collection of multiple markers will be screened in the population and used to expand the existing linkage map. In addition, we will test for the expression level of genes linked to the markers using RT-PCR analysis. Confirmation of gene expression and marker association will enhance further understanding of heat-tolerance mechanisms and the efficiency of marker-assisted selection for heat tolerance.

Summary Points

- Several methods of detecting polymorphism have been utilized to develop markers for genes associated with heat tolerance, including using EST sequences in the NCBI database to create allele-specific PCR-based markers, as well as cleavage-amplified polymorphisms(CAPs) markers which employ the use of restriction enzymes.
- Potential markers for 18 candidate genes are being tested in a hybrid mapping population. Eight markers have shown segregation in the mapping population. Of those eight, six have been added onto the existing linkage map which had previously been created using the mapping population. The six markers are catalase, cysteine protease, expansin, and heat shock proteins 26, 70 and 101 kDa.
- Heat stress trials have confirmed phenotypic variation in heat tolerance in the mapping population and collected data can be used to expand QTLs.

Development of Seeded Zoysiagrass Cultivars with Improved Turf Quality and High Seed Yields

A. Dennis Genovesi and Ambika Chandra
Texas A&M University

Objectives:

1. Develop seeded type zoysiagrass germplasm/cultivar(s) with high seed yields that offer an economical alternative to vegetative types with the potential for rapid turf establishment.
2. Breed improved characteristics such as turf quality, competitive ability, and persistence under biotic and abiotic stresses.

Start Date: 2010
Project Duration: 3 years
Total Funding: $89,434

Zoysiagrass is most often vegetatively propagated since it produces a higher quality turf. Marketing and distribution are, however, easier with seeded cultivars. Cost to establish one acre of fairway with sod, not including preparation, is between $12,000 and $15,000 while seeding costs only around $870. Moreover, the number of weeks needed to achieve established zoysiagrass fairways with seed is 16 versus 24 weeks with sprigs and 4 weeks with sod. Our current research focuses on the development of seeded cultivars that are genetically stable with improved turf quality, high seed yields, persistence, and competitive ability.

The seeded type zoysiagrass breeding effort here at Texas AgriLife Research Center – Dallas began in 2000-2002 when interspecific hybrids between *Zoysia japonica* and *Z. matrella* were made yielding 1,600 progeny. After a two-year grow-in period, 53 advanced lines were selected based on high seed yield potential and turf quality. Current funding support is directed towards the evaluation of these selected experimental lines for possible commercialization, as well as the initiation of additional breeding cycles of recombination and selection of germplasm to generate new seeded families.

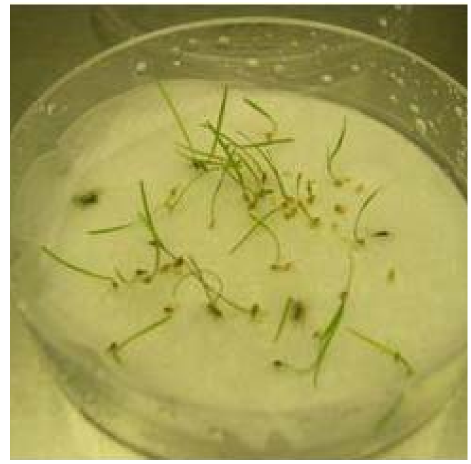
Seed scarification involves soaking in 40% KOH for 20 minutes, then rinsing three times with deionized water.

Due to limited resources, we have targeted our breeding efforts to work solely on the fine texture class (19 out of 53 selected lines) and place seed from the medium coarse and coarse texture classes into cold storage. Our breeding approach focuses on recurrent selection with alternating between Spaced Plant Nurseries (SPN) in 2011 and isolation blocks in 2013. As experimental lines develop in the 2011 SPN, we will focus on the following traits: fine texture, seedhead production (density and height), turf quality, flowering time, and nicking between families.

When selecting potential seed parents they should represent different pedigrees, but have approximately the same flowering time in order to enable cross pollination. Recurrent selection targets population improvement by stacking genes for seed yield and moving the population mean. Replicated field trials planted in 2011 with experimental seed lots will evaluate turf quality according to NTEP protocols.

During the spring of 2011, we have focused our efforts on the germination of seed harvested from the 2009 isolation block nurseries. Seed from 15 of 19 fine textured genotypes were germinated this spring in both the lab as well as the greenhouse. Since zoysia has hard seeds, it was necessary to scarify it to enable quick germination (4). The protocol developed in our program for scarifying zoysia seed is chemically using a strong base (40% KOH).

Three reps of 50 seeds each were scarified before germinating on moistened filter paper in Petri plates to determine percent germination for each genotype. This effort has produced a population of 684 progeny, which was planted on 4-ft. centers in the 2011 SPN on September 23, 2011. The progeny population will be evaluated for seedhead production and turf quality characteristics in 2012 and 2013. The best seed parents will be selected for another cycle of cross pollination in isolation blocks in 2013.



In vitro *germination of seed on moist filter paper.*

At the same time, we will introgress new germplasm identified from other sources with the potential for good seed production into the 2013 isolation block to insure a broad genetic base thus minimize inbreeding. A replicated field trial with 3 ft. x 3 ft.test plots was planted on August 26, 2011 for all 15 fine textured seeded families in order to evaluate their turf quality in 2012.

Summary Points

- Fifteen fine textured parental lines with the potential for good seed production were allowed to open pollinate in isolation blocks (planted in 2009) and seed harvested in 2010.
- Seed lots were tested from each seed parent to determine % germination and seedling vigor and the resulting progeny (684) were planted in a SPN for the next cycle of seed parent selection. 'Zenith' was included as a check.
- Field trials were planted using the experimental seed lots of fine textured zoysias to evaluate turf quality. Seed was scarified and planted according to NTEP specifications of 1 lb./1,000 sq. ft.

Molecular Characterization of Chinch Bug-Resistant Buffalograsses

T. Heng-Moss, K. Amundsen, R. Shearman, F. Baxendale, P. Twigg, B. Abeyo, L. Baird, and G. Lu
University of Nebraska

Objectives:

1. Assess the role of oxidative enzymes, specifically peroxidases, in the defense response of buffalograsses resistant to the western chinch bug.
2. Increase the genomic resources available for buffalograss using next generation sequencing technology.
3. Identify genes differentially expressed between chinch bug-infested and noninfested buffalograsses through the use of normalized and subtracted cDNA libraries for susceptible and resistant plants.

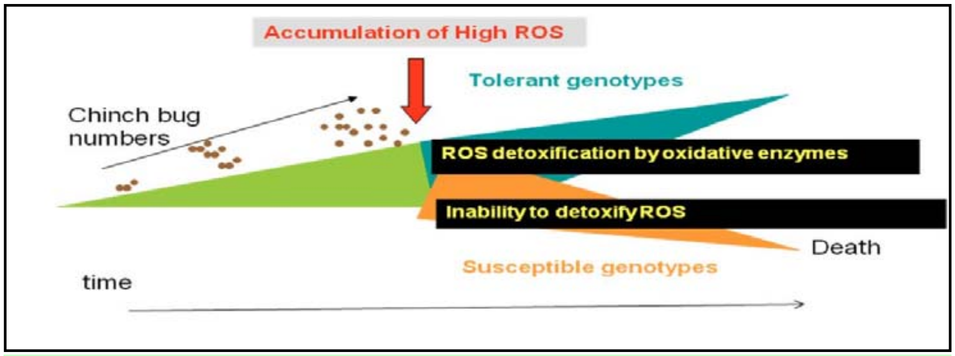
Start Date: 2010
Project Duration: 3 years
Total Funding: $79,423

Turfgrass resistance (specifically tolerance) to insects, when used as part of an integrated pest management (IPM) program, offers the opportunity to effectively and economically reduce chinch bug infestations while dramatically reducing pesticide inputs. Unfortunately, deployment of chinch bug-resistant turfgrasses has been seriously hampered by insufficient knowledge of plant resistance mechanisms and genes contributing to the resistance.

This information is fundamentally important for formulating plant breeding strategies, and subsequently developing chinch bug-resistant germplasm through conventional breeding and biotechnological techniques. In addition, knowledge of specific resistance mechanisms would be valuable for identifying biochemical and physiological markers for use in germplasm enhancement programs, and for characterizing plant defense strategies to insect feeding.

Plants have developed defense strategies to overcome the abiotic and biotic stresses to which they are exposed. One component of this defense system uses a wide array of stress-related proteins which can be elevated or repressed in response to specific or global stress conditions. Changes in the expression of these proteins can play direct or indirect role(s) in the plant's defense response to stress. Documenting changes in these stress-related proteins can provide important information on the extent and severity of a particular plant stress response, as well as the ability of the plant to overcome a specific stress and potential resistance mechanisms.

Reactive oxygen species (ROS), such as hydrogen peroxide, are known to be important early signals for altering gene expression patterns in plant cells in response to abiotic and biotic stressors. Despite the benefits gained from molecules like hydrogen peroxide as defense signals, accumulation of these ROS can be toxic to cells. To protect themselves from the effects of ROS accumulation, plants have developed defense-related enzymes (peroxidases and catalases) that break down the ROS.



To protect themselves from the effects of ROS accumulation, plants have developed defense-related enzymes (peroxidases and catalases) that break down the ROS.

Previous research by our group has documented increased levels of peroxidases following chinch bug feeding in the resistant (tolerant) buffalograss, 'Prestige', and a loss of catalase activity in the susceptible buffalograss, '378'. Our research group has also successfully identified two peroxidases that are specifically up-regulated in 'Prestige' plants in response to chinch bug feeding. These findings support our working hypothesis that an initial plant defense response to chinch bug feeding is to elevate the levels of specific oxidative enzymes, such as peroxidase, to help detoxify peroxides that accumulate as a result of plant stress.

A second component of this research is to increase the genomic resources available for buffalograss using next generation sequencing technology. To accomplish this, RNA was extracted and purified from chinch bug-infested and non-infested '378' and 'Prestige' buffalograsses. These samples were reverse transcribed and subjected to Solexa DNA and 454 sequencing technology.

The next step will be to assign and compare expression profiles between genotypes at different time points after infestation and identify candidate transcripts that may serve as markers for selecting buffalograsses with improved chinch bug resistance. A final objective of this research is to use the next generation sequencing data to identify specific genes conferring resistance to chinch bug.

Summary Points

- This research will (1) allow comparison of gene expression between resistant and susceptible buffalograsses, and serve to identify genes differentially expressed in response to chinch bug feeding, (2) provide insights into the biological pathways impacted by chinch bug feeding, and help elucidate plant tolerance mechanisms, and (3) facilitate development of improved buffalograsses with tolerance to chinch bugs through marker-assisted selection.
- This research will also shorten the timeframe needed to identify and improve buffalograsses with superior chinch bug resistance, and because of shared genomics among members of the grass family, may contribute to similar improvements in other grass species.

Examination of Cold Deacclimation Characteristics for Annual Bluegrass and Creeping Bentgrass

Michelle DaCosta and Lindsey Hoffman
University of Massachusetts

Objectives:

1. Determine the effects of different above-freezing temperature and duration combinations that result in a loss in freezing tolerance of creeping bentgrass and annual bluegrass.
2. Examine early changes in carbon metabolism associated with deacclimation of creeping bentgrass and annual bluegrass.

Start Date: 2010
Project Duration: 3 years
Total Funding: $60,000

Premature deacclimation associated with warming periods during winter and early spring can negatively impact turfgrass freezing tolerance and enhance susceptibility to freezing injury. Some limited research suggests that annual bluegrass (*Poa annua* L.) and creeping bentgrass (*Agrostis stolonifera* L.) may differ in their capacity to resist premature deacclimation, which can contribute to interspecific differences in winter injury potential. Therefore, research is necessary to understand the factors that trigger deacclimation in grasses and to identify plant traits that contribute to enhanced deacclimation resistance and freezing tolerance.

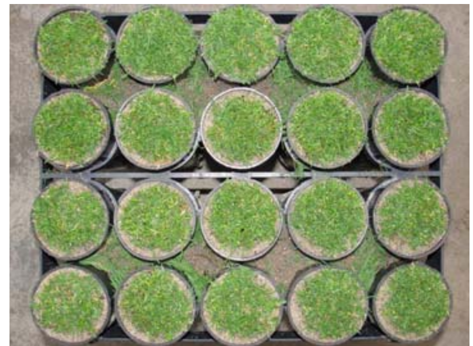
In Experiment 1, plant materials consisted of one annual bluegrass (AB) ecotype (previously shown to exhibit sensitivity to freezing temperatures) and one creeping bentgrass (CB) cultivar ('L-93'). Following establishment, plants were moved to a controlled environment growth chamber and exposed to a cold acclimation regime of 2° C for 2 weeks, followed by subzero acclimation -2° C for 2 weeks. Next, plants were exposed to one of six deacclimation treatments that consisted of the following temperature degree and duration combinations: 4° C for 1day or 5 days, 8° C for 1day or 5 days, and 12° C for 1day or 5 days. Changes in freezing tolerance (lethal temperature at which 50% of plants were killed, LT_{50}) for each species were monitored during cold acclimation and deacclimation.

Differential survival of annual bluegrass and creeping bentgrass following a deacclimation event. (Photo credit: Michael Buras, Longwood Cricket Club)

We found that creeping bentgrass achieved higher freezing tolerance at the end of the cold acclimation period (LT_{50} of -21.2°C) compared to annual bluegrass (LT_{50} of -17.7°C). When plants were exposed to 4° C for 1 day, both species exhibited a small loss in freezing tolerance compared to that at -2° C. However, annual bluegrass deacclimated to a greater extent compared to cree[omg bemtgrass in response to most deacclimation treatments. As expected, greater deacclimation for both species was observed at higher above-freezing temperatures (i.e., 12° C) and in response to greater duration of exposure (i.e., 5 days).

To better understand the underlying causes for differences in deacclimation resistance among the two species, we conducted a second experiment to examine early physiological changes of AB and CB in response to deacclimation, with a focus on carbon metabolism parameters. For Experiment 2, one AB ecotype (freezing sensitive, SS-1) and one creeping bentgrass cultivar ('Penncross') were exposed to a cold acclimation regime of 2° C for 2 weeks, and subzero acclimation at -2° C for 2 weeks. Following the cold acclimation period, plants were then exposed to a deacclimation treatment of 8° C for 5 days. During the cold acclimation and deacclimation periods, we measured canopy photosynthesis and respiration rates, leaf chlorophyll fluorescence parameters, and leaf and crown carbohydrate contents.

Similar to results from Experiment 1, we found that CB achieved higher freezing tolerance compared to AB, and CB also maintained higher freezing tolerance after exposure to 8° C for 5 days.



Annual bluegrass and creeping bentgrass were exposed to deacclimation conditions in controlled environment growth chambers.

During deacclimation, AB restored carbon metabolism parameters more rapidly compared to CB, as exhibited by a more rapid increase in photochemical yield and higher photosynthesis and respiration rates.

Although more rapid up-regulation of carbon metabolism may provide AB with a competitive advantage during spring recovery, these responses may also lead to greater susceptibility of AB to freezing injury in response to mid-winter warming events. Research is currently underway to understand additional factors that may be responsible for differences in deacclimation resistance between AB and CB.

Summary Points

- The freezing tolerance of AB and CB following a period of cold acclimation was influenced by both the magnitude of temperature increase and duration when exposed to simulated winter warming events.
- AB generally exhibited a greater loss in freezing tolerance at lower temperatures and shorter durations, which may account for greater susceptibility to freezing injury for this species.
- In response to deacclimation, AB exhibited a more rapid capacity to restore carbon metabolism compared to CB, based on higher photochemical yield, photosynthesis, and respiration rates.

Production and Maintenance of Triploid Interspecific Bermudagrass Hybrids for QTL Analysis

Brian Schwartz
University of Georgia

Objectives:

1. To evaluate the B17 F1 mapping population in replicated tests at Tifton, GA and Griffin, GA for turfgrass performance characteristics with the goal of identifying quantitative trait loci (QTL) for these traits.
2. To increase the size of the B17 F1 mapping population to 200 or more individuals.

Start Date: 1999
Project Duration: ongoing
Total Funding: $120,000

A framework genetic map was created using single-dose restriction fragments (SDRF) by Bethel, Sciara, Estill, Bowers, Hanna, and Paterson in 2006. In 2010, 75 simple sequence repeat (SSR) and 70 expressed sequence tag (EST) markers were identified to assess genetic diversity, identify cultivars of bermudagrass including those cultivars derived from 'Tifgreen', confirm pedigrees, and differentiate contaminants from cultivars. In the field, two replicated field trials of the B17 F1 mapping population were planted in Tifton and Griffin, GA to assess the phenotypic variation of these bermudagrass plants as observed in two distinct environments.

A number of traits will be measured or estimated in Tifton and/or Griffin, GA over the duration of this experiment. They include the length of the longest stolon during grow-in, stolon internode length, leaf width, leaf length, plant canopy height in the absence of mowing, seedhead density, number of racemes per flower, raceme length, number of spikelets per raceme, % green color, genetic color estimated with digital image analysis, plot color, turf density, turf quality, spring green-up, fall dormancy, and the variation of anthocyanin content between individuals within the mapping population.

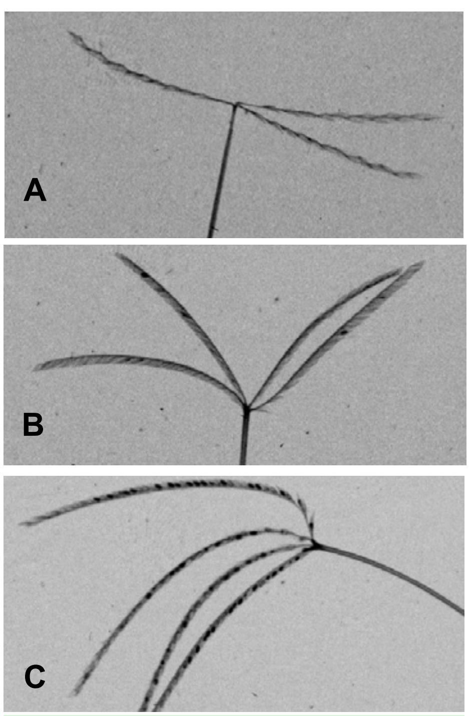


Figure 1. X-ray images were used to estimate percent seed-set of bermudagrass genotypes. (A) triploid 'TifSport 'bermudagrass: no seed. (B) tetraplid 'Tifton 11' bermudagrass: 2 seeds (C) tetraploid T89 bermudagrass: 47 seeds

The majority of our efforts during 2011 were focused on measuring stolon internode length (1,134 measurements), leaf width (1,134 measurements), plant canopy height (378 measurements), seedhead density (counted seedhead number in a 1' × 1' sample area on 756 plots), number of racemes per flower (records on 1,134 seedheads), raceme length (approximately 3,402 measurements), number of spikelets per raceme (counting between 30 and 250 spikelets on 1,134 seedheads), % green color (1,512 digital pictures evaluated), genetic color (1,512 digital pictures evaluated), turf density (1,512 ratings), and fall dormancy (756 digital pictures will be evaluated).

The majority of these measurements and ratings are finished, but have not yet been entered into spreadsheets. Seedhead morphological characteristics will be measured this fall and winter on samples which were collected at maturity during the growing season and have been dried down for long-term storage.

Figure 1 illustrates a technique used in the turfgrass breeding program at the University of Georgia to estimate percent seed-set of bermudagrass genotypes using X-ray images. (A) Triploid 'TifSport' bermudagrass: no seed. (B) Tetraploid 'Tifton 11' bermudagrass: 2 seeds. (C) Tetraploid 'T89' bermudagrass: ~47 seeds.

T89 × T574 hybrids were germinated and planted in the field during 2011.

Work continues to increase the B17 F1 mapping population by making hand pollinations between T89 and T574. During 2011, 256 new hybrids were germinated and planted from 2010 crossing efforts. Lab analysis has not yet been completed to determine what percentage of these new hybrids are truly T89 × T574 crosses. To reach our goal of a mapping population of 200, only 60 of the 256 new hybrids (~25%) will need to be identified as hybrids and not self-pollinations.

Additional crosses were made again in the spring of 2011. The seed has been harvested and will be planted out in the greenhouse this winter in an attempt to increase the B17 F1 mapping population well beyond the goal of 200 individuals.

Summary Points

- 14,364 different measurements, counts, or ratings were made on individuals of the B17 F1 mapping population in replicated tests planted on the Tifton and Griffin Agricultural Experiment Stations during 2011.
- 256 new hybrids were germinated from 2010 T89 × T574 crosses.
- Approximately 1,000 seed were harvested from T89 × T574 crossing efforts conducted in the spring and early summer of 2011.

Environmental Impact

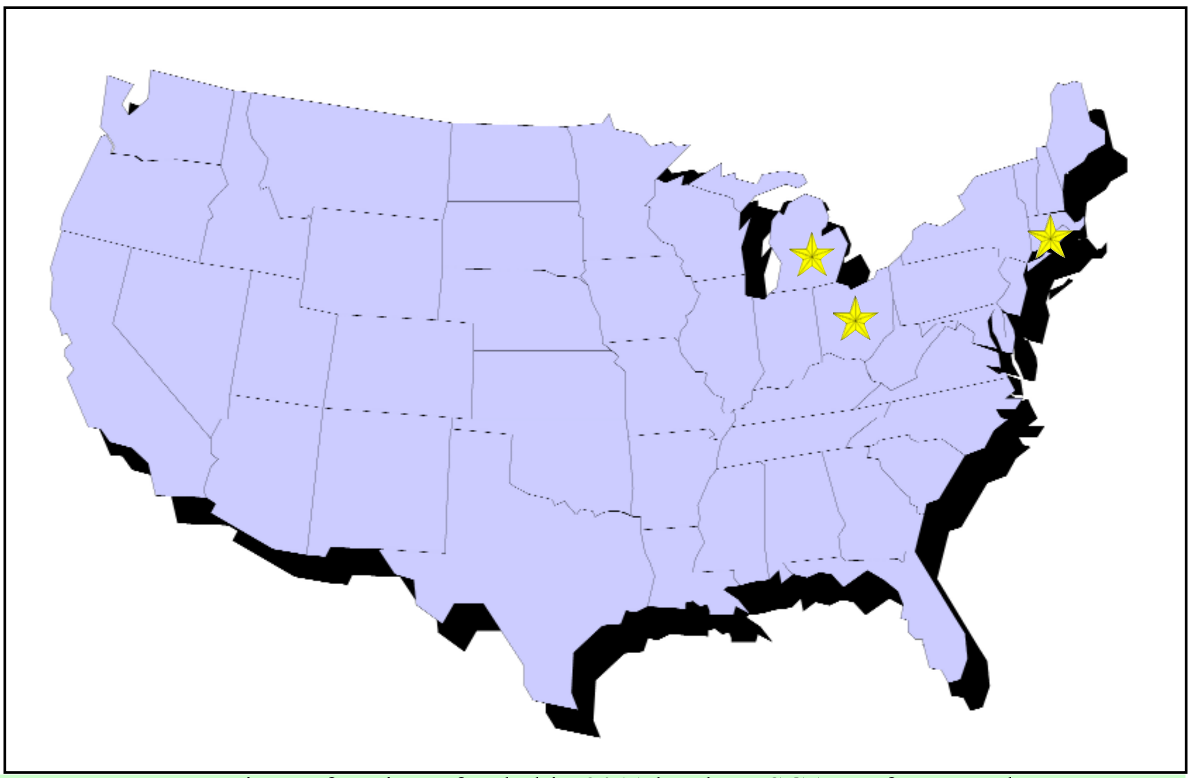
The public is concerned about the effects of golf courses on the environment. In response to this concern, the USGA has conducted research examining the fate of pesticides and fertilizers since 1991. The USGA continues to support scientifically based investigations on the environmental impact of golf courses. The focus remains on research to understand the effects of turfgrass pest management and fertilization on water quality and the environment.

Research on best management practices evaluates pesticide and fertilizer programs for golf courses in order to make turfgrass management recommendations that protect environmental quality. The research is conducted on university experiment stations and golf courses. The projects evaluate pesticides or nutrients that pose an environmental risk, and identify cultural practices that minimize volatilization, surface runoff, and groundwater contamination.

Pesticide and nutrient fate models are used to predict the environmental impact of turfgrass pesticides and fertilizers. From 1991 through 1997, research sponsored by the USGA demonstrated:

1. Measured nitrogen and pesticide leaching was minimal, and surface transport (runoff) posed a greater problem for golf courses, especially on heavy-textured soils in high rainfall areas of the country.
2. The turf/soil ecosystem enhances pesticide adsorption and degradation that greatly reduces the amount of chemical that moves below the rootzone.
3. Current agricultural fate models need modification to predict the fate of pesticides and fertilizers applied to turfgrasses grown under golf course conditions.

The results of USGA-sponsored pesticide and fertilizer fate research is being used to calibrate and validate existing pesticide fate models for turfgrasses managed under golf course conditions.



Locations of projects funded in 2011 by the USGA Turfgrass and Environmental Research Program under the category of Environmental Impact

Optimization of Vegetative Filter Strips for Mitigation of Runoff from Golf Course Turf

B. DeFlorio, J. Marshall Clark, Jeffery J. Doherty, and Guy R. Lanza
University of Massachusetts

Objectives:

1. Use selected plant species in a field study to evaluate the efficacy of vegetative filter strips (VFS) and their most effective arrangement.
2. Determine the fate of pesticides retained in VFS and the major mechanisms of degradation.

Start Date: 2008
Project Duration: 3 years
Total Funding: $90,000

The loss of pesticides and nutrients into surrounding bodies of water and the resulting decreases in water quality has led to the use of best management practices on golf courses. One such practice is the use of vegetative filter strips (VFS) to intercept runoff water and thus prevent its loss and the loss of any associated pesticides and nutrients to surrounding water bodies.

Joint greenhouse and field studies have been implemented to evaluate selected plants for their effectiveness in removing pesticides and nutrients from turfgrass runoff waters that enter vegetative filter strips (VFS). A greenhouse pot study determined five species (big blue stem, blue flag iris, eastern gama grass, prairie cord grass, and woolgrass) most effectively removed the six selected pesticides (2 fungicides, 2 herbicides, and 2 insecticides) from a silt loam soil.

In 2008 a run-on plot, consisting of 12 VFS planted in replicates of three (unvegetated, random mixture of plants, succession of plants, and turfgrass cut to three heights), was established; and an overhead simulated rainfall system was constructed similar to those used in previous USGA-funded runoff studies in Minnesota.

During the 2009 growing season, we installed additional lysimeters 1' underground and conducted two studies using an estimated runoff volume generated during a 1-year storm event of 25.4 gallons over the course of 24 hours. The 25.4 gallons of run-on was applied to the top edge of each VFS as a water mixture with bromide (15.1 g/gal) via a solvent transfer pump, once using inground irrigation and once using an artificial rainfall system. Runoff water was continuously collected from the bottom of the VFS. There were little differences in runoff volumes from the VFS planted as turfgrass (0.5 gallons), mixture of plants (0.2 gallons), and succession of plants (0.3 gallons) compared to the bare strips (7.1 gallons).

Bromide was detected in the runoff from the unvegetated VFS only (average time to bromide detection was 6.5 minutes). An average of 32.4 mg of chlorothalonil, 10.9 mg chlorpyrifos, 6.3 mg pendimethalin, 11.3 mg propiconazole, and 68.6 µg of imidacloprid were detected in the runoff collected continuously from the unvegetated VFS. Chlorothalonil (0.7 mg), propiconazole (0.1 mg), and imidacloprid (2.0 µg) were detected in two of the three succession of plants VFS. Pesticides were not detected in the runoff from either the random mixture of plants or turfgrass VFS.

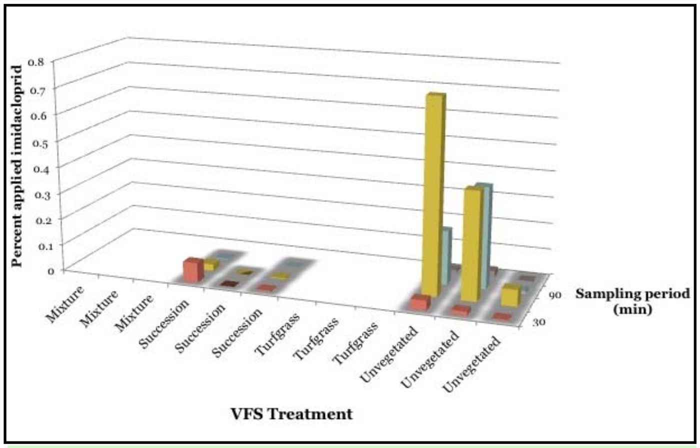


***Figure 2.** Percent of applied imidacloprid detected in the pore water from 1-ft. lysimeters following pesticide application.*

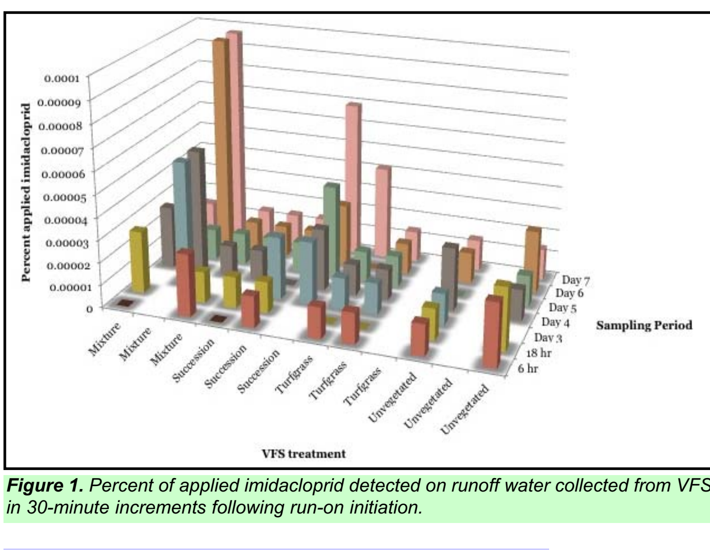


***Figure 1.** Percent of applied imidacloprid detected on runoff water collected from VFS in 30-minute increments following run-on initiation.*

As seen in Figure 1, imidacloprid was detected in all sampling intervals (30, 60, 90, and 120 minutes) in the runoff water from the three replicated unvegetative plots. It was also detected in the runoff from the succession VFS. It was not detected, however, in the runoff from the turfgrass and mixture VFS. Imidacloprid was detected in the pore water samples collected from the 1' lysimeters over time for all treatments. Nevertheless, the lysimeter samples from the turfgrass VFS were substantially less contaminated that the lysimeter samples from the other treatments.

These results are supportive of the contention that the thatch layer may be an efficient barrier to pesticide runoff and leaching, in that no imidacloprid was found in the runoff water from turfgrass VFS and less imidacloprid apparently was available for leaching in these plots.

Summary Points

- Preliminary data suggests that all of the vegetative treatments work to retain runoff water and prevent pesticide loss.
- The turfgrass VFS works as well, if not better, as the other vegetative treatments.
- Mixtures of plants are unsustainable.

Long-Term Nutrient Fate Research

Kevin W. Frank
Michigan State University

Objectives:

1. Determine nitrate-nitrogen and phosphorus leaching from a turfgrass stand that has been continually fertilized for 20 years.
2. Continue data collection from the Long-Term Nutrient Fate Research Area at MSU; currently we have data collection for 12 consecutive years.

Start Date: 2003
Project Duration: 12 years
Total Funding:
2008-2010: $34,800
2003-2007: $68,886
2000-2002: $64,612

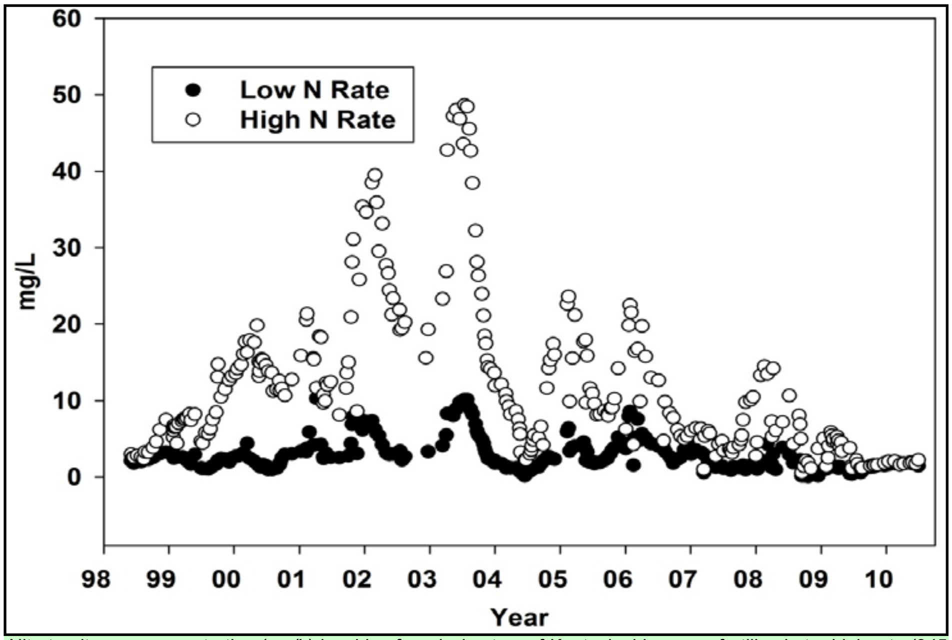
The USGA initially funded research at Michigan State University to determine nitrogen fate and leaching from a Kentucky bluegrass turf in 1991. Similar to previous research, the initial research at MSU conducted from 1991 through 1993 indicated that there was minimal risk of nitrate-nitrogen leaching from Kentucky bluegrass (*Poa pratensis* L.) turfgrass. Since the summer of 1998 percolate samples have been collected from the same monolith lysimeters and analyzed for nitrate-nitrogen (NO_3-N). As of 2011, the turfgrass area has now been under continual fertilization practices for 21 years with percolate collection for the last 13 years consecutively.

From July 1998 through 2002, lysimeters were treated annually with urea at a low N rate 98 kg N ha^{-1} (24.5 kg N ha^{-1} application^{-1}) and a high N rate of 245 kg N ha^{-1} (49 kg N ha^{-1}). From 1998-2002 for the high N rate there was a dramatic increase in NO_3-N leaching from 5 mg L^{-1} in 1998 to 25 mg L^{-1} in 2002. During the same time frame, there was a modest increase in NO_3-N leaching from 3 mg L^{-1} in 1998 to 5 mg L^{-1} in 2002.

In 2003 the N rate was reduced to 196 kg N ha^{-1} for the high N rate while the low N rate remained at 98 kg N ha^{-1}. Since 2003, phosphorus from triple superphosphate (20% P) has been applied at two rates, 49 and 98 kg P ha^{-1} split over two applications. The phosphorus application dates coincide with nitrogen application dates in the spring and autumn.

In 2003, the concentration of NO_3-N leaching from the high N rate treatment did not decline from the previous years. The average NO_3-N concentration leached from the low and high N rate treatments was 6.3 and 31.6 mg L-1. In 2004, the concentration of NO_3-N leaching from the high N rate treatment declined drastically from previous years. The average concentration of NO_3-N in leachate for the high N rate was 8.5 mg L^{-1}. This was a decrease in NO_3-N concentration of 23.1 mg L^{-1} from 2003. For the low N rate the average concentration of NO_3-N in leachate for the low N rate was 1.2 mg L^{-1}.

The average concentration of NO_3-N in leachate for the high N rate from 2004 through 2010 was 7.5 mg L^{-1}. In 2009 the mean NO_3-N concentration in leachate for the high N rate was 3.2 mg L^{-1} and in 2010 the mean NO_3-N concentration declined even further to 1.8 mg L^{-1}. In 2010, the mean NO_3-N concentration in leachate for the low N rate was 1.4 mg L^{-1}.



Nitrate-nitrogen concentration (mg/L) leaching from lysimeters of Kentucky bluegrass fertilized at a high rate (245 kg N ha^{-1} yr^{-1}) and low rate (98 kg N ha^{-1} yr^{-1}) from 1998 through 2010.

The concentration of phosphorus detected in leachate remains very low regardless of treatment. The mean concentration of phosphorus detected in leachate since initiating phosphorus treatments in 2003 has been less than 0.02 mg L^{-1}. This research indicates that leaching potential from continually fertilized turfgrass sites changes due to the age of turfgrass and annual nitrogen rate.

Summary Points

- For the high N rate, the annual mean $N0_3$-N concentration has been less than 10 mg L^{-1} for 5 of 7 years since 2004.
- For the high N rate, most of the sampling dates that had elevated $N0_3$-N concentrations were during late fall or winter when the turfgrass was dormant but the soil was not frozen.
- For the low N rate, the mean $N0_3$-N concentration has been 5 mg L^{-1} or less for every year except one (2003).

Reducing Watershed-Scale Phosphorus Export through Integrated Management Practices

Kevin W. King
USDA-ARS

James C. Balogh
Spectrum Research Inc.

Objectives:

Demonstrate and quantify the watershed-scale benefits of implementing filter socks and application setbacks from surface inlet structures, limiting phosphorus application to rates less than or equal to soil test phosphorus recommendations, and using the two practices in tandem.

Start Date: 2011
Project Duration: 3 years
Total Funding: $60,000

Hypoxic and anoxic areas in coastal marine and freshwater bodies worldwide result from excess nutrients and continue to be a major environmental concern. Excess nutrients exacerbate the development of phytoplankton, creating algal blooms. In freshwater systems, excess phosphorus has generally been identified as the problem nutrient. In the urban landscape, golf courses are the most intensively managed landuse. Phosphorus losses from managed turf are comparable to export coefficients reported for forests, urban/suburban, and crop production agriculture watersheds.

The experimental site is located on Northland Country Club (NCC) golf course located in Duluth, MN. Specifically, the study area is a 21.8 ha subarea of the golf course that contained 7 greens (0.3 ha), 8 tees (0.5 ha), 10.5 fairways (3.95 ha), grass roughs (8.1 ha), and 8.95 ha of unmanaged mixed northern hardwoods. The course is characterized by several micro-depressions or 'potholes.' In order to facilitate drainage, these potholes are often drained by tapping into the existing subsurface drainage network. A surface inlet is placed at the bottom of the pothole to rapidly remove water that collects in the depression.

Discharge and water quality samples are collected by a combination of grab samples and automated sample collection. In summer of 2002, two three-foot H-flumes with stilling wells and approach sections were installed in the stream that bisects the study area. One flume was positioned at the inflow while another was placed at the outflow. The H-flumes are instrumented with Isco 4230 bubblers programmed to record stage on 10-minute intervals. In the spring of 2004, two tile lines responsible for draining the majority of the study area were instrumented with compound weirs and bubbler flow meters to determine flow rate. All sites are equipped with Isco 6712 automated samplers and programmed to collect discrete flow proportional samples.

In March of 2011, we installed filter socks around each inlet within the eastern portion of the golf course study area. The filter socks were filled with 75% steel slag, 2.5% cement kiln dust (CKD), and 22.5% silica sand by volume.

A surface inlet is placed at the bottom of the pothole to rapidly remove water that collects in the depression.

Hydrology and water samples have been collected at both subsurface sites and at the and outlet stream locations on the course. To date, the chemical analyses have been conducted, but no interpretation of those results has been completed. We anticipate that the amount of phosphorus being transported through the tile line draining the area of the course where socks were installed will be reduced. In 2012, we plan to remove the socks and use a reduced rate or no application of phosphorus on that area of the course.

The findings should provide much needed information on both cultural and physical practices that can be implemented to address offsite nutrient transport.

In March of 2011, filter socks were installed around each inlet within the eastern portion of the golf course study area. The filter socks were filled with 75% steel slag, 2.5% cement kiln dust (CKD), and 22.5% silica sand.

Summary Points

- Filter socks containing 75% steel slag, 2.5% cement kiln dust, and 22.5% silica sand were placed around all surface inlets draining the eastern portion of the course.
- Hydrology, dissolved reactive phosphorus, and total phosphorus data on one drainage outlet with the filters and one drainage outlet without the filter socks have been collected.
- The findings should provide an assessment of both cultural and physical approaches to reduce phosphorus export from managed turf systems.

Audubon International

Audubon International strives to educate, assist, and inspire millions of people from all walks of life to protect and sustain the land, water, wildlife, and natural resources around them. In 1991, Audubon International launched the Audubon Cooperative Sanctuary Program for Golf Courses (ACSP), an environmental education program designed to help golf courses play a significant role in enhancing and protecting wildlife habitat and natural resources. The ACSP provides an advisory information service to help golf courses conduct environmental projects and achieve positive recognition for their efforts.

In addition, the Audubon Signature Program works closely with planners, architects, managers, and key stakeholders of new golf course developments to merge wildlife conservation, habitat enhancement, resource conservation, and environmental improvement with the economic agenda associated with the development. Involvement in the developmental stages of a project enables Audubon International to ensure that biodiversity conservation, environmental quality, and sustainable management are built into the project and continue after construction is completed.

Now in its 20th year, the ACSP for Golf Courses builds on the basic principles of wildlife management conveyed by Ronald Dodson in the early years. Dodson, shown here, walking the property at the Lake Placid Club in Lake Placid, New York, explains that there are basic guidelines that can be applied to any property, including golf courses.

"The wildlife loves it. Very little, if any, wildlife was found on the course in 2004," recalls Scott Sutton of Wildhorse Golf Club in Las Vegas, Nevada. "Now the local Audubon Society chapter visits the course monthly and has identified over 62 species of birds so far this year!" Sutton is one of many members of the ACSP for Golf Courses that is delighted by his cost savings on water, chemicals, and maintenance, but also enjoys the new visitors he has to his course.

At Stone Creek Golf Club in Oregon City, Oregon, protecting water quality is critical. Extended buffers provide filtration while the use of native plants cuts down on the need for fertilizer, pesticides, and irrigation.

*This small yellow flower is an Illinois endangered plant known as small sundrop (*Oneothera perennis *L.). There are only eight populations of this plant found in four counties of Illinois. Fortunately, fourteen additional colonies (or six acres) were found at the development site of ThunderHawk Golf Club, a Certified Signature Sanctuary. This unforeseen discovery proved to be a great testament to the fact that when working with people who also care about the environment, even discovering an endangered species mid-construction can have a happy ending. Today ThunderHawk has Sundrop Protection Zone and is actively educating members about sundrop conservation.*

The Audubon Cooperative Sanctuary Program for Golf Courses

Josh Conway

Audubon International

Objectives:

1. Enhance wildlife habitats on golf courses by working with the golf course superintendent and providing advice for ecologically sound course management.
2. Encourage active participation in conservation programs by golfers, golf course superintendents, golf officials, and the general public.
3. Recognize the people who are actively participating in environmentally responsible projects.
4. Educate the public and golfing community about the benefits of golf courses and the role they play relative to the environment and wildlife.

Start Date: 1991
Project Duration: Ongoing
Total Funding: $75,000/year

Audubon International is a non-profit environmental organization that envisions communities becoming more sustainable through good stewardship of the natural environment where people live, work, and recreate through responsible management of land, water, wildlife, and other natural resources. Since 1991, Audubon International has worked in partnership with the USGA to offer the Audubon Cooperative Sanctuary Program for Golf Courses (ACSP).

The program, now celebrating its 20th anniversary, is an award-winning education and certification program that promotes ecologically sound land management and the conservation of natural resources on golf courses. In addition, Audubon Signature Programs provide comprehensive environmental education and planning assistance to new developments.

Today, 2,114 golf courses in 38 countries participate in the ACSP for Golf Courses. More than 70% of those enrolled have developed an environmental plan to guide management of the golf course and 834 have achieved certification for their outstanding best practices.

Today, 2,114 golf courses in 38 countries participate in the ACSP for Golf Courses. More than 70% of those enrolled have developed an environmental plan to guide management of the golf course and 834 have achieved certification for their outstanding best practices. We also awarded 985 “Certificates of Achievement” to recognize golf courses for outstanding accomplishments to improve wildlife habitat, save water, conserve energy, and reduce waste.

Audubon International also provided environmental planning services to 156 projects (128 golf-related) development projects in 37 states and in 11 countries, covering more than 75,000 acres of land, through the Audubon Signature Programs in 2009/10. Three projects achieved certification, bringing the total number of golf courses that have been designated as Certified Audubon Signature Sanctuaries to 92 in 27 states and five countries.

Diamondback terrapins are small turtles that spend their lives in brackish estuaries and are listed as “Species of Special Concern” by the State of New Jersey. Excluder traps installed at Marriott's Seaview Resort and Spa protect diamondback terrapin eggs safe from golfers and predators such as fox and birds.

The voluntary environmental actions taken by members of the Audubon Cooperative Sanctuary Program for Golf Courses are indeed leading to chemical use reduction and increased safety, enhanced wildlife and habitat management, and improved water quality and conservation.

Summary Points

- ***Chemical Use Reduction and Safety***

  94% of respondents have reduced their pesticide use
  70% of respondents have reduced their pesticide costs
  96% of respondents now use pesticides with lower toxicity levels
  91% of respondents have implemented a primary and secondary spill containment systems

- ***Wildlife and Habitat Management***

  89% of respondents now use native plants when landscaping
  On average, respondents reported that they have natural vegetation around 71% of their shorelines.
  On average, respondents reported that they have added 20 acres of wildlife habitat since joining the ACSP

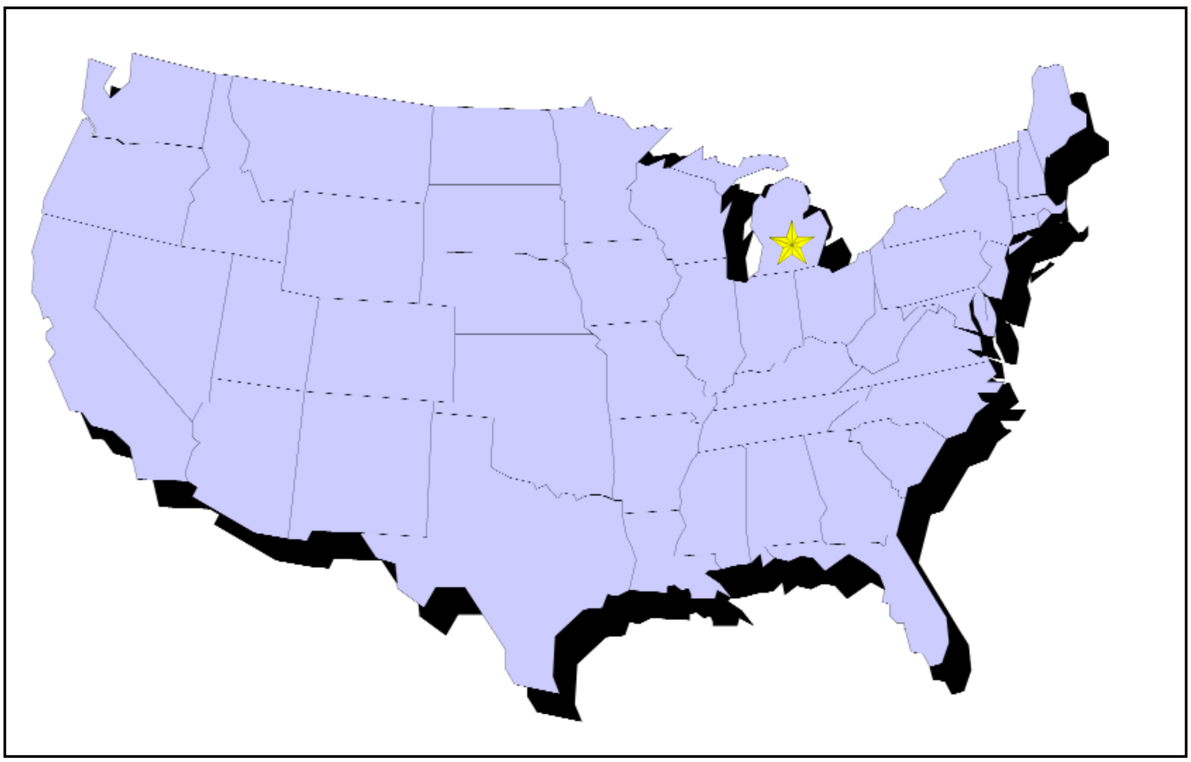
- ***Water Quality and Conservation***

  50% of respondents have removed irrigated turfgrass
  69% of respondents have improved their irrigations systems
  89% of respondents have increased their mowing heights along water bodies to filter runoff
  51% of respondents have reduced their water costs since joining the ACSP

Turfgrass Information Center

The Turfgrass Information Center (TIC), a specialized unit at the Michigan State University Libraries, contains the most comprehensive publicly available collection of turfgrass education materials in the world. TIC has more than 170,000 records in its primary database, the Turfgrass Information File (TGIF), with over 40% linked to the full-text of the item.

The aim of this ongoing project is to provide exhaustive access to the turfgrass research and management literature, regardless of age or language or format of the source material. With much of that rich heritage previously inaccessible to the majority of even heavily networked turf scientists, TGIF intends to aggressively continue to move toward providing "a turfgrass library on your desktop." And, of course, there has to be a physical turfgrass library behind the virtual one, where the cumulative record of turfgrass science is collected, preserved, and made available.



Location of the Turfgrass Information File housed in the Michgan State University Libraries in East Lansing.

The Turfgrass Information File

Peter Cookingham and Turfgrass Information Center Staff
Michigan State University

Objectives:

1. Continue to build and expand the online offerings associated with the USGA Turfgrass Information File database.
2. Index all turf-related research and management articles and reports.
3. Continue to digitize and make available additional turf research and management content from both the present and past.
4. Increase both the usability and reach of the database by turfgrass scientists, practitioners, students, and public policy decision-makers worldwide.

Start Date: 1983
Project Duration: Ongoing

Since construction started in 1984, the Turfgrass Information File (TGIF), a cooperative project of the USGA and the Michigan State University Libraries' Turfgrass Information Center, has offered access to the turfgrass literature in support of more effective turfgrass research and management. From initial print-only search results by mail or fax from the database, to dial-up access beginning in 1988, to Internet access in 1993, to World Wide Web access beginning in 1997, TGIF has steadily grown along with turfgrass science and technology advancements.

Today, turfgrass researchers and students at more than 65 subscribing academic institutions worldwide, corporate and individual subscribers, as well as professional members of the following organizations all have access to TGIF via the web:

American Society of Golf Course Architects
Asociación Española de Greenkeepers
British and International Golf Greenkeepers Association
Canadian Golf Superintendents Association
Golf Course Superintendents Association of America (Class A, SM, C, ISM, AA, or A-RT)
Midwest Association of Golf Course Superintendents
Sports Turf Association
Sports Turf Managers Association
Turfgrass Producers International
Wisconsin Golf Course Superintendents Association

Online use of TGIF data continues a trend of steady, upward growth, reflecting TGIF's fundamental role in:

- supporting more efficient and thorough support for ongoing turfgrass research,
- expanding golf course superintendents' ability to verify product claims, evaluate documented research, and quickly get up to speed on new challenges,
- permitting students to explore widely accepted concepts and practices within the turf industry,
- enabling all users to discover international diversity in turf management practices as reflected in the literature published worldwide.

Over 189,000 records have been uploaded to the Turfgrass Informationn File housed at Michigan State University's Libraries.

TGIF indexes academic journals, professional and trade magazines, organizational publications and special reports, annual research reports, government documents, theses and dissertations, book chapters and books, fact sheets, manuscripts, booklets, registration statements, CD-ROM discs, extension bulletins, etc., as well as the increasing galaxy of online materials, such as video clips, podcasts, online presentations, web documents, digitized blueprints, and webinars.

TGIF's digitization efforts began first with and feature USGA content such as:

USGA Green Section Record (1921-present)
USGA Turfgrass and Environmental Research Online (2002-present)
USGA Turfgrass and Environmental Research Summary (1983-Present)

New major digital content added in 2010 includes:

CUTT (Cornell University Turfgrass Times) in partnership with Cornell Cooperative Extension (1990-Present)
GreenKeepers in partnership with Asociación Española de Greenkeepers (1999-Present)
Sports Turf Manager in partnership with Sports Turf Association (1987-Present Less 6 Months)
SportsTurf in partnership with Sports Turf Managers Association (1985-Present Less 2 Months)
The Grass Roots in partnership with the Wisconsin Golf Course Superintendents Association (1975-Present Less 1 Month)

This work has now expanded to include materials from 19 organizational, agency, academic institutions, or individual partners from around the world. In addition, digitization of relevant turf-related theses and dissertations, and out-of-copyright or non-copyrighted classic turfgrass works are undertaken in order to permit direct access to complete content.

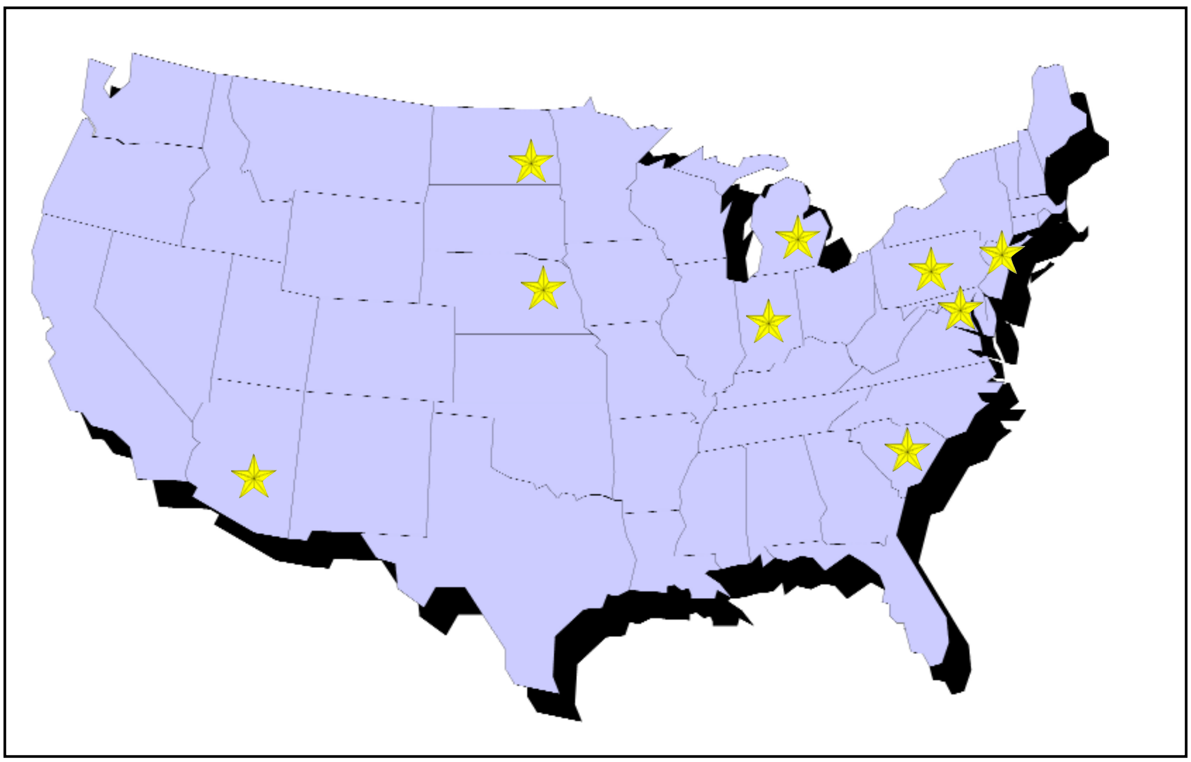
In order to build a sustainable base for all this ongoing work, the Michigan State University Libraries continue to actively seek support to build the Turfgrass Information Center Endowment to underwrite a sustainable operational base. Contributions to the Endowment from organizations, industry, foundations, other academic institutions, individual donors, and reinvested interest have pushed the current balance past $3 million, despite the economic vagaries of the past several years.

Summary Points

- Number of TGIF records: now over 189,000.
- Digitized or online periodical projects hosted in cooperation with partners: 12 public websites, with four upcoming or under construction.
- Ten additional TGIF user-accessible websites, plus the Beard Turfgrass Encyclopedia through TGIF itself.
- Different periodicals monitored routinely for TGIF inclusion (past or present): 946.
- Percentage of TGIF records now linking to full-text content: more than 44%.
- Number of 2010 TGIF search result displays: 1 million +

Grant-in-Aid Research Program

USGA's Turfgrass and Environmental Research Program relies on science to attain answers that will help ensure the long-term success of the golf course management industry. Frequently projects may span several years. Many times, however, golf course superintendents need answers to very applied problems to help them meet the many challenges of properly managing golf courses. The Grant-in-Aid Research Program was created to address this need. This program allows directors of all eight USGA Green Section regions to identify applied problems and the appropriate researchers in their regions to solve those problems. Research projects funded under this program most often include cultural aspects of golf course management. Examples include what fungicides work best on a particular disease, or the management of new turfgrass cultivars, renovation techniques, safe and effective use of herbicides, insecticides, or fertilizers. These projects are usually of short duration (1-3 years), but can offer golf course superintendents answers to practical, management-oriented challenges that they can put into use quickly.



Location of projects funded in 2011 by the USGA Turfgrass and Environmental Research Program under the Grant-in-Aid Program

Can Fungicides Mitigate Summer Stress and Mechanical Injury in an Immature Creeping Bentgrass Green?

P.H. Dernoeden and C.P. Ryan

University of Maryland

Objectives:

Evaluate Chipco Signature, Fore Rainshield, and Insignia fungicides alone or in combination for their impact on summer injury, turf color, and overall turf quality in an immature creeping bentgrass stand maintained as a putting green.

Start Date: 2011
Project Duration: 2 years
Total Funding: $6,000

The objective of this study was to evaluate the three fungicides alone or in combination for their impact on summer injury, turf color, and overall turf quality in an immature creeping bentgrass stand maintained as a putting green. The treatments were as follows: Chipco Signature 4.0 oz; Fore Rainshield 4.0 oz; Fore Rainshield 6.0 oz; Insignia 0.5 oz; and Insignia 0.9 oz/ 1,000 ft^2 applied alone or tank mixed with Fore Rainshield (4.0 oz/1,000 ft^2).

This study was conducted on an immature (i.e., < one year old) stand of an 'Penn A-1'/'Penn A-4" blend maintained under putting green conditions. June and July were very stressful with daily temperatures often exceeding 90° F and night temperatures frequently above 70° F. It also was this period when plots were frequently double-cut during the heat of the day. Temperatures moderated in mid-August and particularly following hurricane Irene on August 28. September was very cool and rainy, and there was no heat stress during the period plots were verticut August 22 and 24.

The AUQC for the period of July 15 and August 19 were most descriptive of the appearance, and therefore the visual stress tolerance, of the putting surface. These and all other data showed that Fore alone (6.0 oz.) and especially Signature + Fore were the most beneficial performance treatments during the period of excessive heat stress.

The AUIC data reflect the effectiveness of treatments in ameliorating the effect of brushing, topdressing, and vertical cutting (i.e., the mechanical stresses). As previously noted, this was performed during a period of little or no environmental stress. These data also showed that Fore (6.0 oz) alone and Signature + Fore were the most effective treatments in minimizing the effects of mechanical stress.

Fore RainShield, Signature ,and particularly Signature + Fore Rainshield effectively ameliorated environmental and mechanical stress injury as well as suppressed algal growth in an immature creeping bentgrass stand maintained under putting green conditions.

Insignia alone did improve overall quality during the period of environmental stress, but had minimal effects when subjected to mechanical stress. For unknown reasons, plots treated with the low rate of Insignia (0.4 oz) + Fore tended to out-perform the high rate of Insignia (0.7 oz.) + Fore during the period that the mechanical stresses were imposed. None of the treatments influenced root length and root surface area significantly, which was attributed to variability in sampling. Signature, Fore, and Signature + Fore reduced algal colonization, but Insignia alone did not.

It was assumed that an immature stand would be damaged more by environmental and mechanical stress than a more mature stand. The resiliency of the 'Penn A1'/'Penn A4' blend was much greater than anticipated and efforts were made to inflict stress such as reducing mowing heights while double-cutting on afternoons when air temperatures exceeded 90° F and in some cases 100° F. Plots even were topdressed and rolled on one occasion (July 27) while being double-cut at 0.130 and lowered to 0.125 inches two to three days prior and after application of the sand.

Despite these and other efforts, it was difficult to injure the stand. Hence, vertical cutting was performed in two directions in late August to inflict more injury, but at this time temperatures moderated and there was frequent overcast weather and rain. Unlike what normally would be expected, little additional data could be collected since environmental stress did not return in Sept.

In conclusion, this study confirms previous field studies conducted in Maryland, which demonstrated that Fore RainShield, Signature ,and particularly Signature + Fore Rainshield effectively ameliorated environmental and mechanical stress injury as well as suppressed algal growth in an immature creeping bentgrass stand maintained under putting green conditions.

Summary Points

- June and July 2011 were marked by extended periods of heat stress with daily air temperatures typically ≥90° F and night temperatures ≥ 70° F. August was relatively cool and rainy.
- All fungicide treatments exhibited improved turfgrass quality versus the control in June and July during periods of heat stress and double-cutting.
- Fore Rainshield alone and especially the tank-mix of Chipco Signature + Fore Rainshield provided the best combination of improved turf color and overall quality in response to heat stress, as well as the mechanical stresses imposed.
- No differences in root length or root surface area were detected among the treatments.
- Chipco Signature and Fore Rainshield reduced blue-green algal colonization, but Insignia did not.

Differentiating the Physiological Responses of Creeping Bentgrass to Carbonate, Chloride, and Sulfate Salinity

Deying Li
North Dakota State University

Objectives:

1. Understand the physiology of leaf firing in creeping bentgrass which is one of the symptoms of salinity stress.
2. Differentiate physiological responses of creeping bentgrass to different types of salinity problems, i.e. carbonate, chloride, and sulfate.

Start Date: 2011
Project Duration: 2 years
Total Funding: $6,000

Creeping bentgrass "Penncross' sod was harvested from an established putting green, washed free of soil, and planted to plastic pots 12.7 × 12.7 × 12.7 cm. The growth medium was sand that conformed to the USGA recommendations of particle sizes and had a pH of 7.09, EC (electrical conductivity) of 0.2 dS m^{-1}, and OM (organic matter) of 0.1%. The grass was mowed at 3 cm height and fertilized every two weeks at 12.2 kg ha^{-1} of N using Nusion 29-2-3 (The Andersons, Mauree, OH). At each fertilization, micronutrients also were applied using Minors Pakage 0-1-1 (The Andersons, Mauree, OH) at a rate of 4.8 L ha^{-1} of product that contains 1% P_2O_5 from phosphoric acid, 1% K_2O from potassium hydroxide, 1% Mg, 0.02% B, 2.45% Fe, 0.25% Mn, and 0.05% Zn.

Four salts (NaCl, Na_2CO_3, Na_2SO_4, and $CaCl_2$) were used in the study with NaCl at 0, 25, 75, 125, 175, 225 mM, while other salts at 0, 25, 50, 75, 100, 125 mM. The different concentration range for NaCl was used in order to achieve either a similar range of electric conductivity (EC) or osmotic potential among the four salts. The salt solutions were applied once every other day. The study was terminated when some of the treatments resulted in complete dead grass. The experiment was arranged in a randomized complete block design with three replicates.

At the same molar concentration, NaCl had the lowest EC or highest osmotic potential compared to other three salts because NaCl is a 1:1 salt with mono charge, while the others are of 1:2 or 2:1 charge ratios. The EC of NaCl at 225 mM is equivalent to $CaCl_2$ at 125 mM. The osmotic potential of NaCl at 175 mM was equivalent to other salts at 125 mM. The four salts have significant different pH.

Creeping bentgrass responded to four salts differently, including growth (clipping yield), visual quality, leaf firing (green density and green color), and evapotranspiration (ET). The plant ET decreased with the increasing salt concentration, and the greatest reduction occurred in Na_2CO_3. The decrease in ET was detected first, and as time proceed, clipping yield also decreased with increasing salt concentration. Leaf firing, as a symptom of salinity stress, resulted in decline in green leaf density, which showed increasing severity with increasing salt concentrations. Toward the end of this experiment, significant reduction of turf visual quality was observed.

Comparing the above responses at the same salt concentration, it was apparent that alkalinity mainly was responsible for the injury caused by Na_2CO_3. However, $CaCl_2$ and Na_2SO_4 injuries were contributed from high EC and alkalinity. Creeping bentgrass was sensitive to both salinity and alkalinity, because NaCl, which had lowest pH, lowest EC, and highest osmotic potential, caused least injury compared to other salts at the same concentrations.

Leaf firing increased with increasing levels of salts. However, different salts showed different symptoms. Leaf firing caused by NaCl started from young leaf tips and developed toward the base as time went on. Chlorosis caused by Na_2CO_3 started with yellowing of the whole young leaf blade and then died as time proceeded. The Na_2SO_4 injury started from the young leaves with discoloration between veins and then bleached out the leaf blade and sheath, as the process went on. Finally, $CaCl_2$ caused leaf injuries from the tips of the leaf blades and turned into straw color as died back toward the base of leaf blades.

Future work on this project will be focused on growth and physiological responses of creeping bentgrass to different salts and different concentrations.

Creeping bentgrass responded to four salts differently, including growth (clipping yield), visual quality, leaf firing (green density and green color), and evapotranspiration (ET).

Summary Points

- At the same molar concentrations, NaCl, Na_2CO_3, Na_2SO_4, and $CaCl_2$ caused different responses in 'Penncross' creeping bentgrass. All salts are not same in physiological and growth responses.
- At the same molar concentration, NaCl has the lowest pH and EC, and highest osmotic potential compared to other three. Na_2CO_3 had the highest pH among the four salts.
- Alkalinity combined with salinity caused the most leaf injury to 'Penncross' creeping bentgrass.
- The stress caused by four salts were ranked in order of Na_2CO_3, $CaCl_2$ and Na_2SO_4, and NaCl at the same molar concentration.
- Leaf firing symptoms were different on 'Penncross' bentgrass caused by NaCl, Na_2CO_3, Na_2SO_4, and $CaCl_2$.

Foliar Nitrogen Use Efficiency of Warm-Season Putting Green Turf under Salinity Stress

Haibo Liu and Nick Menchyk
Clemson University

Objectives:

Evaluate three ultradwarf bermudagrasses (*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy) 'Champion', 'Mini-Verde', 'Tif-Eagle', 'Seadwarf' seashore paspalum (*Paspalum vaginatum* Swartz.), and 'Diamond' zoysiagrass (*Zoysia matrella* (L.) Merr.) under salinity stress with two nitrogen fertility regimes and foliar and root applied N.

Start Date: 2011
Project Duration: 2 years
Total Funding: $6,000

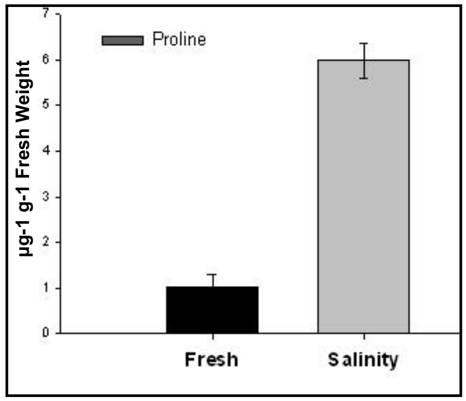
Salinity stress is a widespread turfgrass management problem in coastal areas and environments where water use restrictions are common. However, little is known about salinity stress and how it affects foliar and root fertilization of turfgrasses.

A two-year study was conducted in the greenhouse facilities at Clemson University. The objective was to evaluate three ultradwarf bermudagrasses (Cynodon dactylon (L.) Pers. X C. transvaalensis Burtt-Davy) 'Champion', 'Mini-Verde', 'Tif-Eagle', 'Seadwarf' seashore paspalum (*Paspalum vaginatum* Swartz.), and 'Diamond' zoysiagrass (*Zoysia matrella* (L.) Merr.) under salinity stress with two nitrogen fertility regimes.

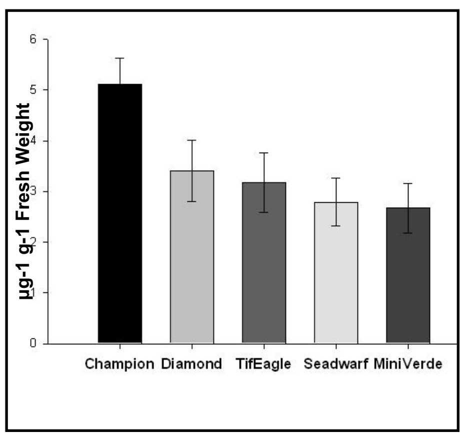
Foliar and root applications of urea-N at 9.76 kg ha^{-1} were applied weekly for 12 weeks. Two salinity levels (0 and 8,000 ppm NaCl) were applied every 48 hours to replenish ET losses. Parameters measured included turf quality, tissue nutrient content, proline accumulation, and electrolyte leakage.

Saline irrigation significantly reduced N, P, and K concentrations in leaf

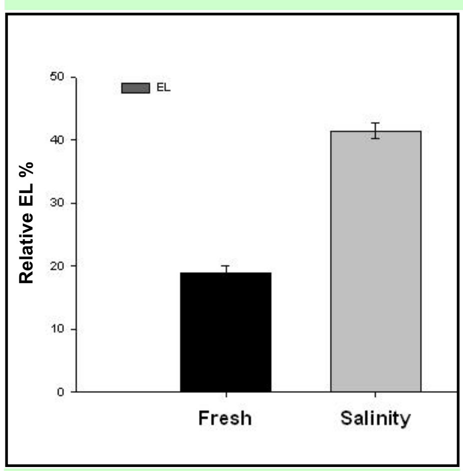
A two-year study was conducted in the greenhouse facilities at Clemson University.



Overall proline accumulation of turfgrasses grown under non-saline (fresh) versus saline (8,000 ppm NaCl) irrigation conditions.



Proline accumulation of turfgrasses irrigated under saline (8,000 ppm NaCl) irrigation conditions.



Relative electrolyte leakage of turfgrasses grown in non-saline (fresh) and salinity (8,000 ppm NaCl) irrigation conditions.

'Champion' ultradwarf bermudagrass maintained under non-saline (left) and saline (right) conditions of 8,000 ppm NaCl.

tissues at the conclusion of both years. Under salinity stress, 'Seadwarf' seashore paspalum exhibited significantly higher N, P, and Na concentrations in leaf tissues under foliar applications of urea. Tissue K concentrations in 'Champion' were reduced in the greatest amount by saline irrigation at 6 and 12 weeks in both years of the study.

By the conclusion of the study, all turfgrasses exhibited significantly higher levels of proline under salinity stress, with 'Champion' displaying the greatest increase in accumulation from > 1 µg /g FW under fresh water irrigation to over 9 µg /g FW.

Summary Points

- Turf quality and macronutrient concentration were significantly decreased by salinity stress.
- Fertility regimes of foliar or root applied N had no effect on macronutrient concentration of leaf tissue.
- Root applications of urea nitrogen significantly increased sodium concentration in leaf tissue at the conclusion of the study.
- Salinity stress significantly increased overall electrolyte leakage and proline accumulation.
- 'Champion' exhibited significantly higher proline in leaf tissue than all other species tested at the conclusion of the study.
- The correlation of Na content and proline accumulation illustrates the plant response to salinity stress.

Impact of Sand Size and Topdressing Rate on Surface Firmness and Turf Quality of Velvet Bentgrass

James A. Murphy and James W. Hempfling
Rutgers University

Objectives:

Determine the short-term effects (within the 2011 season) of sand particle size distribution and application rate on turfgrass quality and surface firmness using coarse-medium and medium-fine sands on putting green turf exhibiting a lack of firmness.

Start Date: 2011
Project Duration: 2 years
Total Funding: $6,000

Sand topdressing is expected to increase surface firmness through the bridging of sand particles within the turf canopy and surface layer of accumulating thatch. Research on fairway turf indicates that using finer sands for topdressing can provide greater firmness compared to coarse sands. However, topdressing with fine sands has been reputed to negatively affect drainage properties.

A field trial was initiated in 2010 on 'Greenwich' velvet bentgrass putting green turf and included four topdressing treatments; a coarse-medium (310) and medium-fine sand (Drier 50) were applied biweekly at 0.5 and 1 ft^3 1,000 ft^{-2}. The experimental design was a random complete block with three replications. Data collection included turf quality (9 = highest rating), turf color (9 = highest rating), sand presence (9 = no sand present), digital image analysis, post-topdressing clipping collection, volumetric water content (Field Scout TDR 300), and surface hardness [Clegg Impact Soil Tester (2.25 and 0.5 kg) and USGA TruFrim].

Substantial differences in firmness or quality were not apparent during 2010. However, all topdressing treatments displayed better turfgrass quality than the non-topdressed check by early June 2011. By the end of June 2011 and on 10 of the following 14 rating dates, a topdressing rate effect was observed. Plots topdressed at 1 ft^3 1,000 ft^{-2} exhibited better turfgrass quality than plots topdressed at 0.5 ft^3 1,000 ft^{-2} .

All topdressing treatments displayed better turfgrass quality than the non-topdressed check by early June 2011.

On 3 of the 20 rating dates in 2011, the medium-fine sand provided better turf quality than the coarse-medium sand. A significant treatment interaction on these dates indicated that topdressing needed to be applied at the higher rate to observe a difference in turf quality between the sand sizes.

There were obvious differences both years in the amount of sand remaining above the turf canopy after topdressing events. As expected, the 1 ft^3 1,000 ft^{-2} rate of topdressing and the coarse-medium sand both required more time for the sand on the turf surface to dissipate after topdressing compared to the 0.5 ft^3 1,000 ft^{-2} rate of topdressing and the medium-fine sand, respectively.

Clippings were collected on 2 dates after topdressing was applied. We are developing a method to accurately separate sand from clippings to quantify the amount of sand collected during the mowing of topdressed plots. Image analysis of digital images is also being used to document differences in the incorporation of sand into the canopy.

A second field trial was initiated in late June 2011 on annual bluegrass putting green turf. The topdressings treatments used in this trial were a non-topdressed check and three sand sizes: a medium-coarse sand (310), a medium sand [the medium-coarse sand sieved with a #35 sieve (500-µm screen) to remove coarse sand], and a medium-fine sand (Drier 50). Topdressing was applied at 0.5 ft^3 1,000 ft^{-2} every 14 days during the summer months. The experimental design was a random complete block with four replications. Data collection in this trial was similar to the velvet bentgrass trial. Additionally, anthracnose severity was evaluated every 7 to 10 days.

Data collection included surface hardness [Clegg Impact Soil Tester (2.25 and 0.5 kg) and USGA TruFrim].

All topdressing treatments exhibited better turfgrass quality ratings than the non-topdressed check on 5 of 8 rating dates. The non-topdressed treatment also had greater anthracnose disease severity on 2 rating dates compared to all sand topdressing treatments. No differences among sand sizes were observed in this trial during 2011.

Summary Points

- On velvet bentgrass turf, biweekly sand topdressing, particularly at 1 ft3 1000-ft-2, provided better turf quality compared to the non-topdressed check. On a few rating dates, plots topdressed with a medium-fine sand had better turf quality than plots topdressed with medium-coarse sand.
- Regardless of sand size, biweekly topdressing on annual bluegrass improved turf quality compared to the non-topdressed check. In addition, anthracnose disease symptoms were less severe in all topdressed plots by late summer.
- To date, we have not observed any negative effects of topdressing with finer sand on either velvet bentgrass or annual bluegrass maintained as putting green turf.

Nitrogen Requirements of Various Saltgrass Genotypes under Salt Stress Conditions

Mohammad Pessarakli
University of Arizona

Objectives:

Compare nitrogen requirements (i.e., total-N and ^{15}N absorption) of various clones of saltgrass grown under non-saline and sal-stress conditions.

Start Date: 2011
Project Duration: 2 years
Total Funding: $6,000

Saltgrass (*Distichlis spicata*) is a warm-season potential turfgrass species that has the ability to grow under highly saline conditions with limited available water sources. This characteristic could prove to be beneficial in certain turfgrass areas requiring low maintenance such as arid regions with saline soils and limited water and nutrient availability.

Various saltgrass clones were studied in a greenhouse to evaluate their nitrogen uptake under normal (control, non-saline) and saline conditions (NaCl at EC 20 dSm^{-1}) using ^{15}N in a hydroponics system. Nitrogen-15 was used to find exactly how much nitrogen was taken up and partitioned between the roots and the shoots of the grasses under salt stress and control conditions.

The plants were grown vegetatively in polyethylene tubs containing half-strength Hoagland solution. A randomized complete block (RCB) design with four replications of each treatment was used in this study. The plants were allowed to grow in this nutrient solution for 6 months to reach full maturity and develop uniform and equal plant size. During this period, shoots were harvested weekly and the clippings were discarded. At the last harvest, roots and shoots were cut to have uniform roots and shoots prior to the initiation of the salt stress phase of the study.

The salt treatments were initiated by adding NaCl to the culture solutions to raise the electrical conductivity (EC) of the solutions 5 dS m^{-1} every other day until the final EC 20 dS m^{-1} was reached. The culture solution levels in the tubs were maintained at 10 liter volume, and solution conductivity was monitored and adjusted to maintain the prescribed treatment salinity level. After the final salinity level was reached, the shoots were harvested and the harvested plant materials were discarded prior to beginning the ^{15}N treatment.

For both total-N and ^{15}N contents of the shoots, there were statistically significant differences found among the various clones under either the control or the salinity stress condition.

The ^{15}N treatment was started by adding 5 mg ^{15}N as 22.931 mg ammonium sulfate [$(^{15}NH_4)2SO_4$], 5.3% ^{15}N) per liter of the culture solution per day. After the ^{15}N addition, plant shoots were harvested weekly for determination of the ^{15}N absorption. The harvested plant materials were oven dried at 65° C and dry weights were measured and recorded. Six harvests were made. Plant shoots and roots were analyzed for total N and ^{15}N contents using an auto-analyzer and a mass spectrometer, respectively.

Except for 3 entries (clones A37, A136, and A138), the rest of the clones showed statistically no difference in their total-N contents under salinity stress as compared with the control plants. Nevertheless, all clones, except A86, had numerically lower total-N contents under salinity stress as compared with the control plants. Under the control condition, clone A138 statistically had the highest and clone A86 numerically the lowest total-N content. However, under stress condition, clone 240 had numerically the highest and clone A37 the lowest total-N content.

The ^{15}N content of the shoots did not follow the same pattern as the total-N content. For clones A37, 72, A136, A138, 239, and 240, there were statistically significant differences found in the ^{15}N contents of their shoots under salinity stress as compared with the control plants. The differences in the ^{15}N contents of the shoots of the rest of the clones were not significant between the salinized plants as compared with their corresponding controls.

Under control condition, clones A136 and A138 had statistically the highest and clone A107 numerically the lowest ^{15}N content. However, under the salinity stress condition, clones A138 and 240 had statistically the highest and clone A107 numerically the lowest ^{15}N content. As was observed for the total-N content of the shoots, all the clones, except A86, had numerically lower ^{15}N content under the salinity stress compared with the control plants.

For both total-N and ^{15}N contents of the shoots, there were statistically significant differences found among the various clones under either the control or the salinity stress condition.

Summary Points

- Most of the clones showed statistically no difference in their total-N or ^{15}N contents under salinity stress condition as compared with the control plants.
- Except for clone A86, the rest of the clones had only numerically lower total-N and ^{15}N contents under salinity stress condition as compared with the control (non-salinized) plants.
- Although the results showed satisfactory nitrogen (total-N and ^{15}N) uptake by the various saltgrass clones under this relatively high salinity stress level, there were some differences found among the various clones under both control and salinity stress conditions.

Controlling Poa annua *on Putting Green Turf in Indiana, Michigan, and Nebraska*

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Ron Calhoun and Aaron Hathaway
Michigan State University

Aaron Patton and Dan Weisenberger
Purdue University

Objectives:

Evaluate seven season-long treatments of growth regulators or herbicides to control annual bluegrass on putting greens. By completing identical studies at four locations that differ widely geographically, we are able to extrapolate our results to a large portion of the United States.

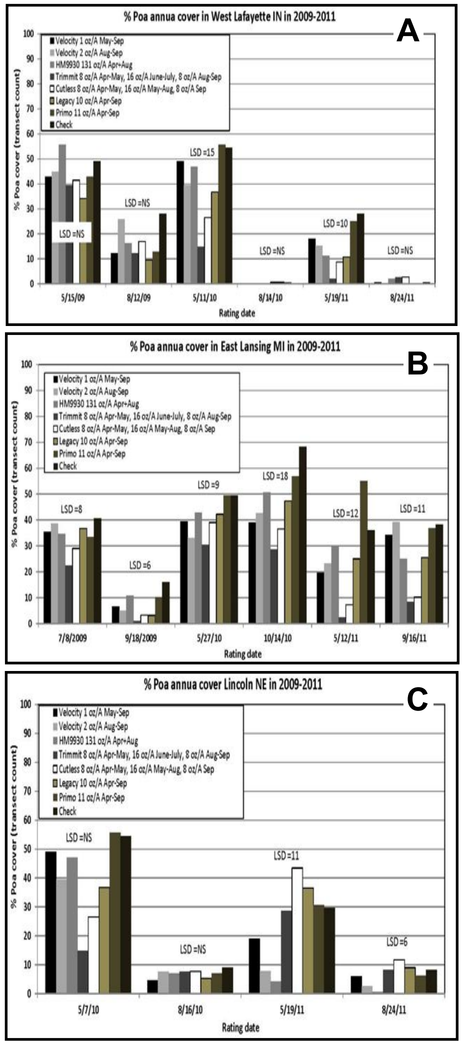
Start Date: 2011
Project Duration: 2 years
Total Funding: $18,000

Annual bluegrass (*Poa annua*) is the most troublesome and probably the most studied weed on golf courses throughout the United States. A number of herbicides and growth regulators are labeled and effective for *Poa annua* control on fairway height turf including bispyribac (Velocity), ethofumesate (Prograss), flurprimidol (Cutless), and paclobutrazol (Trimmit, TGR).

We are evaluating seven season-long treatments of growth regulators or herbicides to control annual bluegrass on putting greens. By completing identical studies at four locations that differ widely geographically, we are able to extrapolate our results to a large portion of the United States.

Plots of green-height annual bluegrass/creeping bentgrass were already established on putting greens that are mowed daily at 0.125” and sand-topdressed regularly. The areas receive 2.5 to 3.0 lbs. N/1,000 sq ft/yr. Treatments are applied in 2 gal. water/1,000 sq ft. Most of these treatments are within label limits, and are based on superintendents and label recommendations, as well as previous research experience. Treatment 3 is an experimental herbicide with potential for *Poa annua* control.

Visual quality and percent cover of creeping bentgrass and annual bluegrass are recorded monthly and transect counts are taken in mid-May and mid-August, the expected high and low points for annual bluegrass populations, respectively. The transect counts minimize subjectiveness between rates and will allow reliable comparisions between years within locations and across locations. This study has been done on the same plots in West Lafayette, IN, and East Lansing, MI, in 2009-2011,



Trimmit has been the best performer at Purdue (A), Trimmit and Cutless at Michigan State (B), HM9530 and Velocity at 1 oz./ A at University of Kentucky, and Velocity at 2 oz./A at University of Nebraska (C).

Lexington, KY, in 2009-20010, and Lincoln, NE, in 2010-2011. We expect this study to continue one more year in IN, MI, and NE.

Annual bluegrass populations naturally are at a seasonal high in April or May, drop to a seasonal low in August and then return to a seasonal high the following spring. Our data show that regardless of treatment, annual bluegrass cover dropped dramatically over the summer to almost insignificant populations. Therefore, one could deduce incorrectly that their strategy is working if no untreated area for comparison is included on the course.

Annual bluegrass control was highly variable from location to location and among years. Though data were recorded on 72 dates over the four locations and three years, treatment differences were only evident on 44 of the dates. This suggests that regardless of the control regime attempted, the superintendent will not see any detectable differences on 40% of the days the greens are examined. Therefore if an annual bluegrass control program is attempted, it is critical to manage expectations of the staff and other decision makers who might expect dramatic results.

The three best treatments improved annual bluegrass control vs the untreated check on 36% of the rating dates over the four locations and three years. Velocity at 2 oz./A applied 4 times, Trimmit, and Cutless were the best performers across all years and locations.

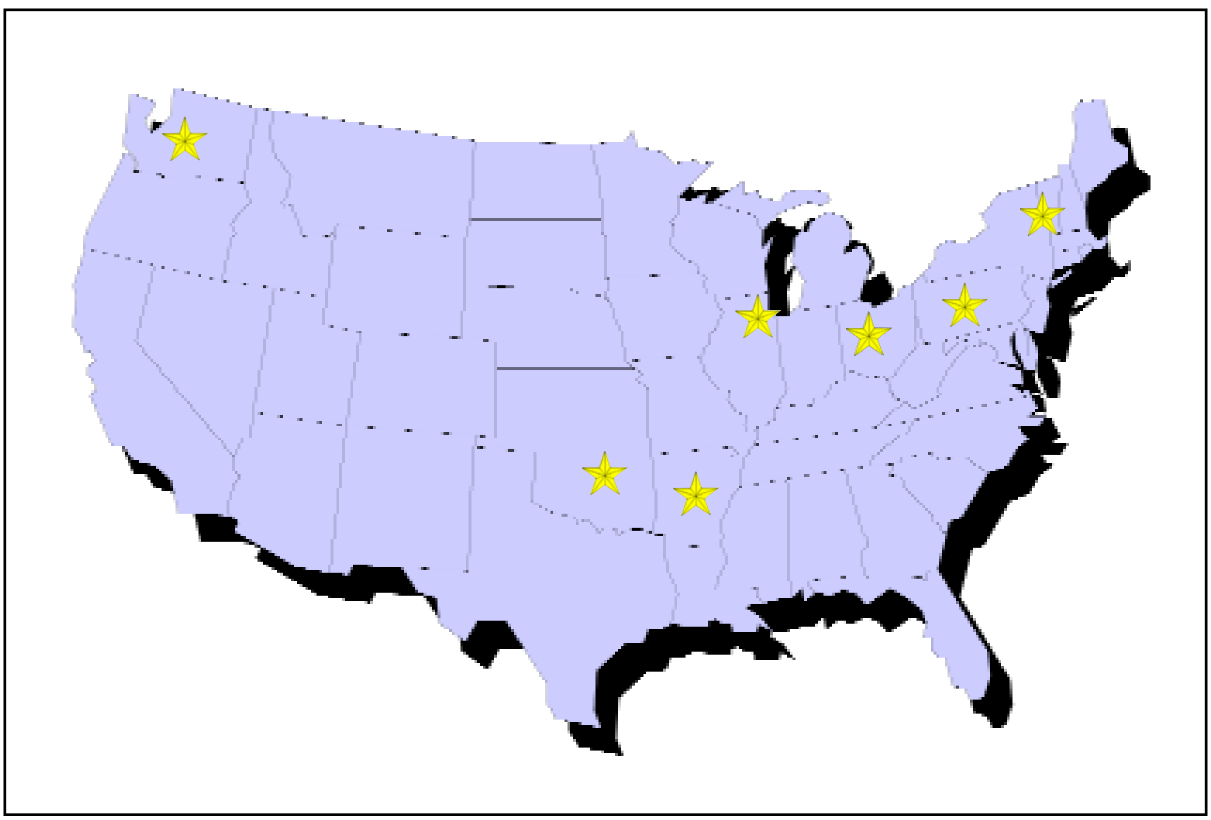
Within locations, Trimmit has been the best performer at Purdue, Trimmit and Cutless at Michigan State, HM9530 and Velocity at 1 oz./ A at University of Kentucky, and Velocity at 2 oz./A at University of Nebraska. These results not only help explain the highly variable anecdotal results from superintendents across the country, but also suggest that a superintendent may have to experiment to find the best treatment for controlling annual bluegrass on a particular golf course. ..

Summary Points

- Velocity at 2 oz/A applied 4 times, Trimmit, and Cutless were the best performers across all years and locations.
- Within locations, Trimmit has been the best performer at Purdue, Trimmit and Cutless at Michigan State, HM9530 and Velocity at 1 oz./ A at University of Kentucky, and Velocity at 2 oz./A at University of Nebraska.

Product Testing Program

Every year golf course superintendents are introduced to new products in the marketplace. Without results from properly designed, objective research, superintendents are asked to make buying decisions based on word-of-mouth, previous experience from colleagues, or recommendations of the product representation. Several surveys indicate that golf course superintendents desire side-by-side product evaluations to assist them in making product purchases. The result of this desire for this type of information is the Product Testing Program section of USGA's Turfgrass and Environmental Research Program. Currently, USGA is funding one project that falls into this category of USGA-supported research, including cooperators at sites across the country (see map below).



Locations of projects funded in 2011 by the USGA Turfgrass and Environmental Research Program under the category of Product Testing

Managing Phosphorus Export from Golf Courses Using Industrial Byproducts as Filter Materials

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USDA-ARS

Aleksandra Drizo
University of Vermont

Objectives:

This project will investigate the ability of industrial byproducts, namely steel slag, activated carbon, and biochar, to remove excess P in golf course effluent. Various blends of the byproducts and filter casing designs will be investigated to determine optimal conditions for P removal.

Start Date: 2011
Project Duration: 2 years
Total Funding: $20,000

Each tile was filled with 28.5 kg of steel slag that was previously removed of fines with a U.S. Standard Mesh #16, 18 mm sieve.

Golf courses, and in particular the tees, fairways, and putting greens, are vulnerable to loss of phosphorus (P) as dissolved reactive P (DRP) through sandy, porous grass rooting media and subsurface tile drainage. Excess levels of phosphorus in surface waters promotes eutrophication, which, in turn, can have significant ecological, commercial, and public health ramifications for affected waterbodies .

In the past 25 years, sorption and precipitation of dissolved P using industrial byproducts and natural materials has received considerable attention. In the current study, we used steel slag as the primary P filter after trials runs with different blends of industrial byproducts proved it to be the most effect at capturing dissolved P.

A 30.5-cm (12-inch) subsurface pipe with flow control structure was installed to route irrigation reservoir water at the western edge of the course through two, 200-cm (78.7 in) long, 10.2-cm diameter corrugated black tiles. Each tile was filled with 28.5 kg of steel slag that was previously removed of fines with a U.S. Standard Mesh #16, 18 mm sieve. The pore volume of the material was 6.5 L. Flow into the tiles from the 30.5 cm pipe was regulated using in-line, adjustable, gated valves.

Flow through the tiles was recorded at the outlet of each tile using Thel-mar compound v-notch weirs in conjunction with Isco flow meters. Water samples to be analyzed for DRP were collected prior to filter interaction and 1 – 30 seconds post filter depending upon flow rate. Both continuous flow and storm-simulated samples were collected. Continuous flow samples were 1-2 times a week for a 7 week period. Two 4 hr storm simulations each were conducted within the 7 week period.

A subsurface pipe with flow control structure was installed to route irrigation reservoir water at the western edge of the course through two corrugated black tiles.

Summary Points

- Of all the samples processed, approximately 93% of samples had DRP concentrations greater than or equal the 0.03 mg/L DRP threshold known to promote eutrophication.
- Average DRP reduction across all continuous and storm-simulated conditions was 56.4% ± 5.1%. For continuous flow samples, which averaged a flow-rate of 0.012 L/second mean reduction in incoming DRP was 79.6% ± 21.6%. The large variation in the mean value is a consequence of the slag's decreasing ability to remove DRP over time because of the occupation of DRP sorption/precipitation sites.
- The two storm simulations averaged a flow of 0.74 L/s and a mean reduction in DRP by 51.5% ± 3.3%. While DRP reduction for the storm simulation appears to have remained constant, it is also expected to decrease with time.
- For both continuous flow and storm events, pH and electrical conductivity of the slag filtered effluent did not differ significantly from the pre-filter samples. In contrast, it appears that the slag reduced the total suspended solids (TSS).

Evaluation of an Inorganic Soil Amendment to Reduce and Manage Fairy Ring Symptoms in Turfgrass

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Derek Settle
Chicago District Golf Association

Henry Wetzel
Sustainable Pest Management

Objectives:

Evaluate chemical and cultural treatments to manage fairy ring symptoms on fairway turf.

Start Date: 2011
Project Duration: 3 years
Total Funding: $29,250

Fairy ring is an enigma because we do not exactly know how to choose a fungicide for it. Why? Multiple fungi cause this disorder of turf and so location to location the causal organism will vary. Fairy ring are several soilborne fungi of a group called Basidiomycetes. Some produce mushrooms–Agaricales. Some produce puff balls–Lycoperdales. Fairy ring on Chicago golf greens are most always associated with the puffball types. More research is needed, but multiple studies have yielded a couple of important facts on strategies for fairy ring suppression on golf greens in Chicago. Fairy ring development can be sporadic.

Alternatives and fungicides were evaluated to suppress active fairy ring on number 5 fairway, at Biltmore Country Club, in N. Barrington, IL; a northwest Chicago suburb. The fairway is located on an area of clay soil and the playing surface is primarily bentgrass (*Agrostis stolonifera*), but has a level of *Poa annua* ,as well.

Fairy ring are several soilborne fungi of a group called Basidiomycetes. Some produce mushrooms–Agaricales. Some produce puff balls–Lycoperdales (shown above).

The turf was mowed 2-3 days weekly to a height of 0.5 inches and fertilized with a total of 2.25 lb. granular and 0.5 lb.liquid N/1,000 ft^2 during the season. Individual plots were 4 ft x 6 ft and arranged in a randomized complete block design that used 4 replications.

Number	Treatments and Rate (per 1,000 sq ft)
1	Untreated (Healthy Turf) ….
2	Untreated (Fairy Ring Affected) ….
7	Revolution 6.0 fl oz Wetting agent
10	Aeration
11	Aeration + Renovate Plus 25 lbs
12	Aeration +Renovate Plus 25 lbs + Revolution 6.0 fl oz
13	Aeration +Revolution 6.0 fl oz + Prostar 4.5 oz
14	Aeration + Renovate Plus 25 lbs + Revolution 6.0 fl oz +Prostar 4.5 oz
15	Blue XL w/ Bio□Cat Booster 4.5 fl oz + Huma□MnFe 2.3 fl oz +H20 rx 0.8 fl oz +Root and Groom 1.5 fl oz
16	Prostar 4.5 oz Fungicide
17	HeritageTL 2.0 fl oz Fungicide

Some of the chemical and cultural treatments applied to manage fairy ring symptoms at the Biltmore country Club, N. Barrington, IL.

Fairy ring symptoms and puff balls were visible on July 18 when the first and only applications occurred. A total of 17 treatments were used. Granular treatments were carefully spread on individual plots by hand. All liquid treatments were delivered using a CO_2-powered backpack sprayer with 8004 TeeJet flat fan nozzles at 40 psi in water equivalent to 2 gal./1,000 ft^2.

Immediately following application, all treatments were watered in by hand with 0.1 to 0.2 inches of water. As needed, a Toro ProCore 648 aerifier with needle tines was used. Fairy ring was visually evaluated per plot as percent area affected, number of rings per plot, and color intensity (0-4, with 4 dark green). Normalized Difference Vegetation Index (NDVI) was taken using 2 subsamples per plot with the handheld Field Scout TCM 500 (Spectrum Technologies, Plainfield, IL).

Visual quality was rated (1-9 scale, where 1 = entire plot area brown or dead; 6 = minimum acceptable color and quality for a putting green in summer; and 9 = optimum greenness, texture and density) to monitor for acceptable quality and quantify any phytotoxicity. On July 27, soil samples were taken using a 0.75-inch diameter probe to a 2-inch depth. The upper verdure and thatch of each core was discarded.

Summary Points

- Fairway flooding on July 23 caused an aggressive outbreak of type II fairy ring with puff balls to suddenly end. Redevelopment did not occur.
- At study start on July 18, range of a type II fairy ring averaged from 6% to 20% across treatment plots.
- On one date, August 4, certain treatments reduced brown patch.
- No statistical differences existed on any date for visual quality and NDVI. Plant health data did show treatments were safe as no phytotoxicity occurred.
- Across all soil parameters tested 9 days after treatment, only nitrate N showed differences among treatments and ammonium N showed similar trends.

Improving Turf Quality During Tournament Preparation through Ethylene Inhibition

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University of Arkansas

Objectives:

1. Examine the growth of creeping bentgrass in an ethylene-enriched environment to determine if ethylene has a negative effect on turfgrass similar to other plants.
2. Determine the phytotoxicity of AVG (aminoethoxyvinylglycine hydrochloride) to creeping bentgrass putting green turf.
3. Determine if applications of AVG to stressed creeping bentgrass putting greens will reduce the decline in turfgrass quality and improve recovery.

Start Date: 2011
Project Duration: 2 years
Total Funding: $17,250

Little is known about the effects of direct ethylene exposure to turfgrass. In previous research, ethylene production was measured and correlated to other measurements such as turfgrass quality. However, there is a possibility that even though ethylene levels were elevated, other factors may have caused the decline in turfgrass quality. The effects of direct ethylene exposure to creeping bentgrass have not been demonstrated.

Creeping bentgrass plugs from an established creeping bentgrass green were harvested and acclimated in a greenhouse for two weeks. Afterwards, the plugs were sealed in glass jars and subjected to ethylene levels of 0, 100, 250, 500, ,1000, 1,500, 2,500, 5,000, 7,500, 10,000, and 15,000 ppm for a period of three hours. Gas chromatography was used to determine actual ethylene concentration at the conclusion of the three hours or exposure. Digital image analysis was used to evaluate turfgrass color. Regression analysis determined that no significant relationship existed between turfgrass color and ethylene exposure.

Creeping bentgrass plots treated with varying rates of AVG.

Aminoethoxyvinylglycine hydrochloride (AVG) is a naturally occurring compound from the process of fermentation that inhibits the production of ethylene in plants through reducing enzyme activity within the Yang cycle. Previous research has indicated that AVG was effective in preventing temperature stress-related injury and ethylene production on creeping bentgrass grown in a growth chamber, and the results from the study indicated that AVG could be used to prevent injury. However, the study had limited detail on the amount of AVG that could safely be applied to creeping bentgrass, or more importantly, how safe AVG was on creeping bentgrass being maintained as a putting green. Therefore, the objective of this study was to determine maximum application rates for AVG on creeping bentgrass putting greens that would not produce phytotoxicity.

The results of this study indicated that higher rates of AVG (> 0.3 pounds per acre) were phytotoxic at 4, 7, and 14 days after treatment, but symptoms of injury were not present after 21 days. The lower rates (<0.3 pounds per acre) did not cause any injury to the turf. When injury ratings were averaged over the entire 28-day evaluation period, AVG application ratings were not significantly different.

Creeping bentgrass is often used in areas of the United States, such as the transition zone, that are outside the optimum temperature range for the species. Recent studies have shown that under high temperature stress, the production of the plant stress hormone ethylene was increased in creeping bentgrass in a growth chamber. In addition, other stressors such as wounding have been shown to stimulate ethylene production in many plants.

Tournament conditions in putting green management in places where high temperature stress is prevalent may be

Apparatus for determining the effects of ethylene exposure to creeping bentgrass.

some of the most stressful conditions for turf. During tournaments, mowing heights are lowered, mowing frequency increased, light weight rolling is added, and irrigation is reduced to produce hard and fast putting surfaces. However, these practices are detrimental to the overall quality of the turf and slow the recovery afterwards.

No significant differences were noted across any treatments from applications of AVG or the untreated control for turfgrass quality, color, relative chlorophyll content, or tiller density. The lack of differences may be attributed to a cooling of temperatures over the evaluation period.

Summary Points

- To date, no effects of exogenous ethylene on creeping bentgrass have been demonstrated.
- Applications of the ethylene inhibitor, AVG at rates < 0.3 lb / acre did not produce any phytotoxic injury symptoms on creeping bentgrass putting green turf.
- To date, applications AVG have had no effect on the quality of creeping bentgrass when managed under stressful conditions.

Development of Phosphorus Filtering Systems for Environmental Protection

Chad J. Penn and Gregory E. Bell
Oklahoma State University

Objectives:

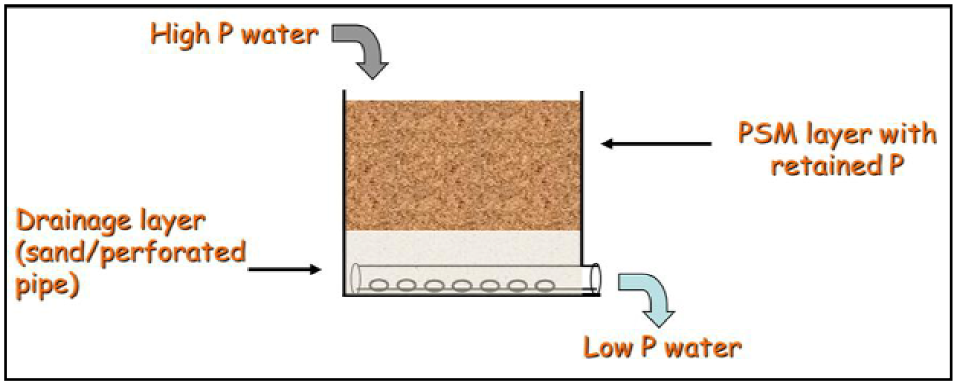
1. Test steel slag material for its dissolved P-reduction potential in both active and passive filtering systems.
2. To determine approximately how much runoff P from a mature bermudagrass site is due to natural causes (rainfall, soil, plant material) and how much can be attributed to synthetic fertilizer.
3. To identify standard expectations for use in evaluating P-sorbing materials.

Start Date: 2011
Project Duration: 2 years
Total Funding: $20,000

Excessive concentrations of phosphorus can cause deterioration of surface waters through eutrophication. A traditional method for reducing dissolved phosphorus (P) is to apply P-sorbing materials (PSMs) directly to targeted water bodies. However, the effects of surface applied PSMs are often temporary since sorbed and precipitated P can desorb and dissolve with time.

Industrial byproducts have been considered for use as P-sorbing materials. Industrial byproducts show promise for removal of dissolved P when used as filtering components in filter structures. Filter structures have advantages compared to surface applied P-sorbing materials. The structure can separate dissolved P from runoff, and the saturated P-sorbing material can be removed from the site and replaced with fresh PSM when necessary. These byproducts may work equally well when used to fill runoff collection trenches in locations where a trench would be more effective than a ditch filter. The PSMs may also have potential for replacing the typical gravel used to surround subsurface drain pipes.

Plastic containers in half the experimental units will be filled with pea gravel instead of slag for use as an experimental control.



Filter structures have advantages compared to surface applied P-sorbing materials. The structure can separate dissolved P from runoff, and the saturated P-sorbing material can be removed from the site and replaced with fresh PSM when necessary.

The study is proceeding at the OSU Turfgrass Runoff Research Site. Each of 12 plots measures 17 ft. x 35 ft. and is supported by its own automatic sampler and flow meter. Plastic containers filled with steel slag are placed in trenches at the bottom of 'U3' bermudagrass [*Cynodon dactylon* L. (Pers.)] plots located on a 5% slope.

Plastic containers in half the experimental units will be filled with pea gravel instead of slag for use as an experimental control. Studies are initiated when either natural rainfall or irrigation runoff collects in the tubs. Runoff is collected and filtered then conducted by subsurface drain pipes to Parshall flumes. Isco 6700 series (Isco, Lincoln, NE) automatic samplers measure flow rates each minute and collect filtered runoff samples every 5 minutes. Pre-filtered runoff is collected continuously before it flows into the filter structure.

Preliminary testing has focused on determining whether or not washed river gravel is an effective non-P-removing control for comparison with a steel slag PSM. Runoff collected in empty trenches was compared with runoff collected in gravel-filled trenches. Plots were not fertilized nor had they been fertilized for at least two years prior to this portion of the study. By September 17, 2011 runoff from four simulated runoff events caused by sprinkler irrigation and one natural rainfall event were collected.

Statistical comparisons of each runoff event indicated that the empty and gravel-filled trenches did not differ in P concentrations in runoff suggesting that the gravel had no ability to filter P. A single natural rainfall event approximately 10 hours after the application of P fertilizer occurred on September 22, 2011. Statistical analysis of that event indicated that P concentrations in runoff from fertilized plots were significantly greater than non-fertilized plots, but P concentrations in runoff from empty trenches did not differ from P concentrations in runoff from gravel-filled trenches.

Summary Points

- Construction of filter sites on the existing OSU Turfgrass Runoff Research Site was completed in Aug 2011.
- Preliminary tests in September and October indicated that ½-inch river gravel could be used as an effective control for testing steel slag as a PSM.
- Phosphorus in runoff from fertilized plots was substantially greater than that from non-fertilized plots when an application of 0.44 lb. P in superphosphate form was followed by a severe storm approximately 10 hours later.