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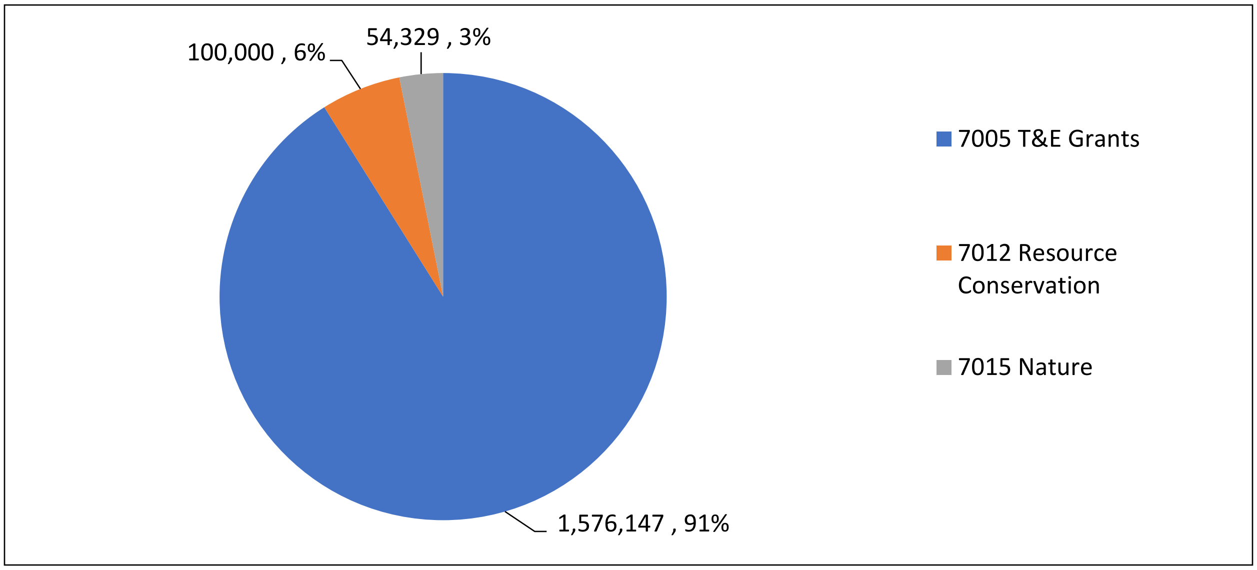
Turfgrass and Environmental Research Program

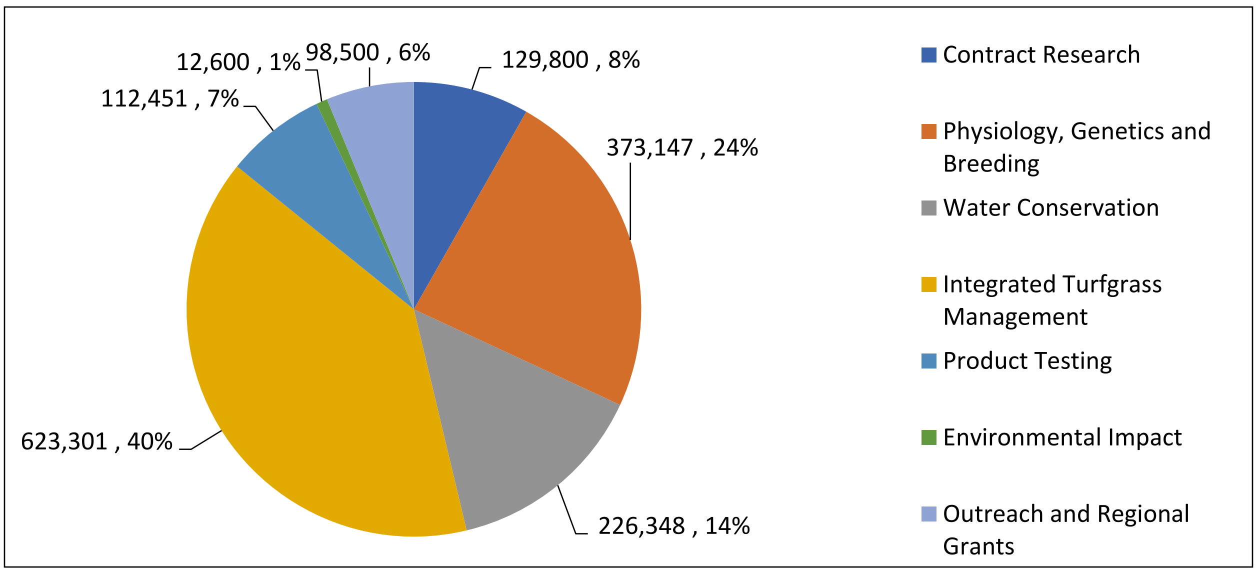
2017 Research Summaries

CONFIDENTIAL – NOT FOR PUBLICATION

Green Section Research Grants - 2017



Turfgrass and Environmental Grants - 2017



Turfgrass & Environmental Research	2016	2017	2018
Contract Research	84,000	129,800	169,797
Physiology, Genetics and Breeding	372,343	373,147	321,829
Water Conservation	100,087	226,348	291,750
Integrated Turfgrass Management	654,656	623,301	615,756
Product Testing	118,586	112,451	95,878
Environmental Impact	30,000	12,600	41,224
Outreach and Regional Grants	96,000	98,500	44,500

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1. Physiology, Genetics, and Breeding

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 will be directed toward the development of turf cultivars that conserve natural resources by requiring less water, and fewer pesticides and fertilizers. Research projects that apply new biotechnological methods toward turfgrass improvement will be considered. Among the characteristics most desirable in the new turfgrasses are:

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

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

Topic **Pg.**

1983-01-001

Project Title: Breeding and Evaluation of Kentucky Bluegrasses, Tall Fescues, Fine Fescues, Perennial Ryegrasses, and Bentgrasses for Turf

Project Leaders: William A. Meyer and Stacy A. Bonos

Affiliation: Rutgers University

Objectives:

1. Collect and evaluate useful turfgrass germplasm and associated endophytes.

2. Continue population improvement programs to develop improved cool-season cultivars and breeding synthetics.

3. Develop and utilize advanced technology to make current breeding programs more effective and efficient.

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

As of October 30, 2017 over 2543, promising turfgrasses and associated endophytes were collected in Corsica, Sardinia, Guernsey, Jersey, Hungary and Romania These are having seed produced in the Netherlands and will be evaluated in New Jersey starting in fall 2017. Over 8,107 new turf evaluation plots, 139,345 spaced-plant nurseries plants and 10,000 mowed single-clone selections were established in 2017.

Over 200,000 seedlings from intra and inter-specific crosses of Kentucky bluegrass were screened for promising hybrids under winter greenhouse conditions andthe superior plants were put into spaced-plant nurseries in the spring. Over 38,770 tallfescues, 7,000 Chewings fescues, 4,000 hard fescues, 43,500 perennial ryegrasses and5,000 bentgrasses were also screened during the winter in greenhouses and superiorplants were put in spaced-plant nurseries. Over 85 new inter- and intra-specific Kentuckybluegrasses were harvested in 2017.

The following crossing blocks were moved in the spring of 20 I7: 2 hard fescues (45 plants), 4 Chewings fescues (101 plants), 11 perennial ryegrasses (437 plants), 17 tall fescues (574 plants), 6 creeping bentgrasses (97 plants),6 velvet bentgrasses (183plants) and 6 colonial bentgrasses (169 plants).

The breeding program continues to make progress breeding for disease resistance and improved turf performance. New Promising varieties named and released in 2017 were Shield, Furlong. Umpqa, Monsieur and Xcellerator perennial ryegrasses, new tall fescues were Trinity, Selkirk, Leonardo, Rockwell, Fantasia, Michelangelo. Reflection, Motiff, Valyrie LS and Bloodhound. There was also one creeping red fescue named Marvel. There was two new creeping bentgrasses named Chinook and Cohoo.

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 releaseof top performing varieties in the NTEP
- Five perennial ryegrasses, 10 new tall fescues, 1 fine fescue, and 2 creeping bentgrasses in 2017
- Published or have in press over 5 referred journal articles in 2017
- 20 Plant variety certificates issued and 14 PVP's applied for in 2017.

Figure 1. Hybrid Kentucky bluegrass nursery in Freehold, NJ.

Figure 2. Hard fescue nursery in Freehold, NJ.

2013-02-463

Project Title: Germplasm Improvement of Low-Input Fine Fescues in Response to Consumer Attitudes and Behaviors

Project leader: Eric Watkins

Affiliation: University of Minnesota

Objective:

The long-term goal of this project if the development of improved, low-input fine fescue cultivars that provide economic and environmental benefits for the public.

Start Date: 2012
End Date: 2017
Total Funding: $50,000

This project provided matching funds for a five-year USDA-NIFA project funded by the Specialty Crop Research Initiative (grant number 2012-51181-19932). The project involved 10 scientists, along with graduate students and support staff, from three universities (University of Minnesota, Rutgers University, and the University of Wisconsin). Our group now includes researchers from Purdue University, Oregon State University, and the USDA-ARS in a new project to continue theses efforts. We recently received a $5.4 million grant, Increasing Low-Input Turfgrass Adoption Through Breeding, Innovation, and Public Education, from the U.S. Department of Agriculture's National Institute of Food and Agriculture to continue our work on increasing the availability and use of low-input fine fescues. Below are summaries from some of our research objectives for this just-concluded project.

Barriers to public land managers (led by Kristen Nelson, Minnesota): We investigated how public land managers in urban and suburban areas make decisions about vegetation management; in particular we were interested in their attitudes about the use of low-input turfgrasses such as the fine fescues. Primary challenges we identified were turfgrass maintenance, funding, public awareness, and natural vegetation management. As environmental challenges are increasingly addressed on the local scale, public land managers must be given the support, resources, and flexibility to introduce new practices such as use of lower input turfgrasses.

Industry and homeowner assessment (led by Chengyan Yue, Minnesota): We assessed both industry stakeholders and consumers about turfgrass trait preferences. The most important trait clusters for both breeders and distributors were abiotic stress resistance and growth characteristics. Breeders were more likely than distributors to select traits related to appearance when setting traits priorities. In general, we found that consumer-driven forces (i.e., turfgrass users and marketing companies) had positive impacts on the breeders' likelihood of selecting the studied traits. We also conducted choice experiments to elicit consumer willingness to pay for various consumer traits. We found both US and Canadian participants were willing to pay the highest premium for better ability to withstand foot traffic, followed by low mowing frequency, low fertilizer requirement, and low water usage. This analysis can help turfgrass breeders and industry supply chain members better understand the market potential for low-input turfgrasses.

Traffic (led by Jim Murphy, Rutgers): A major concern for turfgrass managers considering increasing their use of fine fescues is the ability of these grasses to withstand wear and traffic; this is especially of concern to golf course superintendents who might want to use fine fescues on fairways. We have determined better methods for researchers to select traffic and wear tolerant fine fescues. This new information can be utilized in breeding programs so that consumers can be provided with improved cultivars.

Heat Stress (led by Bingru Huang, Rutgers): Heat stress limits the use of fine fescues in some part of the U.S. We completed several experiments studying the heat stress tolerance of fine fescues (Figure 1). In the first, we examined whether heat or drought stress is more detrimental to fine fescues and found that heat stress is more detrimental. In the second study, we examined differential changes in membrane constituents in response to heat stress in hard fescue and identified major membrane constituents associated with stress response. The objective of the third study was to identify amino acids and soluble proteins associated responses to heat stress. Finally, in our fourth study, we assessed genetic variations in the transcript levels of selected genes in fine fescue cultivars differing in heat tolerance, and identified single nucleotide polymorphism (SNP) markers associated with candidate genes related to heat tolerance that can be utilized in turfgrass breeding programs.

Fine Fescue Diseases (led by Paul Koch, Wisconsin and Bruce Clarke, Rutgers): Fine fescue resistance to various snow mold pathogens was investigated in both field (New Jersey and Wisconsin) and controlled environment chamber settings. In general, the hard fescue cultivars exhibited the greatest resistance to both pink snow mold (Figure 2) and gray snow mold while the Chewings fescue cultivars exhibited the greatest susceptibility. Cultivars of slender and strong had intermediate levels of resistance. Turfgrass managers in areas where snow molds are a concern should utilize hard and sheep fescues, while breeders should work to make improvements in diseases resistance in the other fine fescues species.

We have also identified summer patch, caused by *Magnaporthiopsis meyeri-festucae*, as a major disease of hard fescue; in fact, this disease may severely limit use of this species in certain parts of the US. Through single plant field evaluations (Figure 3), we identified sources of resistance to this pathogen and these materials are now being used in additional studies.

Summary Points

- Primary challenges to public land managers in using fine fescues include turfgrass maintenance, funding, public awareness, and natural vegetation management.
- Consumers were willing to pay the highest premium for better ability to withstand foot traffic, followed by low mowing frequency, low fertilizer requirement, and low water usage.
- Heat stress is more detrimental than drought stress to fine fescues and there is great variation for heat tolerance.
- Hard and sheep fescue have superior snow mold resistance compared to other fine fescues and should be utilized in northern climates where snow mold is a concern.
- Summer patch may severely limit the use of hard fescue in some areas.

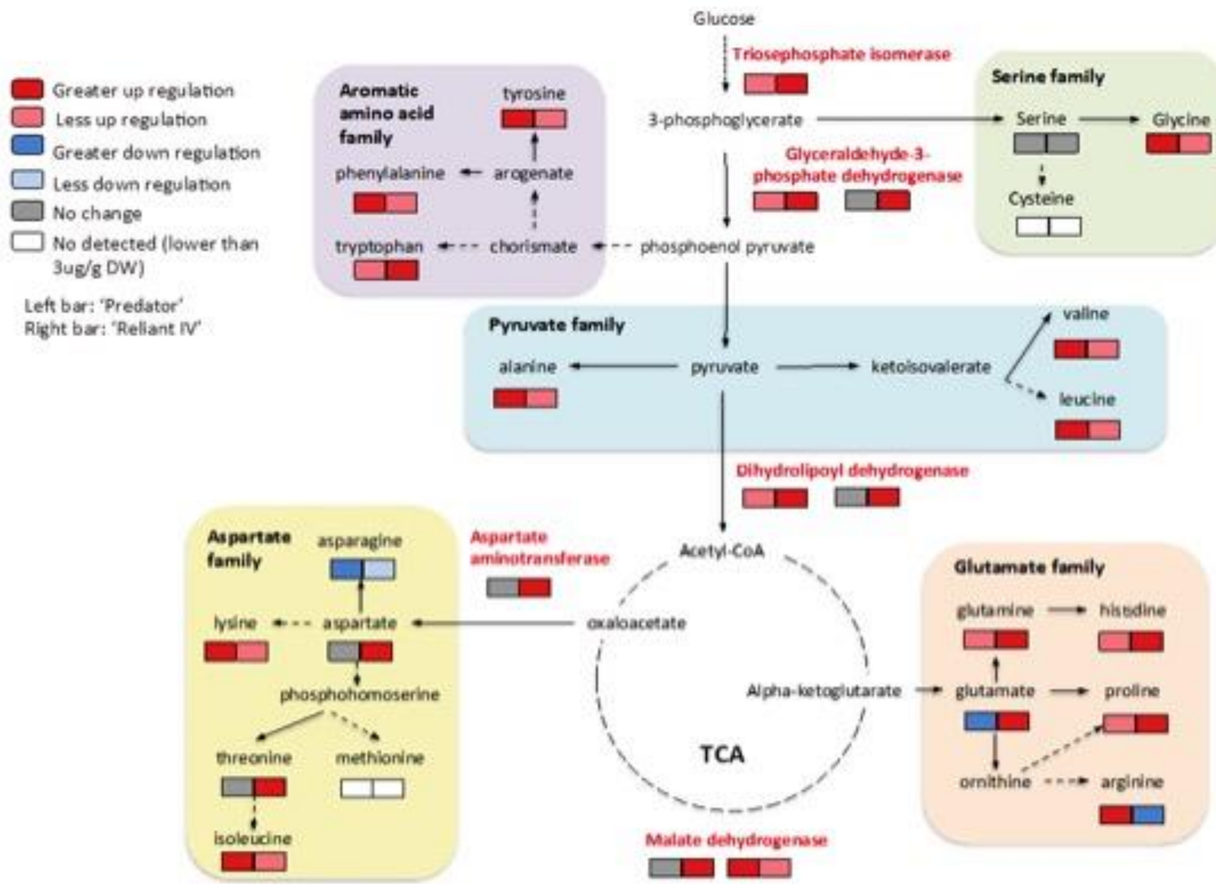

Figure 1: Heat-tolerant 'Reliant IV' and heat-sensitive 'Predator' hard fescue exhibit differential accumulation of metabolites in different metabolic pathways in response to heat stress.

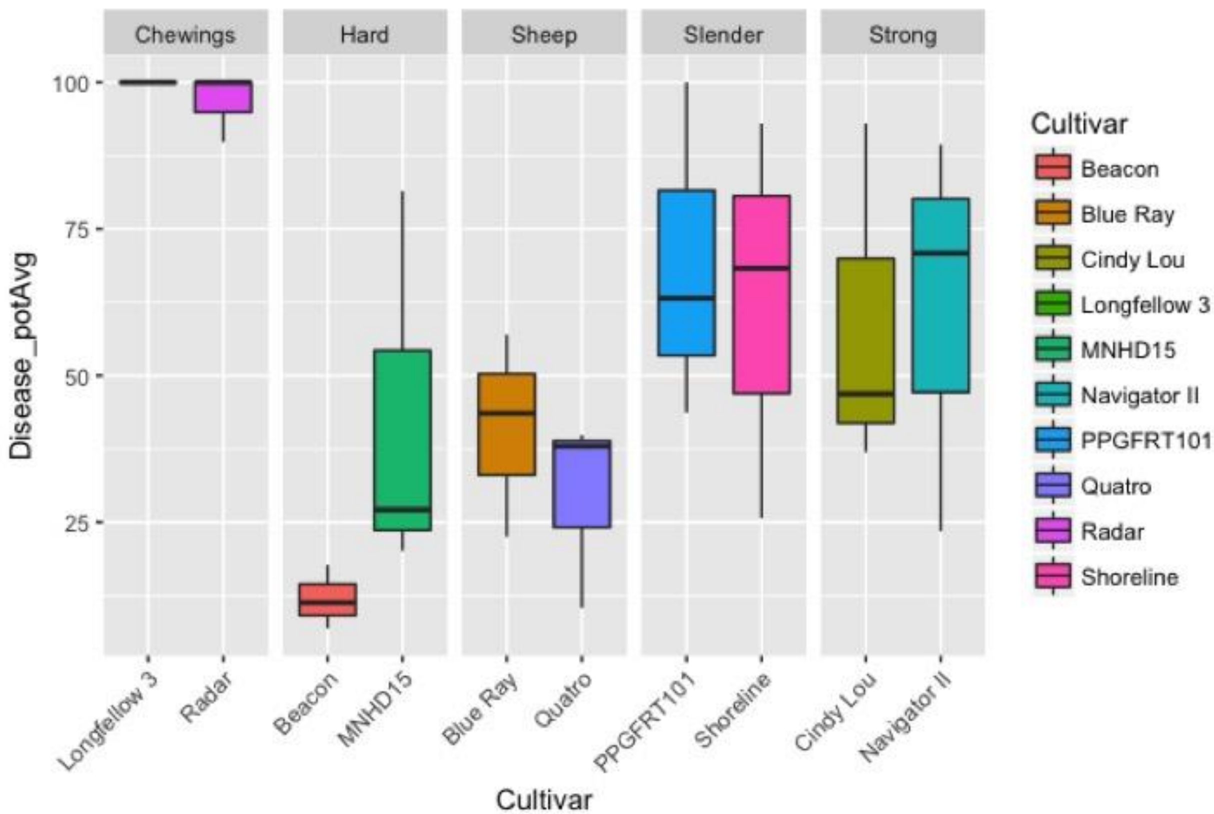

Figure 2: Microdochium patch severity as assessed on inoculated fine fescue cultivars in a controlled environment chamber.

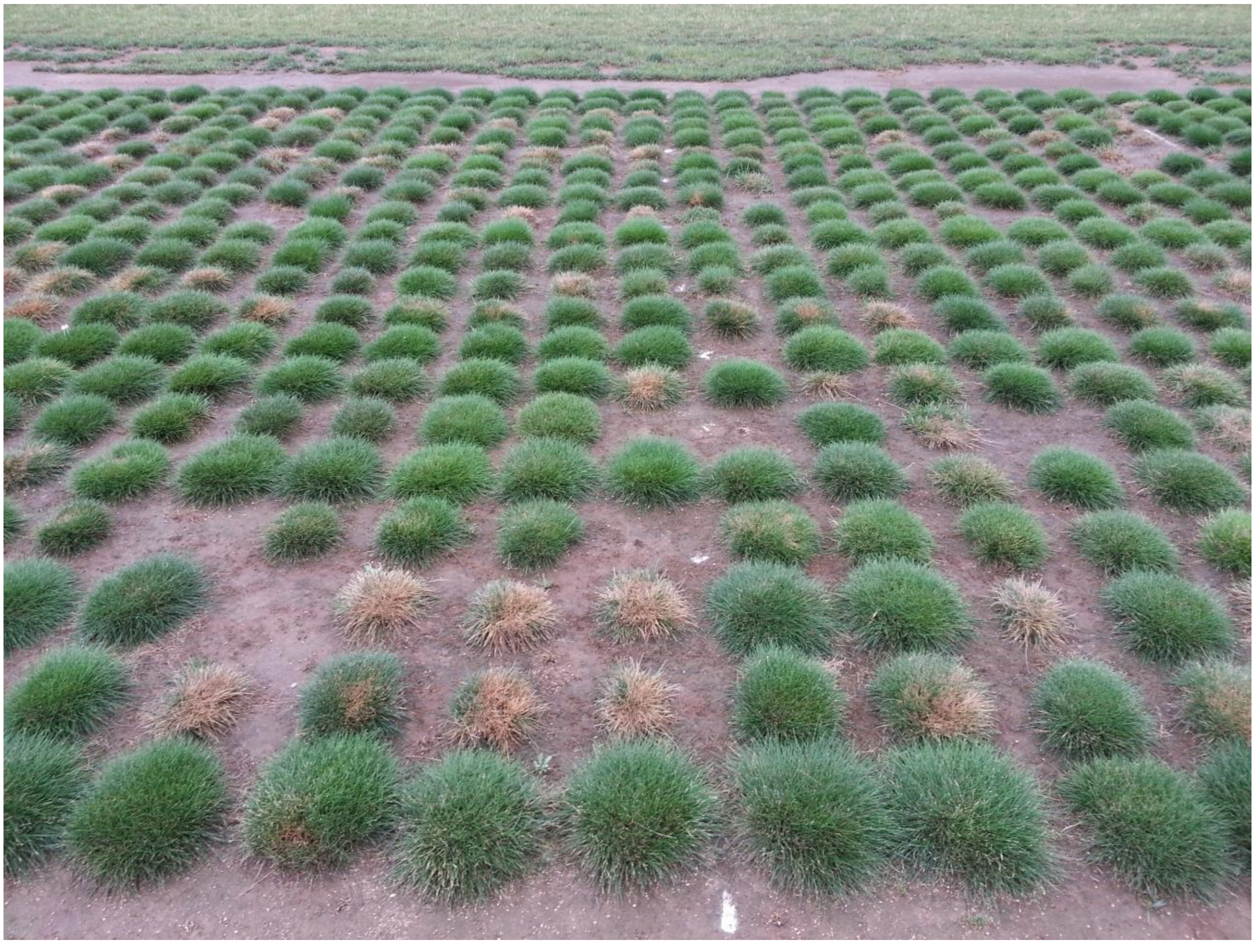

Figure 3: Hard fescue genotypes being screened for resistance to summer patch disease in New Jersey.

2014-02-491

Project Title: The evaluation of novel hybrid bluegrass in northwest Oklahoma as low-input turf

Project leader: Jason Goldman

Objectives:

1. Further evaluate hybrid selections in greenhouse and field trials

2. Establish larger seed production plots for the best performing hybrids

Selecting turfgrass that requires less water and remains green longer under hot dry conditions is a high priority in many breeding programs as water used for irrigation becomes more costly or restricted. The objectives were to combine the heat and drought tolerant traits from Texas bluegrass (*Poa arachnifera*) with the high turf quality and apomictic mode of reproduction from Kentucky bluegrass (*Poa pratensis*) by interspecific hybridization. Crosses were made in the greenhouse in 2009. Eleven hybrids were selected from Texas x Kentucky (TX x KY) F_1 or (TX x KY) x KY BC_1 crosses after two or three rounds of single plant selections from open pollinated plants in field based evaluation nurseries (Table 1). A portion of these hybrids (#21, #57, #67, #71, #87, TK24-SPS) were previously tested in small scale outdoor seeded trials under low management conditions without supplemental irrigation after establishment. Hybrid #67 and #57 produced the best turf quality when conditions were optimal, similar to the Kentucky checks. When conditions became hot and dry, hybrid #67 remained green longer than the Kentucky checks. This year all the hybrid selections were evaluated in a greenhouse trial and a portion in a small field trial. The greenhouse trial was seeded on 12-1-16 at a rate of 200 mg / 4" pot in a randomized complete block design (RCB) with three replications. Plants were cut back on a weekly basis starting on 12-20-16 and fertilized with liquid 24-8-16 every 7 to 10 days. The hybrids were generally slower to emerge than the checks Thermal blue and Baron at two weeks after seeding (Table 1). At approximately eight weeks after seeding (2-10-17) hybrid #67 had the highest turf quality rating of all the hybrids which ranged from 5.3 to 7.3. A genetic color rating on this date indicated hybrids #67, TK24-SPS, #87, and #21 received the darkest color ratings, although not significantly different from many of the other entries tested (Table 1, Figure 1). The hybrids were also seeded outdoors in 2' x 2' plots on 10-19-16 at a 3X (11.5g / plot) rate in a RCB with two replications. In two cases (#67, #174), seeds harvested in 2015 and 2016 were tested. Plots were irrigated when conditions became dry. Two weeks after seeding, emergence ratings were high for hybrids #263, #87, #174 which ranged from 6 to 7 (Table 2, Figure 1d). Most of the other hybrids displayed good emergence (rating 4 to 5) and were not significantly different from #87 or #174. Hybrid #71 and #261 displayed the slowest emergence (rating 2 to 3.5). Slight, non-significant differences were observed between seed lots harvested in 2015 and 2016 which could be the result of residual dormancy present in the 2016 seeds. Turf quality ratings ranged from 3.5 to 7.5 when rated in Dec, May, and Aug (Figure 2). A portion of the remaining seed from the hybrids was used to establish larger seed increase plots at Woodward ARS (Figure 3). The rest of the seed was sent to Oklahoma State University to be tested on a larger scale for turf quality and for resistance to diseases common to Kentucky bluegrass.

Summary:

Under greenhouse conditions all selections produced an attractive turf approximately 6 to 8 weeks after seeding

Larger scale seed production plots were planted in the spring of 2017 at Woodward ARS

Seeds were also sent to OSU to be tested in larger trials where disease pressure not present at Woodward will be present (planting scheduled for week of Sept 18th 2017).

Table 1. Emergence, turf quality, and genetic color of hybrids seeded on 12-1-16 in the greenhouse

Entry	Emergence (1_{slow} - 9_{fast})		Turf Quality (1_{worst} - 9_{best})				Color (1_{light} - 9_{dark})
	12-15-16	12-30-16	1-19-17	2-10-17	3-2-17	3-23-17	2-10-17
Baron - Kentucky Check	6.3	7.7	9.0	8.7	9.0	7.3	5.0
Thermal Blue - Hybrid Check	5.7	7.7	7.7	8.0	8.7	8.0	5.7
$WL63_{(TX)}$ x $Russian_{(KY)}$ - #87	4.0	5.3	6.3	7.0	7.0	7.0	6.0
$TK26_{(TK)}$ x $Scenic_{(KY)}$ - #160	4.0	4.0	5.3	6.7	6.3	5.3	5.3
$TK24_{(TK)}$ x $Huntsville_{(KY)}$ - #67	4.0	3.3	5.7	8.0	8.0	8.0	6.0
TK26 x Scenic - #36:1	3.3	3.3	5.0	5.7	6.0	5.0	4.7
$TK43_{(TK)}$ x $Trenton_{(KY)}$ - #263	3.0	4.0	5.7	6.3	6.7	6.0	5.3
TK43 x Trenton - #261	3.0	3.3	5.7	6.7	8.0	7.3	5.7
TK24 x Huntsville - #71	3.0	2.3	3.7	5.3	6.0	6.0	5.0
TK24 single plant selection (SPS)	3.0	3.3	5.7	7.3	8.3	7.3	6.0
TK43 x Trenton - #57	3.0	2.3	4.7	7.0	7.3	7.0	4.7
Bandera - Hybrid Check	2.7	6.7	8.3	8.0	9.0	7.7	5.3
TK43 x Trenton - #174	2.7	2.7	4.7	6.7	7.0	6.3	5.0
Midnight Kentucky Check	2.3	4.7	6.3	7.0	7.7	7.7	5.7
$D4\text{-}10_{(TX)}$ x $Poland_{(KY)}$ - #21	2.0	2.0	4.0	7.0	7.7	7.0	5.7
LSD*	1.1	1.1	0.96	0.93	0.99	1.4	0.75

*Least Significant Difference (α = 0.05)

Table 2. Emergence and turf quality of hybrids seeded on 10-19-16 in 2' x 2' field plots

Entry*	Emergence (1_{slow} - 9_{fast})	Turf Quality (1_{worst} - 9_{best})		
	11-2-16	12-16-16	5-28-17	8-11-17
$TK43_{(TK)}$ x $Trenton_{(KY)}$ - #263 (15)	7.0	6.0	6.5	5.5
$WL63_{(TX)}$ x $Russian_{(KY)}$ - #87 (15)	6.0	6.0	5.0	4.0
TK43 x Trenton - #174 (15)	6.0	7.0	6.0	5.0
$TK26_{(TK)}$ x $Scenic_{(KY)}$ - #160 (16)	5.0	5.0	3.5	3.0
TK43 x Trenton - #174 (16)	4.5	4.5	6.0	5.0
$TK24_{(TK)}$ x $Huntsville_{(KY)}$ - #67 (15)	4.5	4.0	4.5	5.5
$TK24_{(TK)}$ x $Huntsville_{(KY)}$ - #67 (16)	4.0	4.5	4.5	5.5
$D4\text{-}10_{(TX)}$ x $Poland_{(KY)}$ - #21 (15)	4.0	3.0	7.5	6.5
TK43 x Trenton - #57 (15)	4.0	5.0	7.0	5.0
TK24 x Huntsville - #71 (15)	3.5	3.5	5.0	6.0
TK43 x Trenton - #261 (16)	2.0	3.5	6.5	5.0
LSD**	2.05	1.63	1.76	2.1

*Numbers in parenthesis = seed harvest year, 2015 or 2016

**Least Significant Difference (α = 0.05)

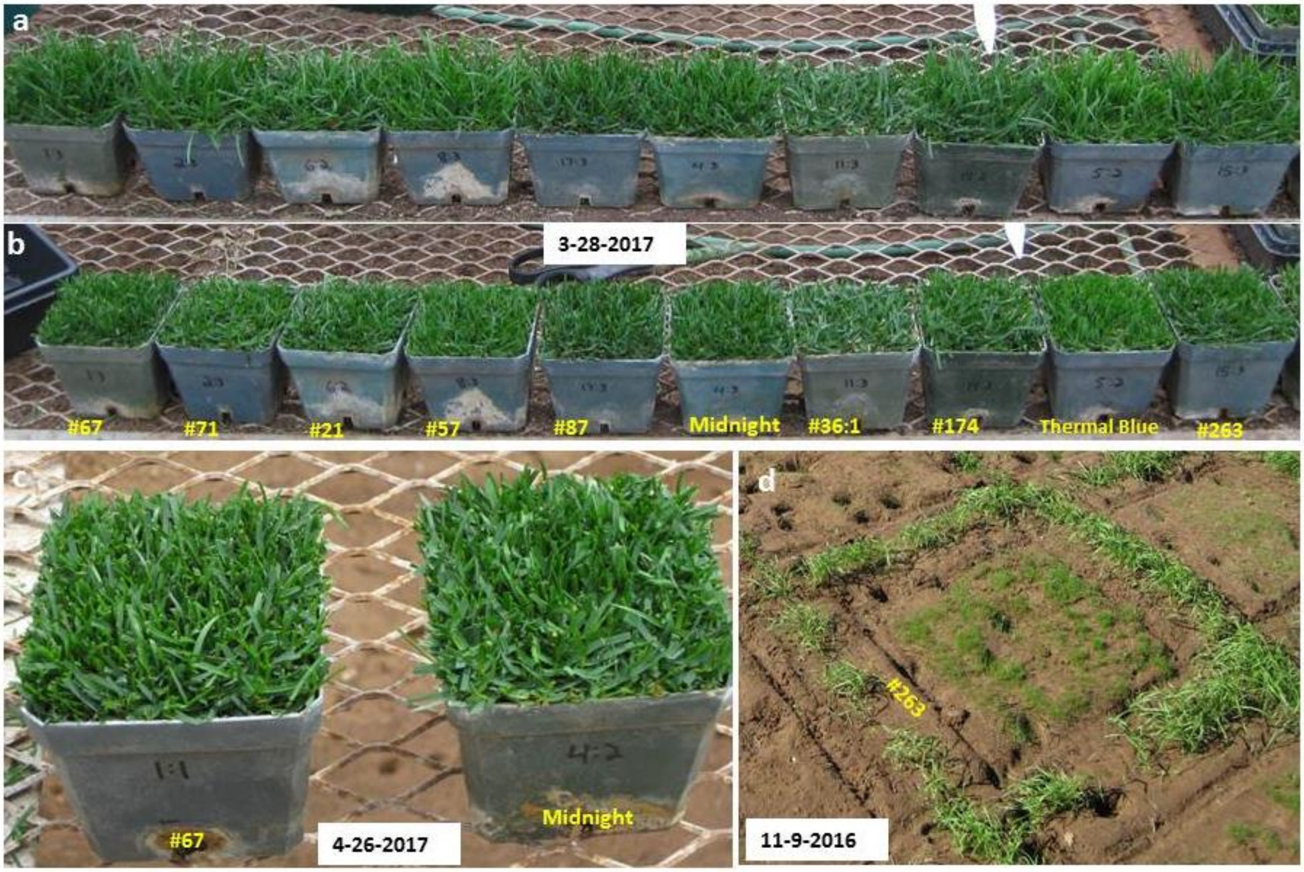

Figure 1. A portion of the hybrids in the greenhouse trial on 3-28-17 before (a) and after (b) being cut back. Midnight Kentucky bluegrass and hybrid #67 after being cut back on 4-26-17 (c). A plot of hybrid #263 three weeks after seeding (d). Wheat was used as a border and the holes are from deer that walked through the plots when they were covered with a turf-cover tarp during germination.

Figure 2. A portion of the hybrids in the outdoor trial on 9-13-17.

Figure 3. Seed increase nursery planted in the spring from plants started in the greenhouse. Plots contain 400 plants / entry. Entries included #57 (1 plot), #67 (3 plots), #71 (1 plot), #87 (2 plots), #160 (1 plot), #174 (1 plot), #261 (2 plots), #263 (2 plots), TK24-SPS (2 plots), #36:1 (1 plot), and #21 (1/2 plot).

2015-01-516

Reduced water consumption of perennial ryegrass in the western USA

Joseph G. Robins and B. Shaun Bushman

USDA ARS Forage and Range Research, Logan, UT 84322

Project Objective(s):

1) Identify the commercially available perennial ryegrass cultivars best adapted to limited irrigation in the Upper West/Mountain region of the US.
2) Identify promising perennial ryegrass accessions for future plant breeding aimed at increasing the turfgrass quality under limited irrigation.
3) Characterize the effect of genotype x environment interaction on the ability of perennial ryegrass to maintain turf quality under limited irrigation.
4) Identify germplasm for future genetic dissection of water use efficiency.

Start Date: 2014

Project Duration: 3 years

Total Funding: $50, 500

Perennial ryegrass's high performance and ease of management make it an important option for golf course use in the U.S. Unfortunately, this species has a relatively high irrigation requirement to maintain high quality. Identification of limited irrigation tolerant germplasm and subsequent selection for this trait is an important component in the effort to maintain perennial ryegrass performance on golf courses while limiting irrigation. The focus of this research is the evaluation of a 31 perennial ryegrass cultivars and 66 perennial ryegrass accessions for turfgrass quality under limited irrigation and traffic.

In 2014, we requested over 70 perennial ryegrass accessions the USDA NPGS-GRIN system. Because the GRIN system could not supply sufficient seed for seeded studies, we increased seed of each accession using plastic sheeting and fencing to create isolation (Figure 1). We transplanted 25 genotypes of each accession to an individual crossing block in 2015. We harvested seed – bulked across accession genotypes – in 2016. After processing and cleaning the resulting seed, we established seeded plots of the 31 commercial cultivars and the 66 accessions which produced sufficient seed at Kaysville and Millville, UT field sites (Figure 2). At both locations, we incorporated two additional treatments into the study: 1) traffic simulation vs. no traffic simulation, and 2) 75 % evapotranspiration replacement irrigation vs. 50 % evapotranspiration irrigation replacement. We initiated the traffic and irrigation treatments in 2017. We also began collecting digital imagery of the plots at both locations on a biweekly basis. We then used the digital images to assign numeric values to each plot corresponding to percent ground cover and green color index.

We completed data collection for the year in October. We are now processing digital images to convert them to quantitative data. Once finished, we will complete the analysis for the 2017 data. We will take another year of data in 2018. At the completion of the study, we will publish a peer-reviewed scientific journal article and have the information to make recommendations to turfgrass managers for improved wheatgrass turfgrass management.

- Completed year 1 of data collection.
- Preliminary data analysis and results available in the next few months.
- Will complete study in 2018.

Figure 1. Crossing block used to produce additional seed for 25 USDA NPGS-GRIN genotypes in 2015.

Figure 2. Plots of the 31 commercial cultivars and the 66 accessions which produced sufficient seed were established in Kaysville and Millville, UT.

2017-12-622

Title: Pre-breeding for bentgrass germplasm improvement

Co-project leaders: Keenan Amundsen[1], Scott Warnke[2], Bill Kreuser[1]

Affiliation: [1]University of Nebraska-Lincoln; [2]USDA-ARS

Objectives:

The goal of this research is to develop genetically narrow but diverse bentgrass families with enhanced abiotic stress tolerance.

Start Date: 2017

Project duration: Three years

Total funding: $51,040

Summary:

There are more than 150 different bentgrass species, but only five that are routinely used in turf applications. Even among the common species, there is significant variation in morphology and turf performance, differences that are exacerbated with a broader representation of species. Many alternative bentgrasses do not have acceptable turf quality, making it difficult for bentgrass breeders to introduce stress tolerance from those sources without also compromising quality of their elite breeding material. This project builds from the previously funded USGA project, *Low input performance of Highland, heat, and drought tolerant bentgrasses*. In the previous study, 69 bentgrass accessions were obtained from the National Plant Germplasm System and evaluated under 5/8 inch and 3 inch mowing heights with minimal supplemental fertility or irrigation inputs following establishment in Mead, Nebraska. Results from the previous study identified accessions with traits that may benefit elite creeping bentgrasses used on golf courses. The current study is focused on preliminary breeding to move desirable traits (drought, heat, low fertility use, late season color retention) into elite bentgrass breeding stocks through introgression breeding to benefit bentgrass breeders.

Two breeding strategies are being implemented. At the University of Nebraska-Lincoln, a population improvement strategy is being applied whereby all of the accessions were allowed to intermate during the 2017 growing season, and viable seed was harvested from 60 of the 69 accessions (Figure 1). With this strategy, the pollen source is not known (open pollinated), but the maternal parent is known and recorded. The seed was started in the greenhouse and multiple plants representing each population are being increased over the winter. In the greenhouse, differences were observed between the progeny for establishment rate, genetic color, texture, and density (Figure 2). The progeny will be evaluated and compared to the original maternal parent to visually identify phenotypically different plants and those with desirable traits under reduced input management. The individuals again will be allowed to intermate, starting an annual recurrent phenotypic selection strategy to improve the population. The other breeding strategy being applied is a more directed approach, whereby a crossing block consisting of 10 colonial bentgrass and 10 creeping bentgrass accessions was established in Beltsville, Maryland.

The plants all flowered at approximately the same time during the 2017 growing season and were allowed to intermate. Seed was harvested as described above. Progeny was started in the greenhouse and DNA was extracted from 2,600 individuals using FTA-cards (Warnke et al., 2017). Molecular markers able to discriminate creeping and colonial bentgrass have already been developed and a subset of markers will be used to confirm species hybrids by high-resolution melt analysis (Warnke et al., 2017). With open pollinated breeding methods, in the absence of distinguishable morphological differences between species, the molecular methods are essential for confirming the formation of hybrids in the bentgrasses. In general, bentgrasses are highly outcrossing but there is still a chance of self-pollination or sib-mating which could slow progress towards advancing desirable stress tolerance traits. Both breeding approaches will be used for at least two generations, and in the third year of the project, selected populations will be compared to creeping bentgrass cultivars under conventional and reduced input management. Resulting from this project, we expect to produce abiotic stress tolerant bentgrass germplasm with acceptable quality, useful for bentgrass breeders to further improve stress tolerance in future cultivars.

Reference:

Warnke, SE, CS Thammina, K Amundsen, P Miljanic, H Hershman. 2017. High-resolution melt analysis of simple sequence repeats for bentgrass species differentiation. Int. Turfgrass Soc. Res. J. 13:1–5. doi: 10.2134/itsrj2016.10.0838

Summary points

1. Genetic markers able to distinguish creeping bentgrass and colonial bentgrass were developed.
2. The markers are being used to confirm hybridization between bentgrass species, currently being tested on 2,600 potential hybrids.
3. Bentgrass seed was harvested from a crossing block consisting of 69 bentgrass accessions and is being evaluated.

Figure 1. Seed from bentgrass accessions at full maturity that were allowed to intermate was collected and is being used in a phenotypic recurrent selection breeding scheme to improve bentgrass abiotic stress tolerance.

Figure 2. Early germinating bentgrass progeny obtained from a bentgrass crossing block consisting of 69 different National Plant Germplasm System accessions.

2015-06-521

Title: Understanding endophyte-mediated dollar spot resistance in red fescue as a new approach to improving management of dollar spot in creeping bentgrass

Project Leader: Faith C. Belanger
Affiliation: Rutgers University
Objectives of the project: The goal of this project is to understand the mechanism behind the well-established phenomenon of endophyte-mediated dollar spot resistance in strong creeping red fescue. This mechanism could possibly be developed as a method for control of dollar spot on creeping bentgrass.
Start Date: 2015
Project Duration: 3 years
Total Funding: $90,000

Summary Text:

Control of dollar spot disease on creeping bentgrass is a major problem for golf course managers and currently relies heavily on fungicide applications. Ongoing efforts to address this problem have focused on breeding tolerant cultivars and on improving management protocols. We are pursuing a different and complementary approach, which is to understand the mechanism of dollar spot resistance in fungal endophyte (*Epichloë festucae*) infected strong creeping red fescue. Endophyte-mediated disease resistance is well established in fine fescues (Clarke et al., 2006), but is not a general feature of other endophyte-infected grasses such as perennial ryegrass or tall fescue. If we can uncover the mechanism of the endophyte-mediated disease resistance in fine fescues, it may be possible to adapt it for use in other turfgrasses such as creeping bentgrass, which are not infected with *Epichloë* endophytes.

Previously we identified an abundant endophyte transcript for an antifungal protein. The antifungal protein gene found in *E. festucae* infecting strong creeping red fescue is not present in most *Epichloë* genomes for which whole genome sequence is available (Ambrose and Belanger, 2012). The transcript abundance and the limited existence of the antifungal protein gene among *Epichloë* spp. suggested the *E. festucae* antifungal protein may be a component of the unique endophyte-mediated disease resistance observed in strong creeping red fescue.

We partially purified the antifungal protein from the strong creeping red fescue apoplastic proteins and showed it did have activity against the dollar spot fungus in a plate assay. The abundance of the antifungal protein among the secreted proteins in the endophyte-infected strong creeping red fescue plants suggests it could come into contact with invading fungal pathogens and may therefore be an important factor in the fungal disease resistance observed in endophyte-infected strong creeping red fescue. We also expressed the antifungal protein in the yeast *Pichia pastoris* and partially purified it from the yeast culture filtrate. The partially purified recombinant antifungal protein also had activity against the dollar spot fungus in a plate assay.

As a first step in uncovering the mechanism of action of the antifungal protein we used the viability stains SYTOX Green and Evans blue, which are dyes that can only enter cells that have damaged membranes. Treatment of the dollar spot fungus with the antifungal protein resulted in uptake of the SYTOX Green (Fig. 1) and Evans blue (Fig. 2) dyes, visualized by the green fluorescence and deep blue color, respectively. In contrast, treatment with the empty vector control proteins had no effect. These results suggested that the antifungal protein inhibited growth of the pathogen by causing damage to the plasma membranes.

The results described above have been published (Tian et al., 2017a,b). The results we have obtained from the *E. festucae* antifungal protein support the hypothesis that it may be a component of the disease resistance seen in endophyte-infected strong creeping red fescue.

The next important question is whether the endophyte antifungal protein can protect the host plant from dollar spot infection. Now that we have confirmed that the endophyte antifungal protein by itself can inhibit growth of the dollar spot fungus we will test its activity on creeping bentgrass and endophyte-free strong creeping red fescue inoculated with the dollar spot fungus. If the antifungal protein is effective in protecting creeping bentgrass from dollar spot, then it could be developed as an alternative method to reduce synthetic fungicide use.

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Ambrose, K.V., Belanger, F.C. (2012) SOLiD-SAGE of endophyte-infected red fescue reveals numerous effects on host transcriptome and an abundance of highly expressed fungal secreted proteins. PLoS ONE 7(12):e53214

Clarke, B.B., White, J.F. Jr., Hurley, R.H., Torres, M.S., Sun, S., Huff, D.R. (2006) Endophyte-mediated suppression of dollar spot disease in fine fescues. Plant Disease 90:994-998

Tian, Z., Wang, R., Ambrose, K.V., Clarke, B.B., and Belanger, F.C. (2017a) Isolation of a potential antifungal protein produced by *Epichloë festucae*, a fungal endophyte of strong creeping red fescue. International Turfgrass Society Research Journal 13: 233-235

Tian, Z., Wang, R., Ambrose, K.V., Clarke, B.B., Belanger, F.C. (2017b) The *Epichloë festucae* antifungal protein has activity against the plant pathogen *Sclerotinia homoeocarpa*, the causal agent of dollar spot disease. Scientific Reports 7:5643

Summary Points:

1. The fungal endophyte (*Epichloë festucae*) that infects strong creeping red fescue produces an abundant antifungal protein that is not found in most *Epichloë* species. It may be involved in the disease resistance observed in endophyte-infected strong creeping red fescue.

2. We have partially purified the antifungal protein from the infected plant and from expression in the yeast *Pichia pastoris*. The partially purified protein had inhibitory activity against the dollar spot fungus.

3. The antifungal protein may act by damaging the membranes of the dollar spot fungus as evidenced by the uptake of dyes that only enter damaged cells.

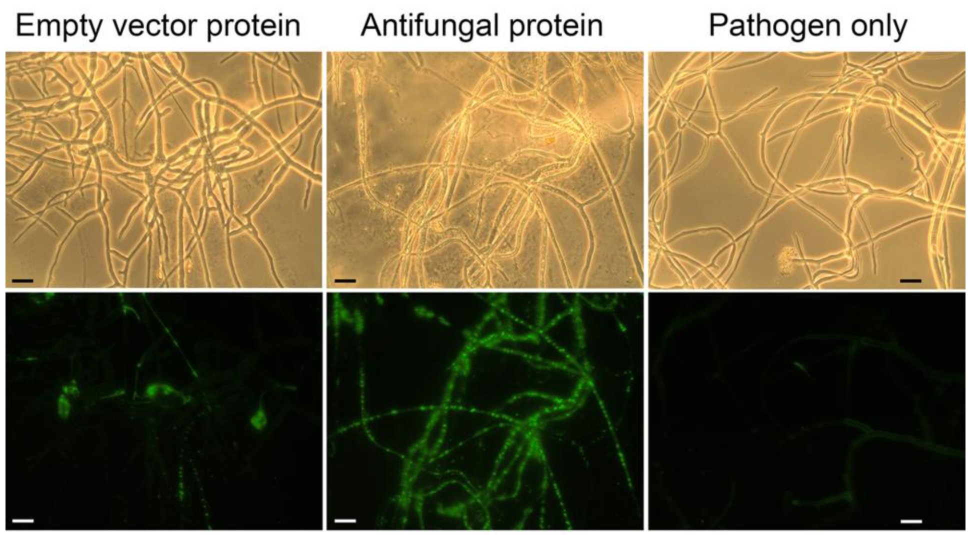

Fig. 1. Microscopy of dollar spot mycelium treated with the purified antifungal protein and empty vector control proteins purified from the yeast culture filtrates. The dollar spot fungus was grown in potato dextrose broth for 2 days and then 17 μg of the antifungal protein or empty vector control proteins were added. After 2 hours of incubation the sample was examined by fluorescence microscopy in the presence of 12 μM SYTOX Green. The upper panels are bright-field images and lower panels are fluorescence images of the same fields. The scale bar is 20 μm.

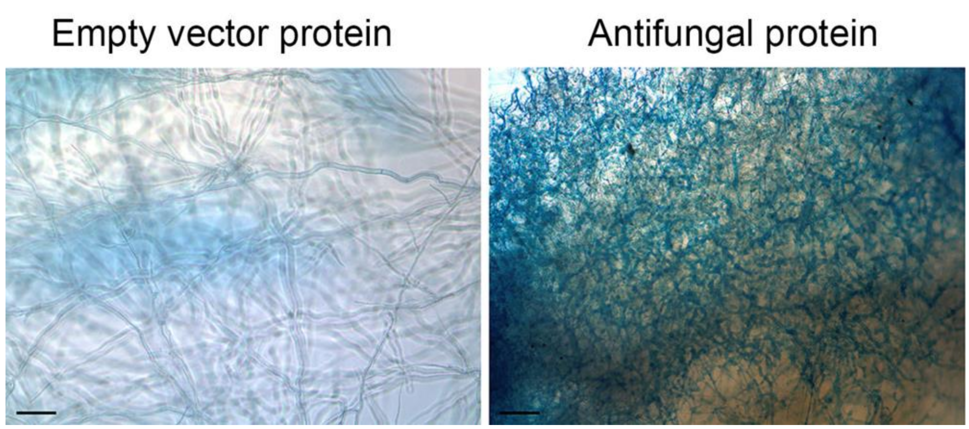

Fig. 2. Microscopy of dollar spot mycelium treated with the purified antifungal protein and empty vector control proteins purified from the yeast culture filtrates. The dollar spot fungus was grown in the center of a microscope slide and was treated with 35 μg of the purified antifungal protein or empty vector control proteins for 1 day and then stained with Evans blue. The scale bar is 100 μm.

2016-25-575

Annual Report – 2017

Genetic engineering of turfgrass for enhanced multi-stress resistance

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Objectives:

The major objective of this research is to genetically engineer enhanced tolerance to various adverse environmental conditions, such as drought, salt, heat and nutrient deficiency in turfgrass plants using transgenic technologies. We proposed to develop methodology to evaluate and demonstrate the feasibility of genetically engineering multi-stress tolerance in transgenic turfgrass through simultaneous overexpression of three genes encoding an *Arabidopsis* vacuolar H^+-pyrophosphatase, *AVP1*, a rice SUMOylation E3 ligase, *OsSIZ1*, and a cyanobacterial flavodoxin, *Fld*. Specifically,

1. We will prepare a chimeric gene construct, p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/ p35S-*bar* constitutively expressing *AVP1*, *OsSIZ1* and *Fld* genes together with a selectable marker gene, *bar*, for herbicide resistance.
2. We will conduct *Agrobacterium*-mediated turfgrass transformation to produce transgenic lines harboring p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/p35S-*bar*.
3. We will analyze putative transgenic plants for transgene insertion and expression.
4. We will Examine plant growth and development in transgenics, and evaluate plant performance under various stressful conditions including drought, heat, salt, P and N starvation in comparison with wild type controls.

Start Date: 2016
Project Duration: 3 years
Total Funding: $60,000

In the face of a global scarcity of water resources and the increased salinization of soil and water, abiotic stress is the big challenge of modern agriculture practice. This project aimed to genetically engineer turfgrass with multiple genes involved in plant stress response for enhanced plant performance under adverse environmental conditions. In our previous report, we presented data obtained in 2016, reporting the successful construction and introduction of a chimeric gene construct, p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/ p35S-*bar* containing expressing cassettes overexpressing *AVP1*, *OsSIZ1* and *Fld* genes together with a selectable marker gene in transgenic creeping bentgrass plants. This year, we have conducted transgenic analysis to evaluate transgene insertion and expression in primary T_0 transgenic plants using PCR and Northern hybridization (see examples in **Figure 1**). Our data showed that all the 20 putative transgenic lines contain the three stress-related genes, *AVP1*, *OsSIZ1* and *Fld* as well as the selectable marker gene, *bar*.

All the transgenic lines were then transferred into soil and grown in greenhouse for further analysis. Morphologically, they did not show significant difference from the non-transgenic controls. Based on transgene expression levels, we selected three representative transgenic lines and they have been vegetatively propagated for further analysis. So far, we have accumulated enough materials of these three representative transgenic lines and are in the process of conducting different experiments evaluating their performance under various abiotic stresses.

Summary Points:

- Conducted molecular analysis of primary putative transgenic plants for transgene insertion and expression, and demonstrated that all the 20 transgenic lines harbor the chimeric gene expression construct, p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/ p35S-*bar*, and express three stress-related genes, *AVP1*, *OsSIZ1* and *Fld*.
- Transferred regenerated transgenic plants into soil and grown in greenhouse for further analysis.
- Selected three representative transgenic lines for vegetative propagation. Enough plant materials have been accumulated and are being used for performance evaluation under various environmental stresses.

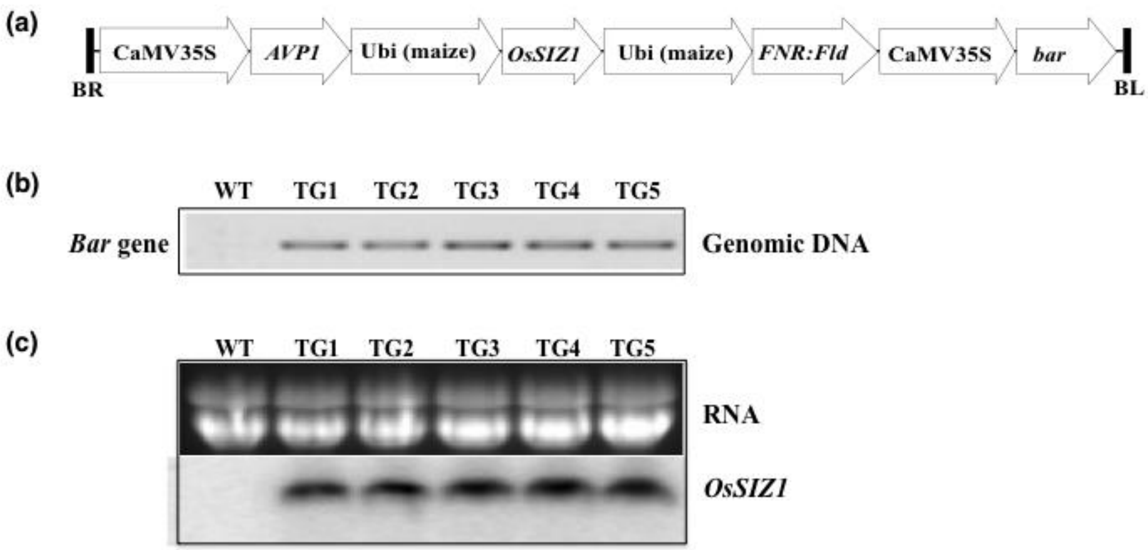


Figure 1. Generation and molecular analysis of transgenic lines expressing *AVP1*, *OsSIZ1* and *Fld* genes . **(a)** Schematic diagram of the chimeric gene expression construct, p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/p35S-*bar* p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/p35S-*bar*, in which the *AVP1* gene driven by the cauliflower mosaic virus 35S (CaMV35S) promoter, *OsSIZ1* gene driven by the corn ubiqintin (Ubi) promoter, and *FNR:Fld* gene (the Fld gene translationally fused to the pea FNR chloroplast-targeting transit signal peptide) driven by the Ubi promoter were linked to the herbicide glufosinate (*phosphinothricin*) resistance gene, *bar*, driven by the cauliflower mosaic virus 35S (CaMV35S) promoter. The right border (BR) and the left border (BL) of the T-DNA in the binary vector were labeled. **(b)** PCR analysis of the *bar* gene using genomic DNA of wild type (WT) and five representative transgenic plants (TG1-5) to detect transgene insertion into the host genome. **(c)** Northern blot analysis demonstrating transgene expression in transgenic plants. *OsSIZ1* gene expression in five representative transgenic lines (TG1-5) in comparison to wild type (WT) control was shown as example. *OsSIZ1* DNA fragment was used as probe for hybridization. EtBr-stained gel shows the amount of RNA from each sample loaded for Northern analysis.

2012-24-458

Title: Development of Large Patch Tolerant and Cold Hardy Zoysiagrass Cultivars for the Transition Zone

Project Leaders: Jack Fry[1], Ambika Chandra[2], Megan Kennelly[1], Aaron Patton[3], Dennis Genovesi[2], Mingying Xiang[1], and Meghyn Meeks[2]

Affiliation: Kansas State University[1], Texas A&M AgriLife Research-Dallas[2], Purdue University[3]

Cooperators: Erik Ervin, University of Delaware; Grady Miller, North Carolina State Univ.; Justin Moss, Oklahoma State Univ.; Mike Richardson, Univ. of Arkansas; John Sorochan, Univ. of Tennessee; Xi Xiong, Univ. of Missouri; Jesse Benelli, Chicago District Golf Association, IL

Objective: Phase III (year 3-6) of the evaluation process is focused on replicated field trials comprised of elite zoysiagrass hybrids at multiple environments. The objective of the Phase III field test is the selection of experimental hybrids that have comparable/superior cold tolerance to Meyer, but finer texture, and improved large patch tolerance.

Summary Text:

This was the third year of field evaluation for 60 zoysiagrass experimental hybids selected from 2,858 progeny. These progeny were developed at Texas A&M AgriLife Research in Dallas, Texas by crossing 22 cold-hardy zoysiagrasses with TAES 5645 (*Z. japonica*) or its derivatives that had demonstrated tolerance to large patch in nonreplicated field trials.

In September 2014, twenty top-performing progeny were selected from spaced plantings in Manhattan, West Lafayette, IN, and Dallas, TX. These sixty progeny were returned to Dallas for propagation. In June 2015, vegetative plugs of the 60 progeny along with the standard cultivars Meyer, Zorro, El Toro, Zeon, and Chisholm, were shipped from Dallas, TX and planted in three replicate plots (25 or 36 sq. ft.) in Manhattan, KS, West Lafayette, IN and Dallas, TX. In 2015, the same progeny were also distributed to research cooperators in Blacksburg, VA; Chicago, IL; Columbia, MO; Fayetteville, AR; Knoxville, TN; Raleigh, NC; and Stillwater, OK for evaluation in replicated plots (Fig. 1).

Data Collection and Results

In 2017, data were submitted from all locations except Virginia where a personnel change recently took place. Zoysiagrass progeny coded family (crosses) are shown in Table 1. For presentation in Tables 2 to 5, the top-performing ten progeny are shown along with the controls (standards). In this progress report, for brevity, comparisons are made to Meyer, which is the standard zoysiagrass cultivar used in the transition zone. Data presented are averages from the locations submitting data for a given parameter, and were analyzed using PROC GLM.

- **Large patch.** Large patch was evaluated at KS and AR, where plots were inoculated in September and October 2016, respectively. Large patch was rated on 19 April and 15 May 2017 in AR, and on 24 May, 24 and 30 Sept, and 20 Oct 2017 in KS. Disease development was variable. Large patch ranged from 2% to 43% severity (% plot exhibiting visual symptoms), when averaged over all the dates and both locations (Table 2). Sixteen progeny had statistically less large patch compared to Meyer, which had an average disease severity of 16% average. Progeny that had ,< 10% disease on all rating dates at both locations were:

6099-151, 6102-307, 6119-179 (Fig. 2), and 6100-146. All of these progeny were statistically similar to Meyer in winter injury, spring green up, and turf quality.

- **Winter Injury.** Winter injury was rated at IN, MO, NC, OK, and TN in late spring 2017 as the percentage of each plot exhibiting symptoms. Meyer had 16.6% winter injury, and because Meyer is known to be quite cold tolerant, this number is likely reflective of factors other than just low temperatures (e.g., large patch damage that was slow to green up). Five progeny had a lower winter injury level compared to Meyer (Table 3). Three progenies had more winter injury than Meyer (up to 60% in OK); all other progeny had winter injury levels statistically similar to Meyer.

- **Green up.** Spring green up was rated visually between 13 March and 21 April on a 1-9 scale as 1 = brown and 9 = fully green at MO, OK, NC, IN, TN, KS, AR, and TX. Green-up ratings ranged from 3.1 to 5.7 (Table 4). Thirteen progeny had slower green up ratings than Meyer, and all others were statistically similar to Meyer.

- **Quality.** Turfgrass quality was rated monthly on a 1-9 scale (1 = poorest quality; 6 = minimally acceptable quality; and 9 = optimum color, density and uniformity) between May and September at TX, KS, IL, MO, OK, AR, NC, and IN. Average quality in mid summer (rated in late July to August) ranged from 5.4 to 7.6; four progeny had quality superior to Meyer (6.0) (Table 5).

Summary Points:

- Sixty zoysiagrass hybrids, each arising from a cross between a large-patch tolerant parent and cold-hardy parent, are under evaluation after initially screening 2,858 progeny for quality and cold hardiness.
- Progeny are being evaluated under golf course management conditions at ten locations throughout the transition zone for turf quality characteristics and large patch tolerance.
- The fungus (*Rhizoctonia solani*) causing large patch disease was inoculated in plots in Manhattan, KS and Fayetteville, AR. Several progeny consistently showed better tolerance to large patch compared to Meyer in KS and AR.
- Progeny showed a wide range of variability in turf quality characteristics including winter injury, spring green up, and turfgrass quality.
- Among this group of experimental zoysiagrasses, there appears to be promising progeny that have good winter hardiness, tolerance to large patch, and improved turf quality characteristics, such as TAES 6095-83.
- Progeny evaluations will continue in 2018-2019.

Fig. 1. Zoysiagrass plots in Stillwater, Oklahoma. The same grasses are under evaluation in Arkansas, Illinois, Indiana, Kansas, Missouri, North Carolina, Tennessee, Virginia, and Texas.

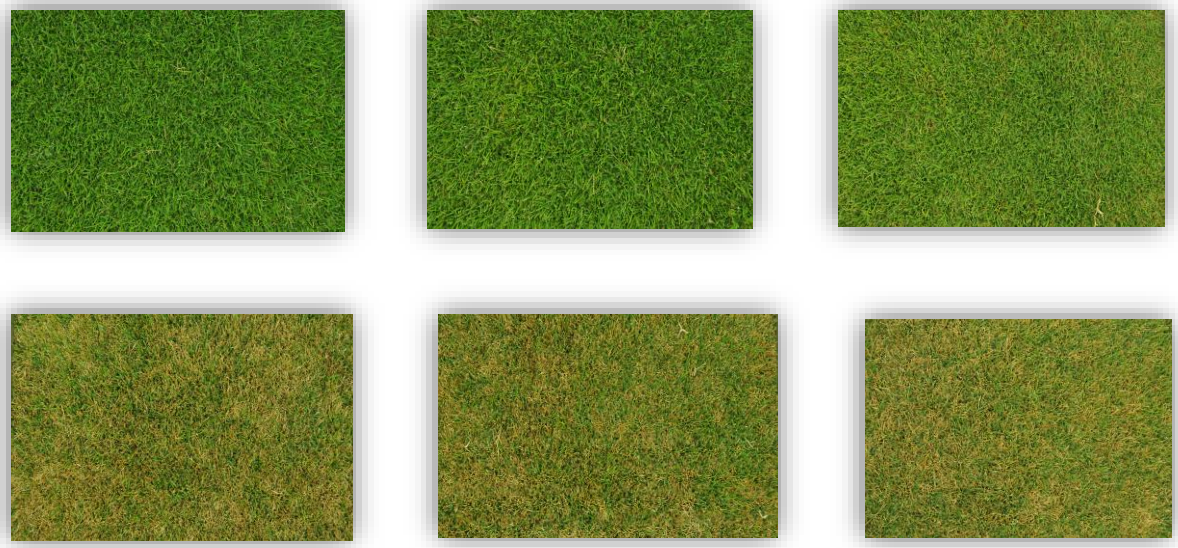


Fig. 2. Overhead photos taken inside a light box of large patch symptoms in a tolerant (6119-179, upper row) and susceptible (6096-81, bottom row) zoysiagrass at Manhattan, KS. Photos were taken on 18 Oct. 2017; each is of a different replicate.

Table 1. Lineage and family codes of top performing Zoysiagrass hybrids.

Coded Family	Zoysiagrass progeny coded family lineage (female × male)
6095	[(*Z. matrella* (L.) Merr. x *Z. matrella*) x *Z. japonica*] x *Z. japonica*
6096	(*Z. matrella* x *Z. japonica*) x *Z. japonica*
6097	(*Z. matrella* x *Z. japonica*) x *Z. japonica*
6099	*Z. japonica*[†] x *Z. japonica*
6100	[(*Z. japonica* x *Z. pacifica* (Gaud.) Hotta & Kuroti) x *Z. japonica*] x *Z. japonica*
6101	(*Z. matrella* x *Z. japonica*) x *Z. japonica*
6102	*Z. japonica* x *Z. japonica*
6119	*Z. japonica* x [(*Z. matrella x Z. matrella*) x *Z. japonica*]

[†]For confidentiality, only species names, and not cultivar names, are provided.

Table 2. Large patch infestation in top-performing zoysiagrass progeny and standard cultivars in spring and fall 2017 in AR and KS.

Entry	**Large patch (%)**[†]
6099-151	1.7
6102-307	2.1
6119-179	2.2
6100-146	2.3
6099-77	3.3
6099-447	3.8
6099-69	3.9
6095-83	4.1
6099-145	4.5
6102-289	4.6
Zorro	14
El Toro	14.4
Zeon	10.9
Chisholm	10.9
Meyer	16.1
LSD	10.0*

[†]Large patch was rated as a percentage of the plot area affected on a 0 to 100% scale on 19 April and 15 May 2017 in AR, and on 24 May, 24 and 30 Sept., and 20 Oct. 2017 in KS. Results are averaged over both locations, 6 rating dates, and three replicates per location (n = 18).
*To determine statistical differences among entries, subtract one entry's mean from another entry's mean. Statistical differences occur when this value is larger than the corresponding LSD value ($P < 0.05$).

Table 3. Winter injury of top-performing zoysiagrass progeny and standard cultivars in late spring 2017 in IN, MO, NC, OK, and TN.

Entry	**Winter injury (%)**[†]
6099-10	3.2
6101-71	3.7
6100-86	3.8
6102-62	3.8
6099-77	4.2
6100-146	4.3
6096-36	5.0
6096-117	5.8
6101-9	6.0
6095-101	6.0
Zorro	20.2
El Toro	24.0
Zeon	14.4
Chisholm	6.5
Meyer	16.6
LSD	12.4*

[†]Winter injury was rated on a 0 to 100% scale; results are averaged over five locations and three replicates per location (n =15).
*To determine statistical differences among entries, subtract one entry's mean from another entry's mean. Statistical differences occur when this value is larger than the corresponding LSD value ($P < 0.05$).

Table 4. Spring green up of top-performing zoysiagrass progeny and standard cultivars in spring 2017 in MO, OK, NC, IN, TN, KS, AR, and TX.

Entry	**Spring green up**†
6102-62	5.7
6101-9	5.7
6095-83	5.4
6101-26	5.4
6099-10	5.4
6099-8	5.4
6097-74	5.4
6099-383	5.3
6099-145	5.3
6096-36	5.3
Zorro	4.7
El Toro	4.4
Zeon	4.5
Chisholm	5.6
Meyer	5.2
LSD	1.1*

†Spring green up was rated on a 1-9 scale (1 = brown; 9 = fully green). Results are averaged over eight locations and three replicates per location (n = 24).
*To determine statistical differences among entries, subtract one entry's mean from another entry's mean. Statistical differences occur when this value is larger than the corresponding LSD value ($P < 0.05$).

Table 5. Turfgrass quality of top-performing zoysiagrass progeny and standard cultivars in summer 2017 in TX, KS, IL, MO, OK, AR, NC, and IN.

Entry	**Turfgrass quality**†
6095-83	7.6
6101-154	7.2
6100-86	7.1
6126-71	7.1
6119-179	7.0
6101-32	7.0
6099-10	7.0
6119-14	7.0
6119-168	7.0
6099-69	7.0
Zorro	6.4
El Toro	6.5
Zeon	6.7
Chisholm	6.4
Meyer	6.0
LSD	1.1*

†Turfgrass quality was rated on a scale of 1-9 (1 = poorest quality; 6 = minimally acceptable quality; and 9 = optimum color, texture, density, and uniformity) in late July or early August; results are averaged over eight locations and three replicates per location (n = 24).
*To determine statistical differences among entries, subtract one entry's mean from another entry's mean. Statistical differences occur when this value is larger than the corresponding LSD value ($P < 0.05$).

2014-03-492

Developing and Validating a New Method to Improve Breeding for Cold-tolerant Bermudagrass

Xi Xiong[1], Yanqi Wu[2], and Reid J. Smeda[1]

[1]University of Missouri and [2]Oklahoma State University

Objectives: To develop a new technique that simplifies evaluation of bermudagrass for cold tolerance, and hence improves breeding efficiency.

Start Date: 2014
Project Duration: 3 years (with the fourth year extended without extra fund)
Total Funding: $30,000

In 2017, a number of experiments were performed to further evaluate the hypothesis regarding the possible linkage of bermudagrass (*Cynodon dactylon* (L.) Pers.) for its responses to aryloxyphenoxypropionate (AOPP) herbicide and cold temperature stresses. Built upon the segregating population resulting from a cross between “A12935” and “A12936” bermudagrass collections, we selected eight progenies with four representing AOPP-tolerant and another four representing AOPP-susceptible genotypes. Assessment of AOPP responses was previously conducted. The entry “A12396” is a breeding line selected from the Oklahoma State University (OSU) bermudagrass germplasm known for its cold hardiness. The entry “A12395” is a collection from Puerto Rico which is susceptible to low temperature stress. Our previous research has determined the LT_{50} (Lethal temperature to 50% of the plants in the population) to be -11.1 ºC and -8.2 ºC for cold-hard “A12396” and cold-sensitive “A12935”, respectively. The four AOPP-tolerant progenies, T27, T36, T41, and T44, collectively showed greater cold-tolerance than the four AOPP-susceptible progenies, S1, S66, S99, and S103, evidenced by the segregation of the LT_{50} (Fig 1). This result further confirmed the correlation between bermudagrasses’ responses to the two stresses, and indicating its likelihood of inheritability.

To decipher the possible mechanism for such a correlation, we have also performed lipid profiling of the two previously-studied bermudagrass cultivars, “Riviera” and “Celebration”, by subjecting them to chilling stress at 4 ºC for a total of 3 weeks. Experimental design was a complete randomized design with 4 replications. Alteration in membrane phospholipids content and increasing in unsaturated membrane lipids has been found in various plant species, including bermudagrass, contributing to their supreme cold tolerance. These changes in lipids increase membrane stabilization and maintain membrane fluidity under cold temperatures. Our results found an increase of phosphatidylcholines (PC) for both cultivars, although “Riviera” showed 10% greater PC at 3 weeks after treatment (WAT) (Table 1). For phosphatidylglycerols (PG) and phosphatidylethanolamines (PE), however, only “Riviera” showed a consistent increase as cold temperature stress was extended. Under cold temperatures, both cultivars showed an increase for double bond index (DBI) of most phospholipids tested, “Riviera” appeared to accumulate a greater amount of double bonds with PC, PG, and PE (Table 2). At 3 WAT, “Riviera” produced 10% or 37% greater double bonds in PC and PG, respectively, compared to “Celebration”. Compared to the DBI prior to treatment application, “Riviera” accumulated 1.9 times greater double bonds of PE at 3 WAT, while “Celebration” only increased 1.4 times. Collectively, these results indicate that alteration of certain membrane lipids or increasing unsaturated lipids likely explains the supreme cold-tolerance of “Riviera” compared to “Celebration”. Based on this knowledge, we have recently shifted our focus to decipher the molecular basis of such a mechanism.

Various attempts were made to identify, clone, and sequence putative genes; part of the difficulty in conducting this portion of the research is the absence of genomic information for bermudagrass. Our recent findings, however, indicate that we might have identified a putative gene that encodes fatty acid desaturase (FAD) from both of the bermudagrass cultivars (Fig 2). The putative genes cloned from “Riviera” and “Celebration” were identical, and shared 75-90% homology with the genes encoding stearoyl-acyl carrier protein desaturase from different crops including wheat and maize. Beyond the funding period, we are planning to confirm the putative *FAD* gene we cloned from bermudagrass. We also plan to evaluate the expression of *ACCase* which we have previously cloned. Our previous results found no mutation which was the known resistance mechanism for other AOPP-resistant crops.

Summary:

- We have generated abundant evidence that indicates the likelihood of the linkage between bermudagrasses’ tolerance to AOPP herbicide and cold temperature;
- Utilizing a segregating population, we produced in-depth evidence that AOPP herbicide can be used as a practical method to select bermudagrass breeding lines based on their cold-tolerance;
- Beyond the funding period, we will continue working on the possible mechanism at the molecular level, and we expect an in-depth discovery sometime in the future.

Table 1. Effects of chilling temperature on phospholipids of 'Riviera' and 'Celebration' bermudagrasses at 0, 1, 2 and 3 weeks after treatment (WAT). PC, phosphatidylcholine; PG, phosphatidylglycerol; PE, phosphatidylethanolamine; PI, phosphatidylinositol; PA, phosphatidic acid.

	0 WAT†	1WAT	2 WAT	3WAT
	PC§			
Celebration	4.63b1	5.30a1	5.50a1	5.47a2
Riviera	4.63c1	4.46c2	5.34b1	6.03a1
	PG			
Celebration	2.36bc1	2.68a1	2.39bc1	2.25c2
Riviera	2.36c1	2.33c2	2.54bc1	2.87a1
	PE			
Celebration	1.18c1	1.72ab1	1.92a1	1.68b1
Riviera	0.88c2	1.26b2	1.83a1	1.71a1
	PI			
Celebration	0.45b1	0.47b1	0.53a1	0.48ab1
Riviera	0.44a1	0.38c2	0.40bc2	0.43ab2
	PA			
Celebration	0.06c1	0.10ab1	0.10a1	0.10ab1
Riviera	0.08b1	0.07b1	0.07b2	0.12a1
	PC/(PE+PA)			
Celebration	3.79a2	2.98bc2	2.72c1	3.15b1
Riviera	4.90a1	3.45b1	2.88c1	3.44b1

†Means in the same rows labeled by the same letters are not significantly different according to Fisher's Protected LSD (*P* = 0.05); Means in the same columns for each variable labeled by the same numbers are not significantly different according to Fisher's Protected LSD (*P* = 0.05).
§The units of phospholipids presenting in the table are mol% except PC/(PE+PA).

Table 2. Effects of chilling temperature on phospholipid double bond indices (DBIs) of 'Riviera' and 'Celebration' bermudagrasses at 0, 1, 2 and 3 weeks after treatment (WAT). PC, phosphatidylcholine; PE, phosphatidylethanolamine; PG, phosphatidylglycerol; PI, phosphatidylinositol.

	0 WAT†	1WAT	2 WAT	3WAT
		DBI		
		---PC---		
Celebration	0.155c1	0.176b1	0.184a1	0.187a2
Riviera	0.154c1	0.152c2	0.180b1	0.206a1
		---PG---		
Celebration	0.052b1	0.059a1	0.051b2	0.049b2
Riviera	0.053c1	0.054bc1	0.058b1	0.067a1
		---PE---		
Celebration	0.043c1	0.060b1	0.068a1	0.059b1
Riviera	0.032c2	0.045b2	0.065a1	0.061a1
		---PI---		
Celebration	0.0116b1	0.0122b1	0.0135a1	0.0128ab1
Riviera	0.0116a1	0.0103b2	0.0106ab2	0.0116a1

†Means in the same rows labeled by the same letters are not significantly different according to Fisher's Protected LSD ($P = 0.05$); Means in the same columns for each variable labeled by the same numbers are not significantly different according to Fisher's Protected LSD ($P = 0.05$).

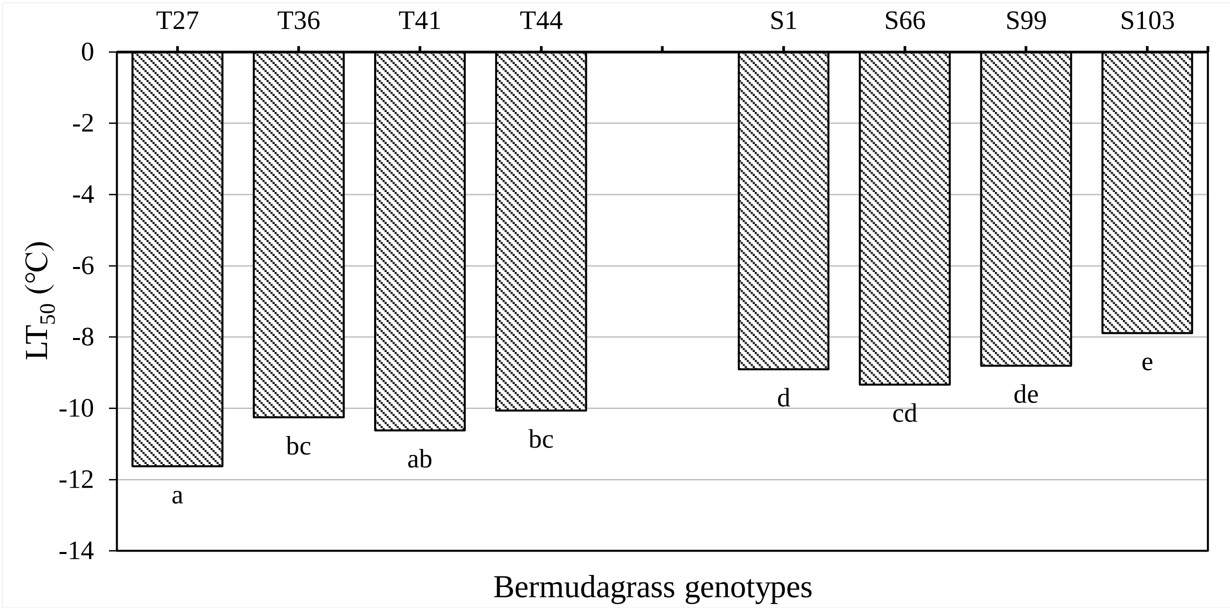


Fig 1. Lethal temperature, based on 50% loss in electrolytes (LT_{50}), of eight bermudagrass genotypes. The eight bermudagrasses represent four genotypes that showed tolerance to aryloxyphenoxypropionate (AOPP) herbicide (T27, T36, T41, and T44), and four genotypes that showed susceptibility to AOPP herbicide (S1, S66, S99, and S103). LT_{50} values marked with the same letters are not significantly different according to Fisher's Protected LSD (*P*=0.05).

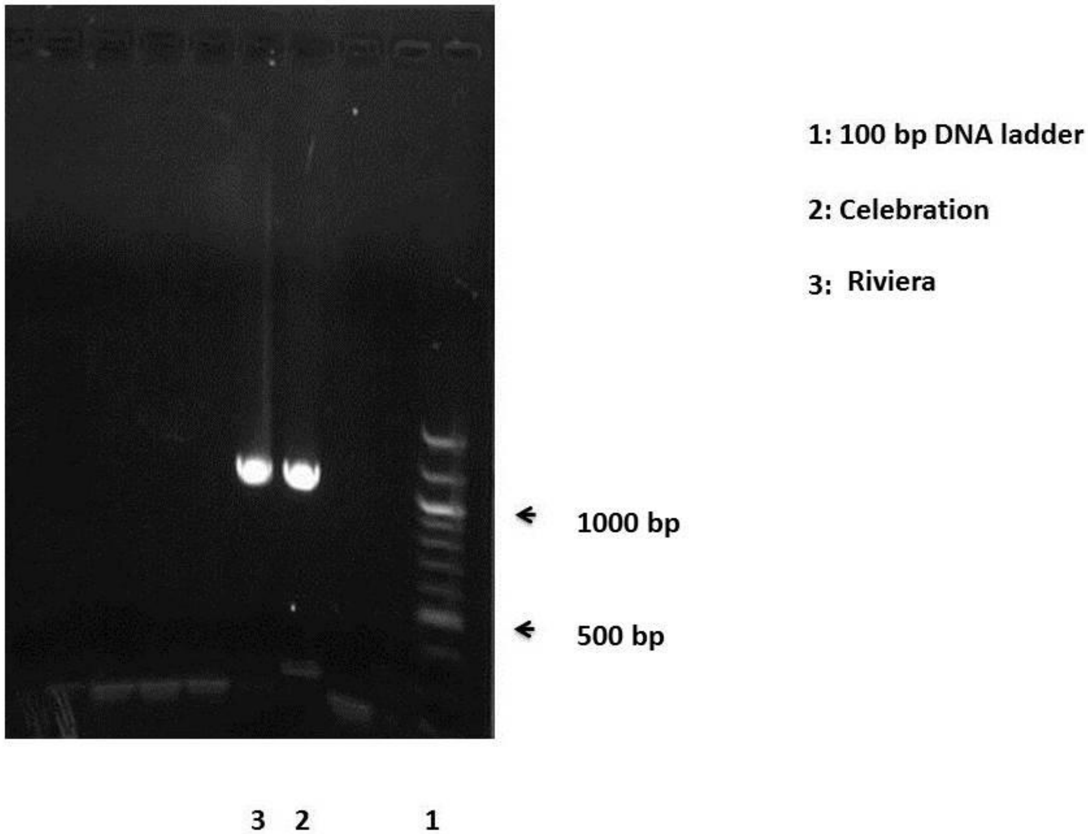


Fig 2. Putative fatty acid desaturase (FADS) genes cloned from "Riviera" and "Celebration" bermudagrasses. The amplified bands were 1,083 base pairs with 361 amino acids.

2015-03-518

Project Title: Utilizing Molecular Technologies to Develop Zoysiagrass Cultivars with Improved Cold Tolerance

Project Leaders: S.R. Milla-Lewis, Aaron Patton, and Brian Schwartz
Affiliation: North Carolina State University, Purdue University, and University of Georgia, respectively.
Objectives: The overall objective of this project is to improve the efficiency of selecting for cold tolerance in zoysiagrass breeding by identifying genomic regions controlling this trait and associated molecular markers that can be used for selection.
Start Date: January 2015
Project Duration: 2 years
Total funding: $20,000

Summary Text:
Zoysiagrass generally requires fewer maintenance inputs compared to many cool- and warm-season grasses. In comparison with other warm-season turfgrasses, Zoysia species have moderate drought and shade tolerance, and lower fertilizer demands. Expanded use of this turfgrass could have a significant impact in making golf courses more environmentally sustainable. One factor limiting widespread use of zoysiagrass; however, is a relative lack of cold tolerance, especially when compared to cool-season grasses. Limited progress has been made in the development of additionally cold tolerant zoysiagrass cultivars since Meyer was released in 1951. This lack of improvement through breeding is in part due to the complexity of cold hardiness traits. The identification of molecular markers that are associated with cold tolerance is needed to improve the efficiency of selection when breeding for this trait. For this purpose, a mapping population of 175 individuals derived from the cross of cold-tolerant 'Meyer' and cold-susceptible 'Victoria' was developed. In June 2014, three replications of each single individual and nine controls including the two parents were planted in a randomized complete block design (RCBD) in 3 x 3 ft plots at the Upper Mountain Research Station in Laurel Springs, NC, and the William H. Daniel Turfgrass Research and Diagnostic Center in West Lafayette, IN. Additionally, the population was replanted at these two locations in June 2015 for secondary evaluations during the 2015-2016 winter season. These four copies of the population and two years of evaluation created six unique environments for winter injury testing. Digital imaging was used to evaluate establishment and winter injury and plots were also rated for pre- (July) and post-freeze (April) turf quality. Significant variation for all four traits was observed within the population (Figure 1), including lines that performed as well as or better than Meyer across all environments (Figure 2).

DNA marker data was collected on the population and used to generate a linkage map of the zoysiagrass genome. A total of 104 simple sequence repeat (SSR) markers and 2,359 single nucleotide polymorphism (SNP) markers were used to construct a high-density genetic map of the zoysiagrass genomes. The map (Figure 3) covers 324 mega basepairs (Mbp) and 2520 centimorgans (cM) as well as all the 20 chromosomes for the zoysiagrass haploid genome. Phenotypic data on winter injury, establishment, and turf quality collected in North Carolina and Indiana in 2014-2016 were used in conjunction with this map to identify quantitative trait loci (QTL) associated with winter hardiness. Fifty-seven putative QTL for winter injury, establishment, pre-freeze turf quality, and post-freeze turf quality were identified within and across six environments. Twelve QTL for winter injury, pre-freeze turf quality, and post-freeze turf quality were identified in two or more environments. Additionally, seven regions of interest where QTL for three or more of these traits co-located were found on chromosomes 8, 11, and 13 (Figure 4). Analysis with NCBI basic local alignment search tool (BLAST) indicated that within these regions are contained proteins that have been previously reported to be related to abiotic stresses including heat, drought, salt, and cold. These genomic regions and markers linked with them could be valuable in implementing marker assisted selection for winter hardiness in a zoysiagrass breeding program.

Summary Points:

- A mapping population of 175 individuals has been developed crossing cold-tolerant cultivar 'Meyer' and cold susceptible cultivar 'Victoria'.
- The mapping population was established in June 2014 in Laurel Springs, NC, and West Lafayette, IN in 3'x3' plots in three replications in randomized complete block design (RCBD). Additionally, the population was replanted at these locations in June 2015 for secondary evaluations during the 2015-2016 winter season.
- The mapping population was evaluated for winter injury establishment, and turf quality pre- and post-freezing in 2014-2016. Significant variation in all four traits was observed in the population, including ten lines that performed as well as or better than Meyer in terms of winter injury across all environments.
- A total of 2,463 DNA markers were used to construct a high-density genetic map of the zoysiagrass genome. The map covers all 20 chromosomes and is the first high density genetic map of the *Zoysia japonica* genome.
- Using the genetic map and field data, seven regions of interest where QTL for three or more of the traits evaluated co-located were found on chromosomes 8, 11, and 13. These genomic regions and markers linked with them will be valuable in implementing marker assisted selection for winter hardiness in a zoysiagrass breeding program.

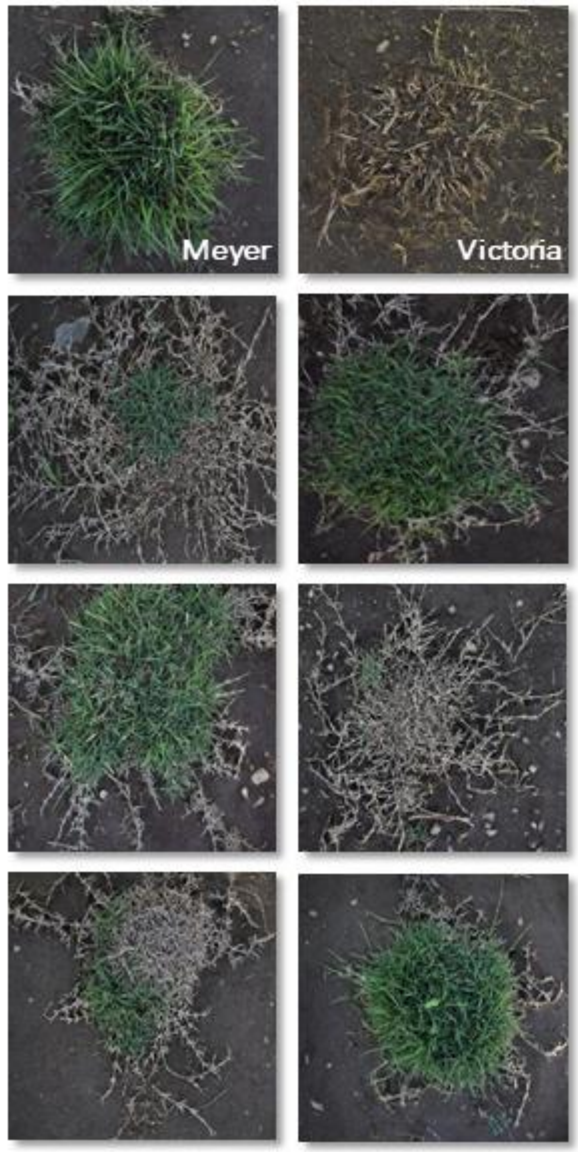


Figure 1: The mapping population and parents showed variation in winter injury levels in the winters of 2014-2015 and 2015-2016.

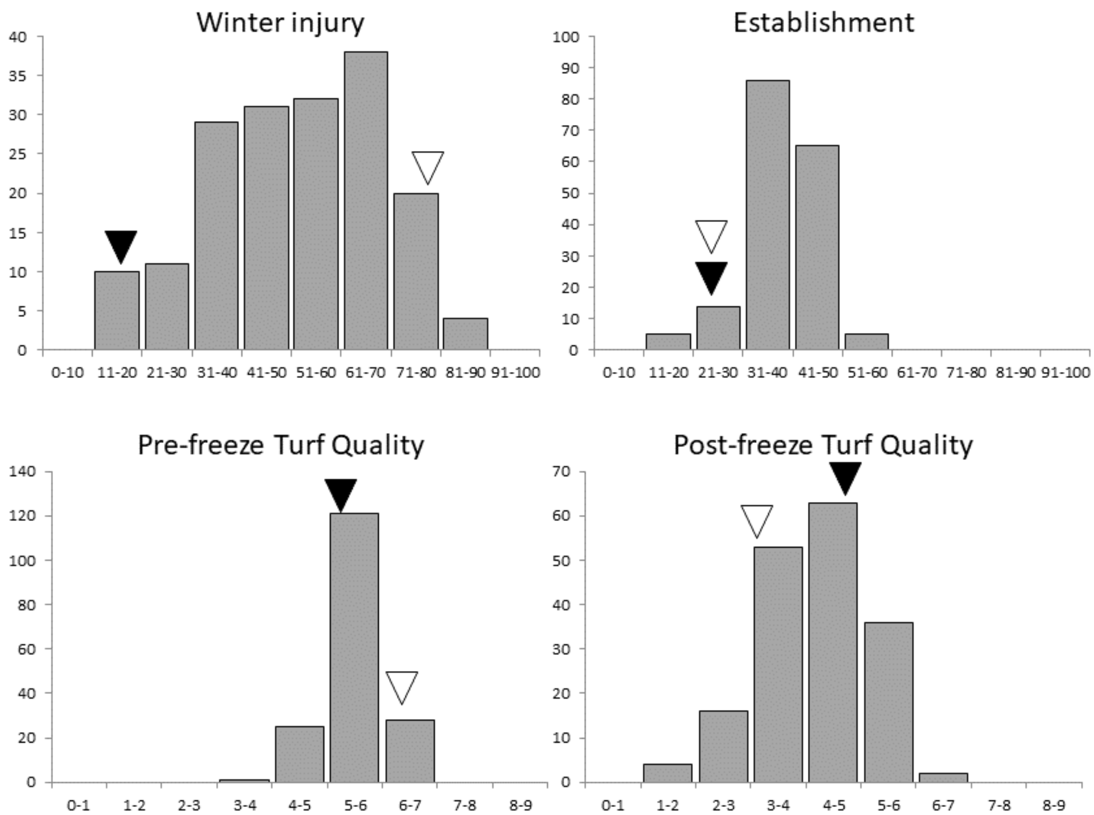


Figure 2: Distribution of winter injury, establishment, and pre- and post-freeze turf quality means for 175 evaluated at Laurel Springs, NC and West Lafayette, IN in 2016. The arrows indicate values of the two parents: 'Meyer' (black) and 'Victoria (white).

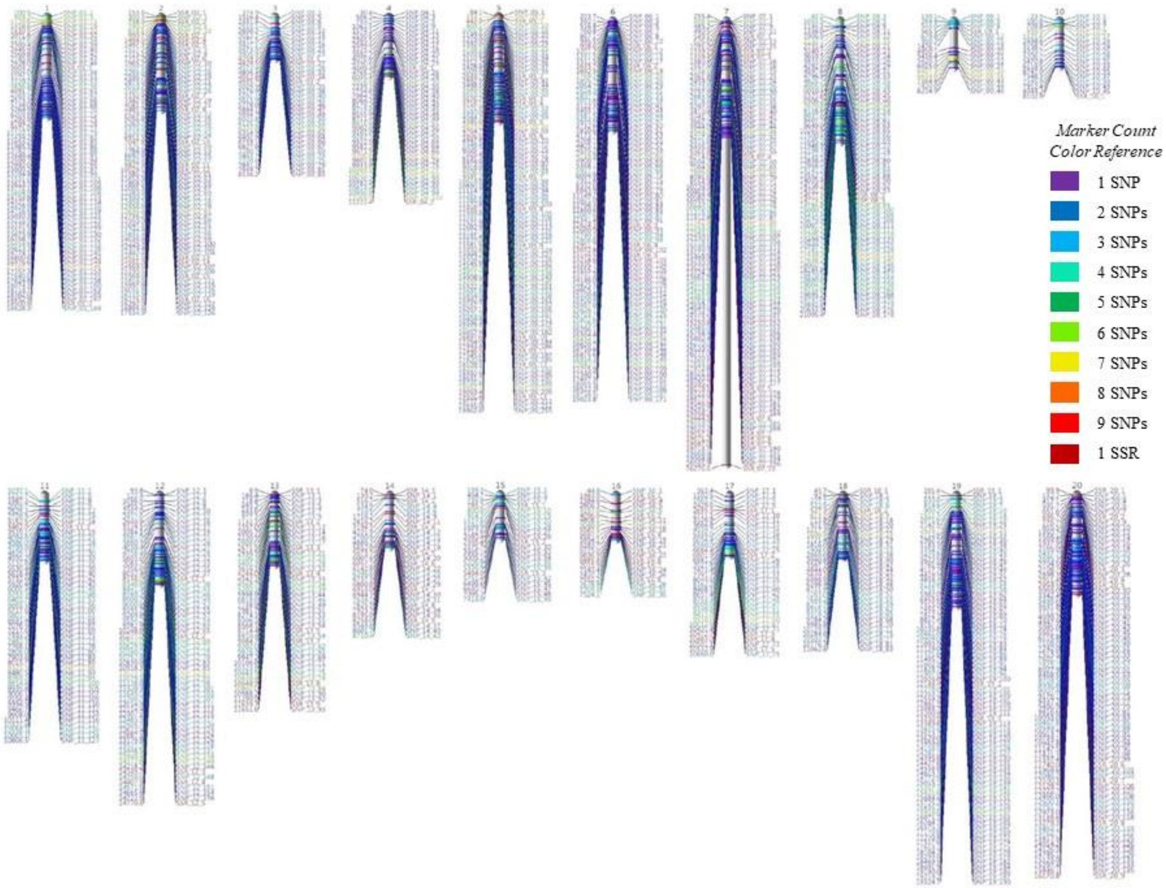


Figure 3: Genetic map of the zoysiagrass genome with 2,418 DNA markers. This high-density map was used to identify genomic regions controlling freeze tolerance.

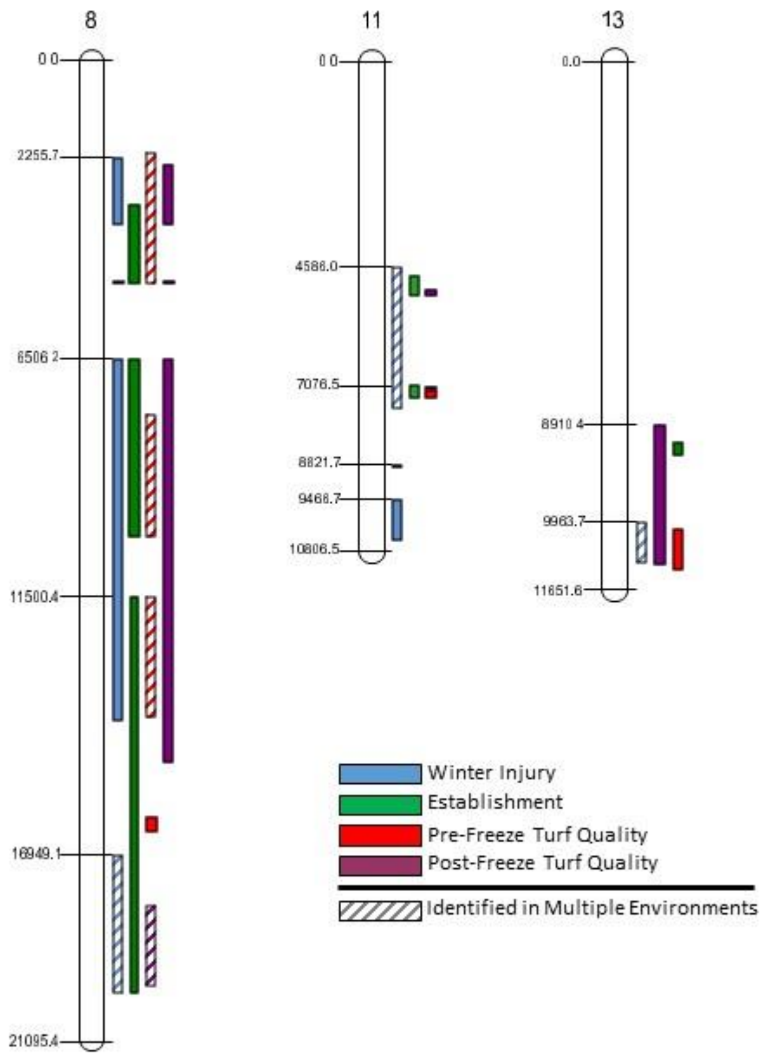


Figure 4: Chromosomal position of QTL associated with winter injury (blue), establishment (green), pre-freeze turf quality (red), and post-freeze turf quality (purple) across combined environments. Map positions for the closest markers are indicated on the left.

2016-01-551

Development of New Bermudagrass Varieties with Improved Turf Quality and Increased Stress Resistance

Yanqi Wu, Dennis Martin, Justin Quetone Moss, and Nathan Walker
Oklahoma State University

Objectives:

1. Improve bermudagrass germplasm for seed production potential, turf performance traits, and stress resistance.
2. Develop, evaluate and release seed- and vegetatively-propagated turf bermudagrass varieties for use on fairways, tee boxes and putting greens.
3. Assemble, evaluate and maintain *Cynodon* germplasm with potential for contributing to the genetic improvement of the species for turf.

Start Date: 2016
Project Duration: six years
Total Funding: $300,000

Bermudagrass is the most widely used warm-season, sod forming turfgrass in the southern USA. Cold hardy, high quality turf bermudagrass cultivars developed and released at Oklahoma State University (OSU) have extended their use in the US transition zone. With the funding from the US Golf Association, the OSU turf bermudagrass breeding program has released seed-propagated cultivars ‘Yukon’ in 1996 and ‘Riviera’ in 2000, and vegetatively-propagated cultivars ‘Patriot’ in 2002, ‘Latitude 36’ and ‘NorthBridge’ both in 2010. The long-term goal of the OSU turf bermudagrass breeding program is to develop seeded and clonally propagated cultivars with high turf quality and improved resistance to abiotic and biotic stresses. Turf bermudagrass breeding and evaluation research activities performed by the OSU team in 2017 are summarized as follows.

One superior vegetatively propagated interspecific hybrid ‘OKC 1131’ developed by the OSU turf breeding program was released by the Oklahoma Agricultural Experiment Station in June, 2017 (Figure 1). The new cultivar has been tested in the 2013 National Turfgrass Evaluation Program national bermudagrass test (http://www.ntep.org/bg.htm). OKC 1131 has exhibited exceptional winter survivability, improved spring greenup, and excellent turf quality; always in the top performing group for these traits over the last four years in the NTEP test. OKC 1131 has significantly improved drought resistance and water use efficiency. The new cultivar has exhibited an excellent establishment rate, effective sod tensile strength for commercial sod production, improved salinity resistance, and high traffic tolerance as well.

Developing greens-type bermudagrass cultivars is an important component of the current project funded by the US Golf Association. Sixteen OSU experimental selections and four commercial cultivars (‘Champion Dwarf,’ ‘Mini Verde,’ ‘Sunday,’ and ‘Tifdwarf’) were tested for putting green turf performance in a replicated field trial established at the OSU Turf Research Center (TRC) in 2015 (Figure 2). In 2016, a second field trial was established including 11 OSU experimental selections and four standard cultivars (Champion Dwarf, Mini Verde, Sunday, and ‘TifEagle’). In the summer of 2017, a new green-type mowing trial of 17 OSU experimental selections and four commercial cultivars trial was established. Data collected in the three trials include establishment rate, spring greenup, disease response (if present), as well as turf quality and its components under different mowing heights. The first trial will be terminated in the summer of 2018 while the two newer trials will continue in 2018 and 2019.

A replicated trial, including 35 OSU vegetatively-propagated experimental selections and four commercial cultivars (‘Astro,’ ‘Latitude 36,’ OKC 1131 and ‘TifTuf’), 11 seed-propagated experimental synthetics and two commercial cultivars (‘Riviera’ and ‘Monaco’), was established at the OSU TRC in the summer of 2017. Data for establishment rate was collected this year. Data for spring greenup, turf quality, disease response, and drought resistance will be collected in 2018 and 2019.

Summary Points

- A new cold hardy, drought resistant, high turf quality bermudagrass cultivar, OKC 1131 was released by the OSU turf bermudagrass breeding program.
- Three sets of OSU experimental turf bermudagrass selections and commercial greens-type cultivars were tested in separate, replicated field trials for turf performance under greens management conditions.
- A new mowing trial of 46 experimental entries and 6 commercial cultivars was established in 2017.

Figure 1. ‘OKC 1131’ turf bermudagrass has fine leaf blades, dark-green color and dense sod as demonstrated in the 2013 NTEP national bermudagrass test plot at Wichita, KS (photo by Y.Q. Wu).

Figure 2. A field image of OSU experimental bermudagrass selections and four commercial standards in a putting green-type mowing trial at the OSU Turf Research Center, Stillwater, OK (photo by Y.Q. Wu).

2016-08-608

Breeding for Resistance to Winter Dormancy in Bermudagrass and Zoysiagrass

Kevin Kenworthy, John Erickson and Kenneth Quesenberry
University of Florida

Objectives:

1) Develop germplasm and cultivars of bermudagrass that are winter dormant resistant.

2) Develop germplasm and cultivars of zoysiagrass that are winter dormant resistant.

Start Date: 2016
Project Duration: 5 years
Total Funding: $150,000

The Florida turfgrass industry is among the largest and most dynamic turfgrass industries worldwide. Florida has more golf courses and acres in sod production than any other state in the U.S. In 1992, within the state of Florida, over $7 billion was spent for production, distribution and use of turfgrass products. These expenses included costs associated with seed, sod, pesticides, fertilizers, equipment, labor, and professional services (Hodges et al., 1994). At $307 million, yearly sales of turfgrass in Florida account for 14% of total horticultural products and services purchased. (Hodges and Haydu, 2002). However, the industry is facing challenges due to imposed water and fertilizer restrictions. To aid golf course superintendents and ensure the continued growth of golf in Florida, better turfgrass cultivars are needed. Here we propose to improve two warm-season genera of turfgrass with the major objective to screen and breed new cultivars that lack an ability to enter winter dormancy. Sub-objectives for improvement include sting nematodes, drought and large patch resistance.

In 2016, an Advanced Bermudagrass trial was planted with 84 total entries. Five entries are commercial controls (Tifway, Celebration, Latitude 36, Tiftuf and Bimini), 8 entries were advanced from a collection of lines obtained from golf courses in south Florida, and 71 lines are from the breeding program. These plots matured through most of 2017 and data collection began in late 2017 to focus on identifying entries that grow and maintain quality through winter. Differences in response to freezing temperatures have been rated (Figure 1). Figure 2 compares the top six overall experimental lines compared to the five commercial cultivars. FB1628 maintained quality through cooler temperatures compared to FB1629 which declined in turf quality in response to reduced temperatures. The changes in turf quality from 8 December to 15 December were the result of several nights with temperatures in the 30s with a freeze occurring 11 December. Figure 3 shows that experimental lines with the best turfgrass quality were also able to maintain acceptable average density through the fall of 2017. The best lines from this study will be replanted in a smaller study for further evaluation. The lines will also be utilized in new crossing blocks.

In 2016, seed was germinated to produce a new population of bermudagrass that resulted in 369 new progenies planted in a single-rep, spaced plant nursery. These matured through 2017 and data collection focused on the identification of those entries that grow and maintain quality through winter. The best lines will be replanted in a replicated study with larger plots.

In the spring 2017 seed were collected from two crossing blocks. One crossing block is made up of advanced lines of common bermudagrass and an elite African bermudagrass, and the second crossing block contains finer textured forage selections previously identified for their lack of dormancy symptoms through winter along with other advanced lines of African bermudagrass. Seed set was extremely poor for both crossing blocks as attempts to geminate harvested seed produced only one or two seedlings. These crossing blocks remain in place and seed will again be harvested in 2018.

In 2016, 88 advanced zoysiagrass entries were planted as part of a USDA-SCRI project at six locations in five states to asses their drought performance. Data is not available from this broader project, but differences in winter performance have been observed. An additional 50 entries are under evaluation in Citra, FL. The majority of these are fine-textured lines with potential uses ranging from golf course putting greens to fairways.

In the fall and spring of 2016 and 2017 crosses were made among elite lines of zoysiagrass that show improved drought tolerance and winter turfgrass performance. These efforts produced over 2,600 new progeny that were planted in the summer of 2017. Lines showing resistance to dormancy will be selected for continued crosses and lines showing persistence after three years will be selected from this population for further evaluations.

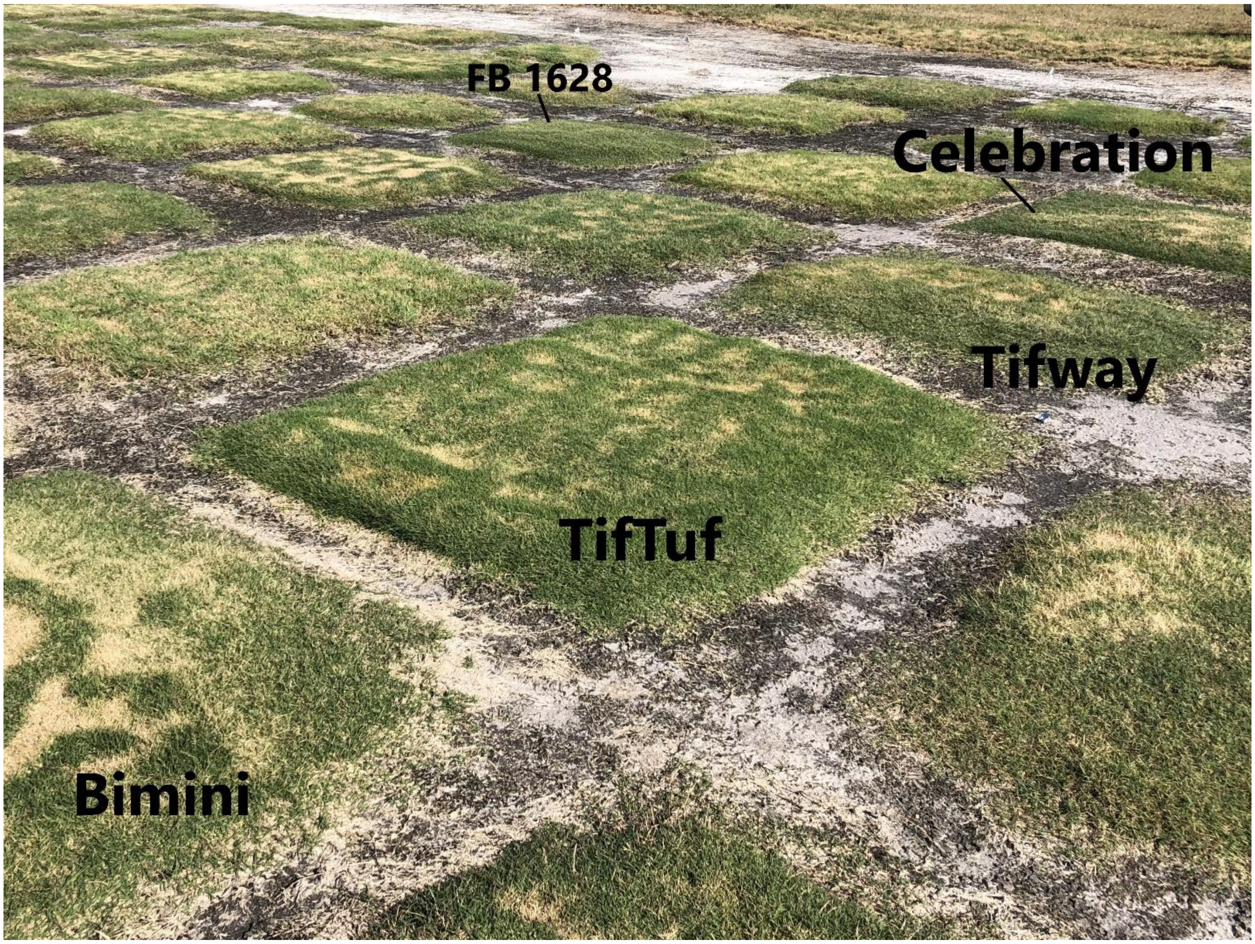


Figure 1. Responses of four commercial bermudagrass cultivars and an experimental line to freezing temperatures. The picture is 10 days after exposure to freezing temperatures.

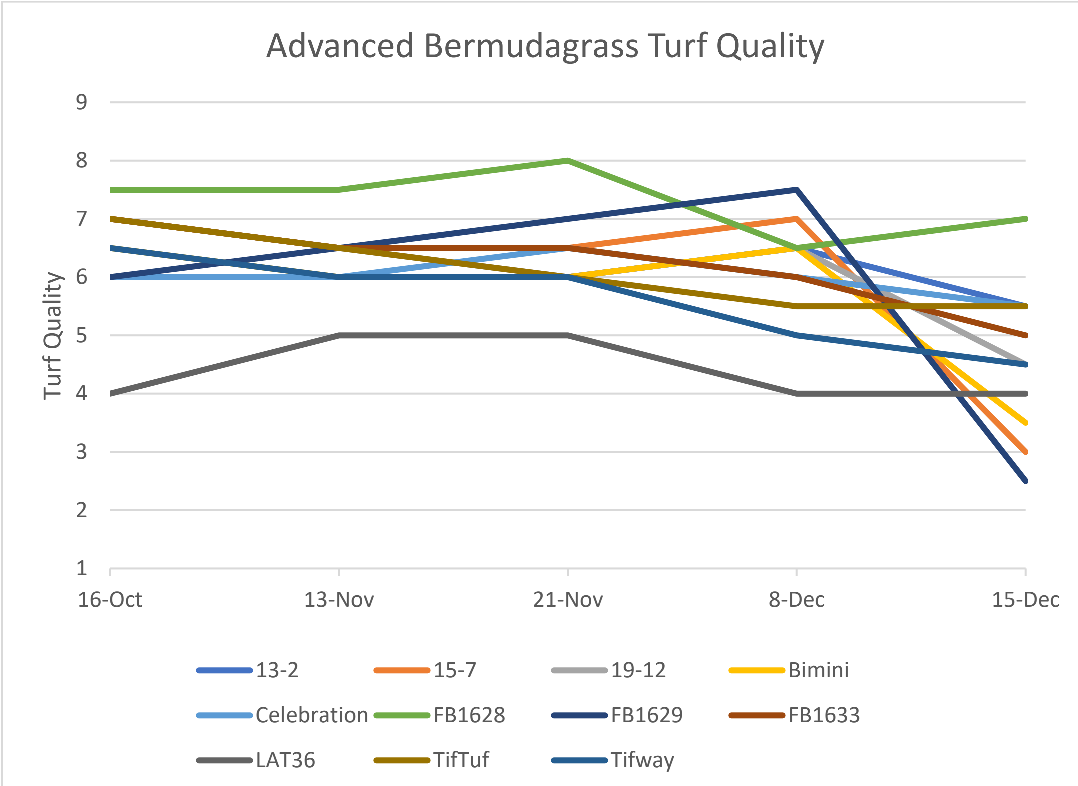


Figure 2. Comparison of the average six best performing experimental lines compared to five commercial bermudagrass cultivars.

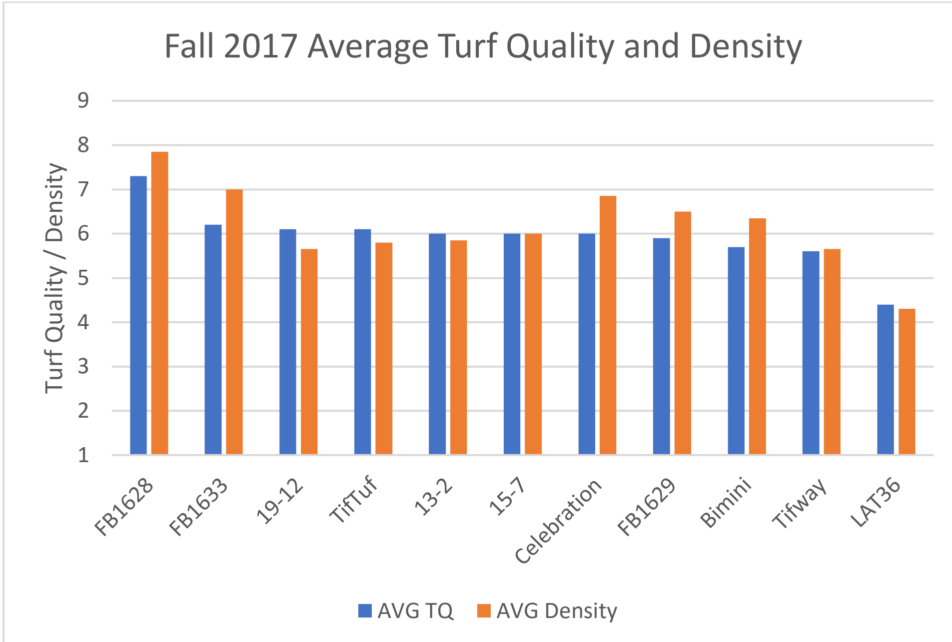


Figure 3. Fall 2017 average Turfgrass Quality and Density of the best six lines (based on TQ) compared to five commercial cultivars of bermudagrass

2016-34-604

Identification of Bermudagrass and Zoysiagrass with Green Color Retention at Low Temperature

Joseph G. Robins and B. Shaun Bushman

USDA ARS Forage and Range Research, Logan, UT 84322

Project Objective(s):

1) Screen germplasm of Bermuda grass and zoysiagrass for green color retention when exposed to cool temperature growth.
2) Identify germplasm sources for ongoing selection for increased color retention under cool temperatures.

Start Date: 2017

Project Duration: 5 years

Total Funding: $225,000

Warm-season grasses thrive under hot temperatures and require lower inputs of irrigation water than many cool-season grasses. Because of these benefits, warm regions of the U.S. now rely on warm-season grasses for many turfgrass settings. Several breeding programs have released and continue to develop improved warm-season grass species that possess higher turf quality and resistance to abiotic and biotic stresses.

Unfortunately, the adaptation of warm-season grasses limits their utility when grown in lower temperature conditions. For example, warm-season grasses provide excellent turfgrass in the desert Southwest during the hotter periods of spring, summer, and fall. Yet, cool temperatures in late fall, winter, and early spring cause these grasses to enter dormancy and lose green color. In response, turfgrass managers frequently over-seed warm-season grasses with cool-season grasses, such as perennial ryegrass, to maintain high turf quality during colder times of the year. This allows for high winter turfgrass quality, but requires higher levels of inputs, including irrigation during the winter months. Therefore, to increase the sustainability of warm-season turfgrass production in warmer regions of the U.S. there is a need to develop cultivars with improved color retention during cool temperature periods.

In conjunction with the USGA, the University of Florida (Gainesville), Oklahoma State University (Stillwater), and Texas A&M University (Dallas), we (USDA) developed an experiment to characterize germplasm sources of Bermuda grass and zoysiagrass for cool temperature color retention. Protected by material transfer agreements, these three universities provided the USDA (Logan) with approximately 900 germplasms of Bermuda grass and zoysiagrass for the purposes of this study. We (USDA) have received the germplasms and have begun to clone them prior to beginning the cool temperature evaluations.

Beginning in 2018, we will screen the germplasms using growth chambers and digital imagery. Once plants have been acclimatized to the growth chamber conditions during a two week phase, we will begin lowering growth chamber temperatures. Beginning at 16 °C, we will expose the plants to lowering temperatures for two week periods. Digital imagery will be used to characterize the color of the plants on a weekly basis during the study. At the end of each two week period, we will lower the chamber temperature by 3 °C. This will continue until all plants in the study have entered dormancy based on the green color evaluation. Using this data, we will calculate a temperature at which a given germplasm is expected to enter dormancy. The study will be replicated with the use of multiple growth chambers and by running the entire experiment at least twice for each germplasm. We plan to conduct and complete the evaluations in 2018.

We expect to find variation for green color retention under cool temperatures in both Bermuda grass and zoysiagrass germplasms. We will publish the results of the study in a peer-reviewed scientific journal and provide the identification of germplasms with highest color retention to the corresponding universities. This information will allow to them to select appropriate parent plants for the development of warm-season turfgrass populations with higher green color retention under cool temperature growth.

- Received approximately 900 germplasm sources of Bermuda grass and zoysiagrass from three participating universities.
- Acclimatized plants to greenhouse conditions in Utah.
- Began cloning of Bermuda grass and zoysiagrass plants prior to study initiation.

2016-35-605

Title: Developing Phenotypic and Genomic Tools to Study Salt-Tolerance in Seashore Paspalum

Project Leaders: David Goad, Ken Olsen, Ivan Baxter, and Elizabeth Kellogg

Affiliation: Donald Danforth Plant Science Center

Summary Text:
Seashore paspalum is becoming a prominent turfgrass for salt affected areas. A driving force in the development of paspalum has been the set of resources generated by breeders such as the world- wide germplasm collection gathered by Dr. Ron Duncan. To maintain this rapid pace of development, we seek to build upon and update these resources in three key ways.

First, while the current germplasm collection is widespread geographically, it may not represent the full breadth of phenotypic and genotypic variation present in the species due to its focus on golf courses and “turf-type” ecotypes. To increase available diversity, we have collected 20 phenotypically diverse individuals from wild populations during a June 2016 collection trip along the southeast coast of the United States (Image 1). Over the next year, we plan to extend our collection efforts both within the US and internationally.

Second, we are developing genomic resources for seashore paspalum. An early draft of the seashore paspalum reference genome has been completed and made available to us. As a pilot study we have resequenced the genomes of six genetically diverse accessions available from the USDA GRIN collection, and have mapped our new sequences to the reference genome sequence for SNP calling and further downstream analyses. These bioinformatic steps are currently ongoing, but preliminary observations suggest that read quality is high and that there is sufficient nucleotide diversity for downstream analyses including population genetics and marker-assisted breeding. A long-term goal is to expand our sequencing efforts to more accessions to identify genomic regions that may contain genes relevant for turfgrass improvement. These sequences and results will be of immense and immediate use to breeders attempting quantitative genetics studies in this system.

Third, as sequencing costs continue to plummet, phenotyping methods are quickly becoming the bottleneck for large-scale quantitative genetics studies. With this in mind we are developing a high- throughput system for scoring salt-tolerance and other phenotypes in seashore paspalum. We combine measurements of the concentration of 20 ions (“Ionomics”) with analysis of images from plants grown at varying salinity levels (Image 2). We have completed a small pilot project of this method in which we collected tissue from each plant for ionomics analysis on two separate weeks. The macronutrients (Na, K, Ca, Mg) show large treatment effects (Figure 1), but genotypic differences remain unclear among the small sample of accessions studied.

We see potential genotypic variation in tissue Na^+ concentration in the second week of our middle salt treatment (ECw = 30); however, whether this is due to genotypic differences or chance is uncertain. In contrast, we notice strong genotypic differences in heavy metal accumulation that are consistent across treatments and time points (Figure 2). The patterns of accumulation are also consistent across heavy metal ions (i.e., genotypes that have high Cd

concentrations tend to also have high Co, Zn, and Cu concentrations). Image analysis is ongoing. A second pilot is currently underway using a modified methodology aimed to improve our ability to detect genotypic differences in salt tolerance.

By increasing diversity in the germplasm collection, improving the genomic resources for the species, and developing high throughput phenotyping methodologies, we have taken the first vital steps toward developing seashore paspalum as a tractable system for large-scale genetic studies.

Summary Points:

- We have added 20 wild accessions to our collection with further collection trips planned.
- We performed whole genome re-sequencing on six accessions at 30x coverage. Bioinformatic analysis is ongoing. Preliminary results indicate abundant nucleotide diversity for further analysis. More accessions will be sequenced in the future.
- A high throughput phenotyping system is in development. A second pilot with improved methods is underway.
- Ionomics analyses suggest that salt tolerance is heavily influenced by the environment (treatment) for this small set of accessions.
- Heavy metal accumulation appears to be under genetic control and to vary among genotypes.

Image 1. A patch of wild seashore paspalum in Georgia. Individuals were collected from this site and others like it along the coast of the South Eastern United States during our June 2016 collection trip.

Image 2. Seashore paspalum accessions being subjected to three salinity treatments in the first pilot of our phenotyping methods.

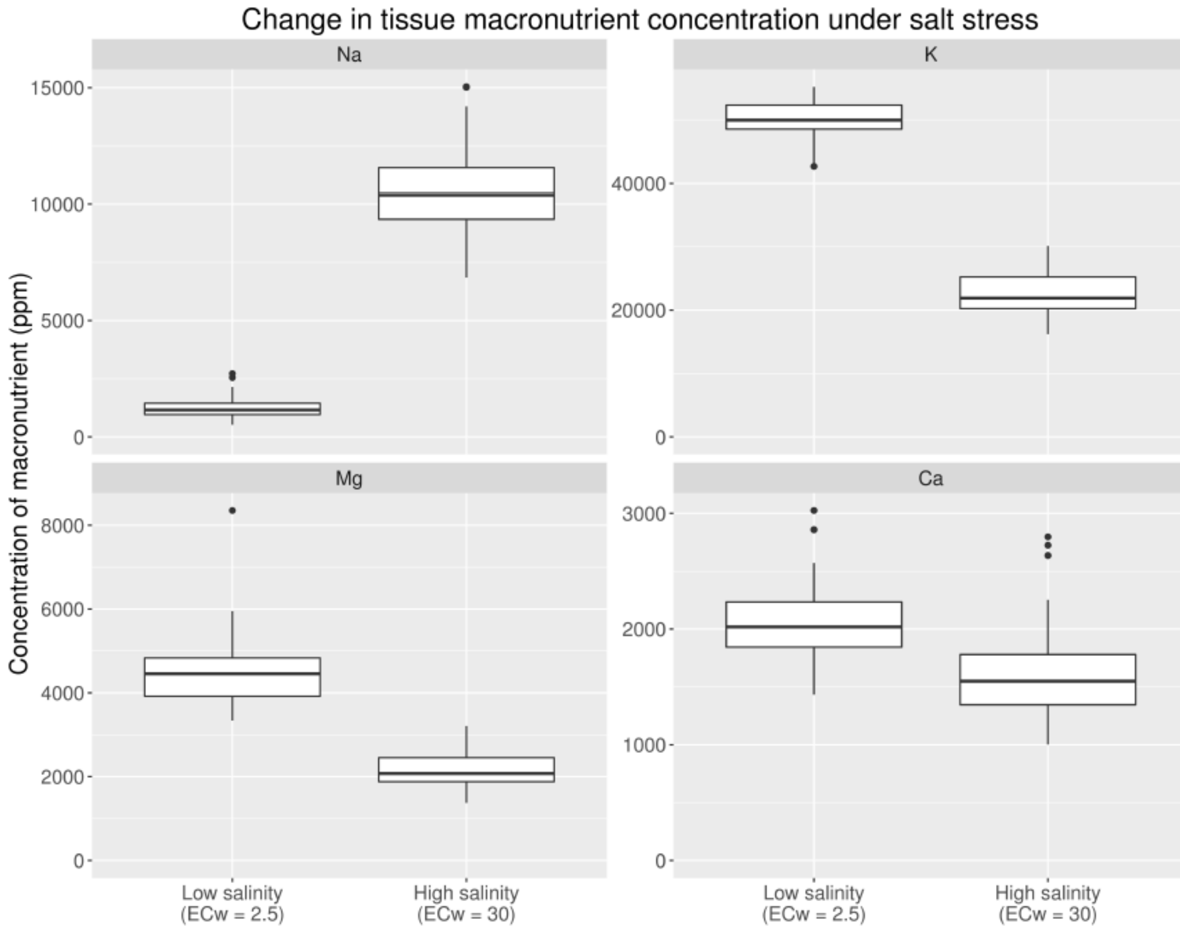


Figure 1. Changes in macronutrient concentration when plants are subjected to salt stress. Data shown are from the first week of tissue collection.

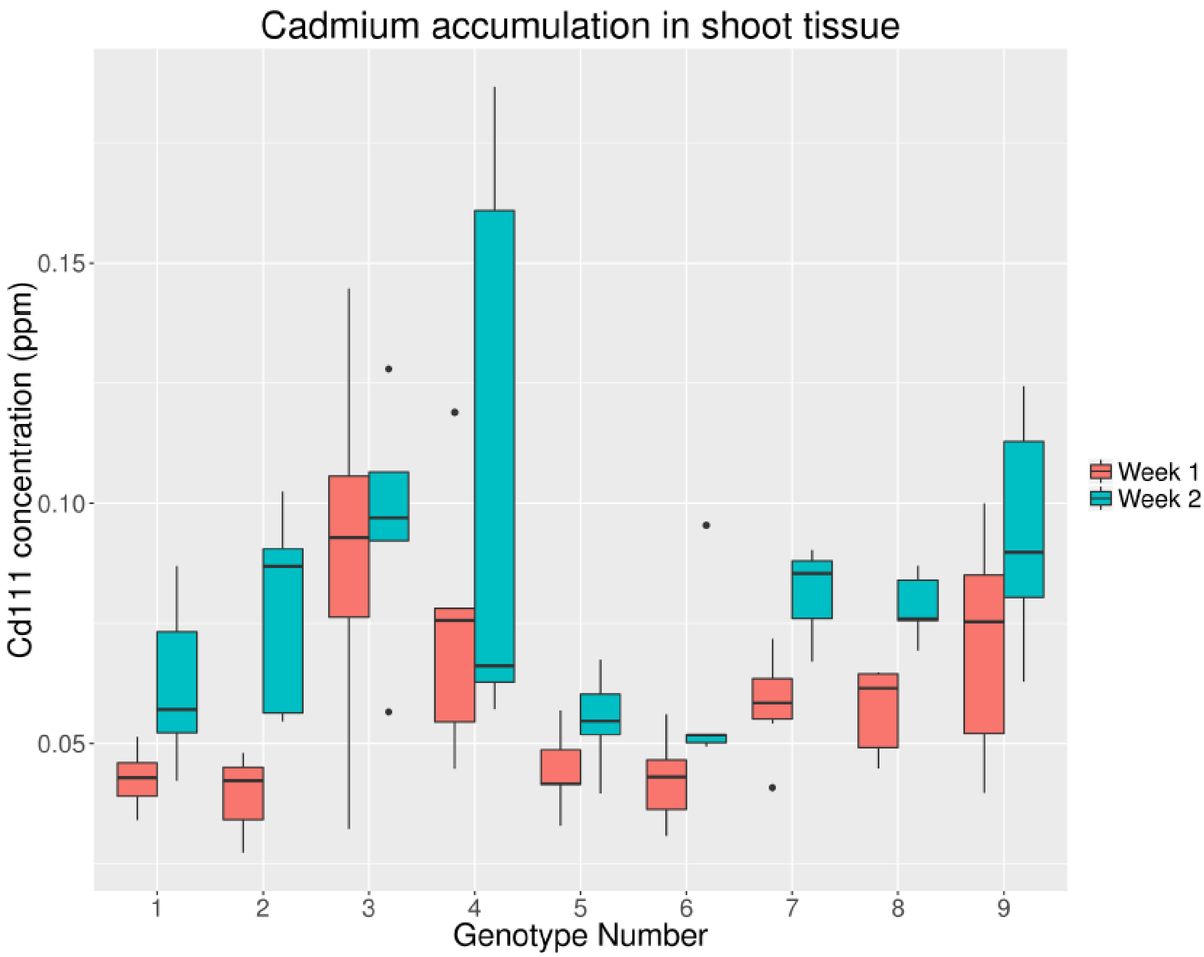


Figure 2. Differences in Cadmium accumulation between genotypes. Tissue was collected from plants in the low salt (ECw = 2.5) treatment on two occasions. A similar pattern is seen in the concentration of other heavy metals.

2017-07-617

Physiological Mechanisms for Developing Improved Drought Tolerance in New Bermudagrasses

Principal Investigators: David Jespersen and Brian Schwartz

University of Georgia

Objectives:

1) Characterize drought tolerance in a collection of new bermudagrass germplasm consisting of commercially available cultivars and experimental materials in both field and controlled environment conditions.
2) Determine the role of physiological mechanisms in providing the levels of drought tolerance found in these grasses by assessing important aspects of plant tolerance including the accumulation of compatible solutes, stomatal regulation, anti-oxidant metabolism, and growth and carbohydrate relations.

Start Date: 2017

Duration: 2 years

Total Funding: $9,800

Drought is a major abiotic stress which leads to damage and decline in turfgrasses throughout the world. These damages include reduced growth and quality, wilting and leaf firing, and eventual plant death. These damages are due to a number of factors including cellular dehydration, the production of reactive oxygen species, and loss of function of cellular membranes and proteins in key metabolic pathways. The ability to thrive in water limited conditions is controlled by the interaction of many complex features including drought avoidance traits such as rooting and water usage, and drought tolerance traits such as osmotic adjustment and anti-oxidant metabolism. New cultivars of hybrid bermudagrasses are constantly being developed, with improved drought tolerance being a major trait of interest. However, drought tolerance mechanisms of new lines, and how they compare of older cultivars is poorly understood. Physiological characterization of traits involved in drought tolerance have not been well documented in many bermudagrasses. Furthermore, much of the work that has been performed has used ‘Tifway’ as the drought tolerant line, despite the cultivar being released over 50 years ago, and new germplasm may utilize drought tolerance mechanisms differently than previous releases. Understanding which traits are contributing to enhanced drought tolerance will help in the development of new lines with increased abiotic stress tolerance as well as help determine the underlying regulation of stress tolerance mechanisms.

The aim of the current project is to characterize drought tolerance in a collection of bermudagrass to better understand key mechanisms affecting performance in water limited environments. This is to be accomplished through both field trials and growth chamber studies. A collection consisting of 3 commercial cultivars, ‘Celebration’, ‘Tifway’ and the recently released ‘TifTuf’, and 3 experimental lines will be used in both field and growth chamber studies. Field studies are being performed under automatic rain-out shelters to prevent rainfall from reaching plots during the drought period when irrigation is with-held. During field trails plants are assessed using NDVI, digital image analysis, relative water content to measure leaf hydration status, membrane stability via electrolyte leakage, osmotic adjustment, and CO_2 flux using an infrared gas analyzer. Growth chamber studies will further characterize drought tolerance mechanisms by measuring shoot and root characteristics, anti-oxidative capacity, and the accumulation of important compatible solutes such as proline, glycine betaine and sugars.

Plots were planted in the spring of 2017 in a randomized complete block, with 4 reps of each cultivar: 'Celebration', 'TifTuf', 'Tifway', and 3 experimental lines. To date, the 2017 field trial has been completed and data are currently being analyzed. The 1st drought trial lasted 7 weeks of plants receiving no irrigation under an automatic rain-out shelter. Significant declines due to drought were found in all lines, as seen by turf quality ratings, however the degree of drought induced damages were significantly different between lines (Fig. 1). The greatest differences in drought were seen at 35 days without water, after which fewer significant differences were found between cultivars. At this point 'TifTuf' had a relative water content of 78%, but values had declined in most other cultivars ('Celebration' 63%, 'Tifway' 65%, 'UGB-208' 64%, 'UGB-70' 67%, 'UGB-42' 71%). A similar trend can be seen with membrane stability measurements, where the percent relative damage in 'TifTuf (23%), and 'UGB-42' (22%) were significantly lower than in 'Tifway' (29%), 'Celebration'(33%), or 'UGB-208' (32%). The cultivar 'TifTuf' was consistently one of the top performing lines, and is likely utilizing a combination of mechanisms for enhanced drought tolerance. Experimental lines such as 'UGB-42' also performed well under drought. These lines maintained canopy color as assessed by NDVI (Fig. 2A), maintained leaf hydration levels (Fig. 2B), had reduced membrane damage (Fig. 2C), and maintained photosynthesis levels (Fig. 2D). The experimental line 'UGB-42' however did not perform as consistently in every trait as 'TifTuf'. For example 'UGB-42' maintained NDVI and leaf water content compared to other lines during drought, but experienced significant declines in photosynthesis.

Future and ongoing work include a growth chamber study to be performed in the winter of 2018, and additional field trials. Plants have been transplanted into pots for establishment in the greenhouse to be used for in depth analysis of key drought tolerance mechanisms in controlled environment growth chambers. Growth chamber studies will quantify root characteristics, anti-oxidant metabolism and the accumulation of important compatible solutes, beyond what has been performed in the field and confirm drought tolerance results. Additionally, fall color and dormancy data are being collected on field plots. A repeated drought trial will be performed in the summer of 2018 to replicate the previous round of drought performed in 2017. Completion of this work will help give additional insight into drought tolerance mechanisms in bermudagrasses, and hopefully assist turfgrass breeders in selecting for key abiotic stress tolerance traits in future cultivars.

Summary Points:

- Significant differences in drought tolerance levels were found among commercial cultivars and experimental lines.

- Top performing lines in the 2017 field trial included the cultivar ‘TifTuf’ and the experimental line ‘UBG-42’
- ‘TifTuf’ had high performance in all measured traits, while other lines such as ‘UGB-42’ maintained leaf water content but had declines in photosynthetic rates, indicating multiple mechanisms may be involved in tolerance be utilized differently.
- Drought tolerance mechanisms will be further explored in controlled environment studies and in a repeated field trial in 2018

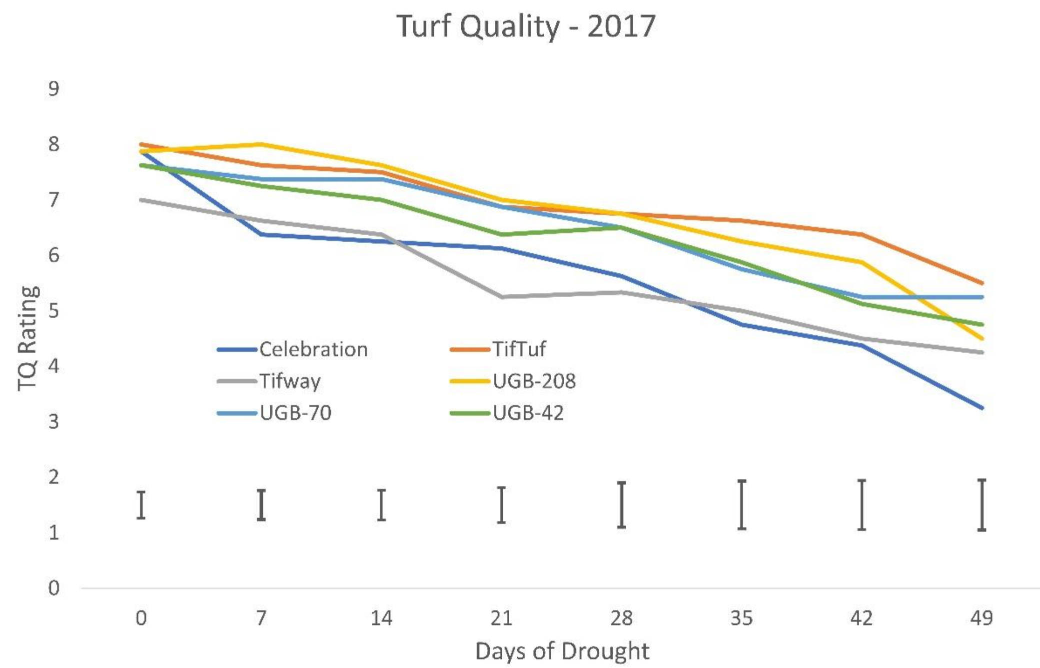


Figure 1. Decline in Turf quality ratings over the 7 week drought trial in period 2017. Bars represent LSD values at $p < 0.05$

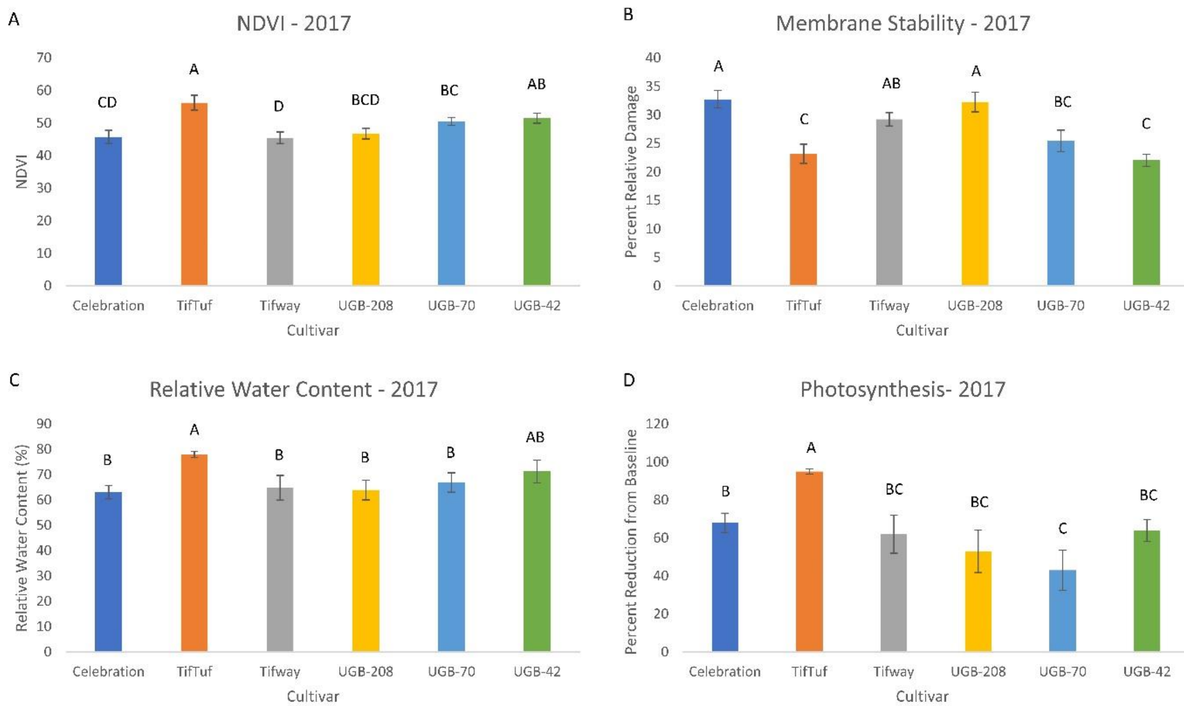


Figure 2. Comparison of lines at 5 weeks of drought stress for (A) NDVI, (B) membrane stability measured by electrolyte leakage, (C) leaf hydration levels determined by relative water content, and (D) percent reductions in photosynthesis as compared to non-stress control. Bars represent standard error, and letters represent LSD groupings at $p<0.05$ with cultivars containing the same letter being in the same statistical group.

2017 Bermudagrass Drought trial

'TifTuf' 'Celebration'

Figure 3. Side by side comparison of 'TifTuf' and 'Celebration' during the 2017 drought trial. These cultivars represent one of the top and bottom performers respectively during the trial.

2017-11-621

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

A. Dennis Genovesi and Ambika Chandra
Texas A & M AgriLife Research - Dallas

Objectives:

1. Development of finer-textured germplasm/cultivar(s) of zoysiagrass with high seed yields that offer an economical alternative to fine textured vegetative types with the potential for rapid turf establishment.
2. Breed to improve characteristics such as turf quality, competitive ability and persistence under biotic and abiotic stresses.

Start Date: 2017 (continued from 2010)
Project Duration: 3 years
Total Funding: $ 89,559

Summary Text –

Zoysiagrass (*Zoysia* spp.) is a warm season, perennial grass used on golf courses and home lawns with a renewed interest because they "provide a high-quality turf at a lower maintenance level than most other turfgrasses" (Murray and Morris, 1988). Most cultivars are vegetatively propagated since they offer a uniform and high quality turf stand. An alternative, relatively inexpensive, way is to propagate zoysiagrass is by seed (Patton et al 2006). Availability of seeded varieties is limited to *Z. japonica* Steud. types with 'Zenith' and 'Compadre' being the most popular. The focus of this research project is the development of a multi-clone synthetic variety which exhibits a leaf texture that is finer than Zenith with seed yields that meet the production goals needed to make it profitable to produce. Since the initiation of the project in 2010, our breeding strategy has been to utilize a classical plant breeding method known as phenotypic recurrent selection, which involves alternating between Spaced Plant Nurseries (SPN) for progeny selection, and isolation crossing blocks to promote outcrossing and recombination. This strategy should allow for the gradual increase, over multiple generations, of desirable alleles affecting seed yields combined with finer leaf texture in the population.

In 2015, we began our third cycle of recurrent selection with the germination of seed harvested from isolation crossing blocks planted in 2013 with 32 entries. The isolation blocks were grouped based on seed head color (red vs green). Seed from each entry was harvested by hand then cleaned and scarified with 30% NaOH (Yeam, et. al. 1985). Seeds were germinated in the greenhouse with fifty of the strongest seedlings from each family planted in Dallas, TX (2015) to establish a SPN of 1,750 progeny with Zenith and Compadre as checks. Data collected during 2016 and 2017 is presented in Table 1. Out of 1,750 progeny, 23 were identified for advancement to 2017 isolation blocks based on seedhead color, seedhead density, height of inflorescence exertion and leaf texture. Data was also taken in 2017 for the number of florets per unit area by counting the number seedheads using a 121-matrix grid where each cell was 8 cm x 8 cm. In addition, water was restricted to the plots for a six-week period during July and August (2017). Plot recovery, once water was re-applied, along with the 2016/2017 performance data allowed us to optimize selection pressure for the best lines with maximum seed production potential. The advanced lines were used to plant 3 isolation blocks (Red #1, Red #2 and Yellow) in 2017 in preparation for the next round of recurrent selection. Iso. blocks were composed of 3 reps each with Red #1 containing 7 entries, Red #2 - 9 entries and Yellow with 7 entries. A subset of these isolation block entries were also identified for use as parental lines in synthetic variety development for possible future commercialization.

In 2016-2017, we continued the evaluation of three synthetics created with our most elite parental lines from the 2013 isolation blocks. Seed was bulked as described in earlier reports and scarified in order to plant a replicated field trial (RFT) in Dallas, TX (2015) at a rate of 2 lbs./1000 sq. ft. Data was collected over a 3-year period and is summarized in Table 2. The turfgrass quality of DALZ 1512, 1513 and TAES 6619 was similar to the seeded checks, Zenith and Compadre, but not as good as the vegetative check, Palisades. The advantage of seeded types over vegetative types is the establishment rates where seeded types are significantly better. As expected, the establishment rate of all three synthetics (DALZ

1512, 1513, and TAES 6619) was better than Palisades and Zorro. In 2017, fall color for DALZ 1512, 1513 and TAES 6619 was better than the seeded checks. Spring greenup of DALZ lines were similar to the seeded checks. Seedhead production was significantly higher on the experimental entries over that of the checks. While this does impact turf quality, it could be viewed as beneficial for planting seed production fields. Seeded experimental synthetics have been provided to Patten Seed Co. (Newnan, GA) and Johnston Seed Co. (Enid, OK) for evaluation. Tim Bowyer with Patten Seed retired in June, 2017 and no update on testing has been provided. John Lamle with Johnston Seed indicates test plots are looking good, but he would like them to experience a cold winter to determine cold hardiness before he expands to test cultivation practices to maximize seed yield.

Of the 23 seeded parental lines advanced to the 2017 Isolation Blocks, the ones with highest seed yields, best drought recovery and turf quality were chosen as parents for 3 new 3-clone synthetics. Those synthetics are identified as 2017 Synthetic Red #1, Synthetic Red #2 and Synthetic Yellow. After grow-in, seed will be bulked in 2018, chemically scarified, and sown to establish RFT in 2019 to evaluate turfgrass quality and performance characteristics of these new DALZ experimental synthetic varieties.

Summary Points

1. Data were collected from the 2015 SPN (1,750 progeny) in 2016 and 2017 with notes taken for turf quality, seed head color, density, height of seedhead exertion, and number of florets per unit area as an indicator of potential seed production capacity. Twenty-three entries were advanced and were used to plant three isolation blocks (Red #1, Red #2 and Yellow) in order to initiate our fourth cycle of recurrent selection.
2. Entries from the 2015 SPN with highest seed yields, best drought recovery and turf quality were chosen as parents for 3 new 3-clone synthetic varieties. These Syn varieties were planted in Dallas, TX (2017) for seed production testing. Seed will be harvested in 2018, and planted as a RFT in 2019 for turfgrass quality/performance evaluation.
3. DALZ 1512 and DALZ 1513, experimental synthetic varieties, exhibited better fall color in 2017 with turfgrass quality and spring greenup similar to the seeded checks. Establishment rate of these synthetic varieties is better than the vegetative checks.

References:

Patton, A. J., Reicher, Z. J., Zuk, A. J., Fry, J. D., Richardson, M. D., and Williams, D. W. 2006. A guide to establishing seeded zoysiagrass in the transition zone. Online. Applied Turfgrass Science doi:10.1094/ATS-2006-1004-01-MG.

Murray, J.J. and K. Morris. 1988. Establishing and maintaining zoysiagrass. Grounds Maint. 23:38-42.

Yeam, D.Y., Murray, J.J., Portz, H.L. and Joo, Y.K. 1985. Optimum seed coat scarification and light treatment for the germination of zoysiagrass (*Zoysia japonica* Steud.) seed. J. Kor. Soc. Hort. Sci. 26(2): 179-185.

Table 1. Progeny evaluation in 2016 and 2017 from the 2015 Seeded Zoysia SPN. Selections were first chosen based on seedhead traits and leaf texture, then quality and recovery from drought. Of the 1,750 individuals in this nursery, a total of 23 from 35 families were identified as seed parents for recombination in isolation (Iso) blocks or synthetics (Syn).

Family TAES No.	Selected (-xx) TAES No.	Isolation Block or/and Synthetic†	Mean seedheads per 8 cm x 8 cm‡	Mean florets per seedhead§	No. Floret per 8 cm x 8 cm¶	Mean Seedhead Density#	Measured Height (cm)††	Mean Quality ‡‡
6585-xx	-34	Iso Y; Syn Y	89	25	2,225	1.4a	13.0a*	5.6a
6593-xx	-10	Iso R 1	63	29	1,827	2.5a	14.7a	4.8a
6594-xx	-09	Iso R1	55	26	1,430	2.9a	14.0a	4.3a
6595-xx	-18	Iso R 1	64	31	1,984	2.0a	15.3	5.0a
6596-xx	-34 -42 -05	-34 (Iso R 1; Syn R 2) -42 (Iso R 2; Syn R 1) -05 (Iso R 2; Syn R 2)	-34 (47) -42 (75) -05 (50)	-34 (34) -42 (24) -05 (29)	-34 (1,598) -42 (1,800) -05 (1,450)	2.8a	13.7a	4.0a
6597-xx	-41	Iso Y	62	27	1,674	2.3a	17.5a	4.3a
6598-xx	-02 -38	-02 (Iso R 2; Syn R 1) -38 (Iso R 2; Syn R 2)	-02 (47) -38 (45)	-02 (30) -38 (26)	-02 (1,410) -38 (1,170)	1.3	12.7a	6.0a
6599-xx	-05	Iso R 2	45	31	1,395	2.6a	14.5a	4.0a
6600-xx	-23 -10	-23 (Iso R 1) -10 (Iso R 2)	-23 (75) -10 (97)	-23 (31) -10 (22)	-23 (2,325) -10 (2,134)	2.8a	12.5a	3.9a
6603-xx	-16 -12	-16 (Iso Y) -12 (Iso Y)	-16 (48) -12 (35)	-16 (25) -12 (30)	-16 (1,200) -12 (1,050)	1.8a	12.3a	5.4a
6609-xx	-24	Iso R 1	39	26	1,014	2.7a	14.2a	4.4a
6610-xx	-36	Iso Y	50	24	1,200	2.7a	13.4a	3.8a
6611-xx	-18	Iso Y	55	21	1,155	2.2a	10.5	5.0a
6612-xx	-15	Iso Y	56	28	1,568	-	-	-
6616-xx	-35	Iso R 2	40	29	1,160	1.7a	10.5	5.6a
6617-xx	-36 -17	-36 (Iso R 1) -17 (Iso R 2)	-36 (68) -17 (43)	-36 (22) -17 (25)	-36 (1,496) -17 (1,075)	2.8a	12.1	3.3
6618-xx	-31	Iso R 2; Syn R 1	81	23	1,863	3.0a	13.9a	3.1
C.V.(%,€)						12.1	14.0	29.5
Family€						< 0.0001	0.0003	< 0.0001

*Significant at the P ≤ 0.05 level.
†Seedhead color was visually rated for selected progeny as either red or yellow/green and used to assign to Isolation Block Red 1 or 2, Isolation Block Yellow or Red or Yellow Synthetic. Two yellow synthetic entries not shown since advanced based on seed weight data from 2015.
‡Using a 121-matrix grid, mean number of seedheads counted from three representative grid cells each 8-cm x 8-cm in size.
§Mean number of florets counted from three representative seedheads from each plot.
¶Number of florets calculated by multiplying mean seedheads per 8-cm x 8-cm and mean number of florets per seedhead.
#Seedhead density was visually rated on a 1-3 scale (1= <30%; 2 = 30-60%; 3 = >60%) on 7 Sept 2016, and was averaged from all selected progeny for statistical comparison using Tukey's HSD.
††Seedhead height is the mean height of three representative seedheads from each plot.
‡‡Quality was visually rated on a 1-9 scale (1= poor; 6=minimum; 9=excellent) on 24 Aug 2016. The quality ratings from all selected progeny in each family were averaged and statistically compared using Tukey's HSD.
€Coefficient of variation was calculated from the ANOVA by dividing the root mean square error by the grand means for each trait and multiplied by 100.

Tables 2. A and B. A 3-year summary of performance of advanced synthetic seeded zoysia lines DALZ 1512, DALZ 1513 and TAES 6619 compared to seeded checks, Compadre and Zenith, and vegetative checks, Palisades and Zorro.

A.

	Turfgrass Quality†											Dry down	Recovery	Fall
Entry	**04/13/16**	**05/11/16**	**05/26/16**	**06/16/16**	**07/12/16**	**08/01/16**	**09/08/16**	**5/2/2017**	**6/1/2017**	**7/21/2017**	**Avg.**	**8/3/2017**	**9/5/2017**	**10/28/15**
DALZ 1512	5.0 abc*	6.0 a	5.0 ab	7.0 a	5.3 ab	3.7 bc	2.0 c	3.7 bc	4.0 bc	7.0 bc	4.9 ab	4.3 b	5.0 d	5.0 ab
DALZ 1513	4.7 abc	5.3 a	4.3 bc	7.0 a	4.7 b	2.3 d	2.0 c	3.3 c	3.3 c	7.3 bc	4.4 b	3.3 bc	6.7 bc	5.3 a
TAES 6619	3.7 bc	4.7 a	4.0 cd	6.0 a	5.0 b	3.7 bc	3.0 b	3.7 bc	4.0 bc	6.7 c	4.4 b	4.3 b	7.0 b	4.0 b
Compadre¶	5.3 ab	5.3 a	3.3 d	7.0 a	5.3 ab	3.3 bcd	2.0 c	4.0 abc	4.3 bc	7.3 bc	4.7 b	4.0 b	7.3 b	5.0 ab
Palisades#	3.3 c	4.7 a	5.3 a	5.7 a	5.0 b	4.3 ab	4.0 a	5.0 a	5.7 a	8.7 a	5.2 ab	8.0 a	8.7 a	5.3 a
Zenith¶	5.0 abc	5.7 a	3.3 d	7.0 a	5.0 b	3.0 cd	2.0 c	4.7 ab	4.0 bc	7.3 bc	4.7 b	2.7 c	5.3 d	5.3 a
Zorro#	5.9 a	5.7 a	5.7 a	6.7 a	6.3 a	5.0 a	3.7 ab	5.0 a	5.0 ab	7.7 b	5.7 a	3.7 bc	5.7 cd	5.7 a
LSD (0.05) ††	1.9	1.7	0.9	1.2	1.2	1.1	0.7	1.2	1.0	0.9	0.8	1.3	1.3	1.3
C.V. (%)‡‡	22.2	17.8	11.9	10.0	12.5	17.2	15.3	20.8	19.8	10	32.8	40.2	24.1	14.5

B.

	Establishment (%)				Greenup†		Fall Color†			Seedheads (%)‡				
Entry	**11/23/15**	**04/13/16**	**08/01/16**	**Avg.**	**03/15/16**	**4/5/2017**	**11/23/15**	**11/11/16**	**11/14/2017**	**05/26/16**	**4/20/2017**	**6/1/2017**	**9/26/2017**	**10/1/2017**
DALZ 1512	95.0 a	73.3 a	100.0 a	90.0 a	4.7 bc	4.3 bc	2.3 b	2.3 c	3.3 b	88.3 a	31.7 a	60.0 a	70.0 a	55.0 a
DALZ 1513	93.3 a	80.0 a	96.7 a	89.4 a	4.0 c	3.3 c	3.3 ab	2.0 c	3.3 b	75.0 b	33.3 a	61.7 a	56.7 b	43.3 b
TAES 6619	71.7 b	63.3 a	95.0 a	76.7 a	4.7 bc	4.3 bc	2.3 b	3.0 b	3.7 b	75.0 b	46.7 a	51.7 a	40.0 c	41.7 b
Compadre§	88.3 a	76.7 a	98.3 a	87.8 a	5.3 ab	4.0 bc	2.0 b	2.0 c	2.3 c	10.0 c	46.7 a	5.0 c	5.0 de	5.0 c
Palisades¶	28.3 c	21.7 b	76.7 b	42.2 b	4.0 c	5.7 a	3.3 ab	3.7 a	5.7 a	6.7 cd	5.0 b	30.0 b	13.3 d	6.7 c
Zenith§	91.7 a	68.3 a	95.0 a	85.0 a	5.3 ab	4.7 ab	2.7 b	2.0 c	1.7 c	15.0 c	50.0 a	5.0 c	0.67 e	1.7 c
Zorro¶	21.7 c	25.6 b	76.7 b	43.3 b	6.3 a	4.0 bc	4.3 a	3.7 a	4.0 b	0.0 d	0.0 b	0.0 c	0.0 e	0.0 c
LSD (0.05)#	10.9	18.0	7.8	17.5	1.3	1.1	1.4	0.6	0.9	8.8	19.2	11.8	10.2	7.6
C.V. (%)††	8.7	16.8	4.8	35.7	15.2	19.8	27.9	12.5	37.5	12.8	71.1	88.3	104.8	103.7

*Significant at the 0.05 probability level.
†Turfgrass quality, fall color, and spring green-up were collected on a 1-9 scale (1 = brown/dormant, 9 = completely green/ excellent; 5 = minimum acceptable green color).
‡Seedhead percentages were collected as a visual estimation of plot coverage.
§Compadre and Zenith were seeded checks sown at a rate of 2 lbs. /1000 sq. ft.
¶ Palisades and Zorro were planted as vegetative plugs with four 10 cm plugs per plot.
#Means were separated using the student's t-test (LSD) at a 0.05 significance level.
††Coefficients of variation (C.V.) were determined from analysis of variance by dividing the root mean square error by the grand mean and multiplying by 100.

2017-14-624

Project Title: Development of a shade-tolerant bermudagrass cultivar(s) suitable for fine turf use.
Principal Leaders: Charles Fontanier and Yanqi Wu
Affiliation: Oklahoma State University

Objectives:

1. *Screen for fine turf qualities and shade resistance in newly developed common and hybrid bermudagrass germplasm,*
2. *Further develop an existing bermudagrass breeding population for superior fine turf characteristics, shade resistance and seed yield, and*
3. *Develop and validate a high throughput method for screening plants for shade resistance.*

Start Date: 2017
Number of Years: 3
Total Funding: $90,000

<u>Background and Rationale</u>
Bermudagrass is a desirable turfgrass for use in the transition zone due to its relatively good drought, heat, disease, and insect resistance, and reasonably good cold hardiness. The main factor that prevents more widespread use of bermudagrass is its poor shade tolerance. Beginning in 2007, 45 common bermudagrasses [*Cynodon dactylon* (L.) Pers. var. *dactylon*] collected from China, Africa, and Australia that exhibited good seed production were tested along with four bermudagrass varieties for shade tolerance and overall turf quality. Of those 45 bermudagrasses, the 10 best-performing selections were chosen for further development. Polycrossing combinations of those 10 selections in 2011 produced three synthetic populations. Two of these experimental cultivars, OKS 2011-1 and OKS 2011-4, were tested for shade tolerance and the third OKS 2011-3 was retained for further selection. OKS 2011-1 and OKS 2011-4 did not outperform existing seeded-type cultivars in severe shaded conditions. From the OKS 2011-3 breeding population, the best performing 90 plants were selected after two years of shade pressure. These plants were tested in the field for turf quality and major seed yield related traits. This project seeks to build on previous work to continue selecting for shade tolerance among common bermudagrasses and interspecific hybrids.

<u>Methods</u>
A rapid throughput screening method was developed to identify genotypes showing enhanced shade tolerance under greenhouse conditions. This was done to reduce cost and time associated with multi-year field trials. In June 2017, 75 bermudagrass genotypes were established from sprigs within 2.5-in dimeter deep pots under three light environments (0, 51, and 63% shade) within a research greenhouse. Once uniformly established (~8-weeks), plants were subjected to shade treatments using neutral density black fabric for 4 months and clipped biweekly at 1.5-in to promote rapid stress. Fertilizer was applied using a commercial soluble fertilizer (Peter’s 20-20-20)

biweekly at carefully metered amounts (0.125 lb N M^{-1}) to ensure uniform application. Turf quality, leaf elongation rate, and above-ground biomass (verdure) were assessed at the conclusion of the 4-month shade treatment.

Early Results
After 4 months of heavy shade treatment, visual turf quality of 7 experimental bermudagrass cultivars exceeded the minimally acceptable threshold of 6 (Fig 1). Industry standard 'TifGrand' demonstrated a mean turf quality score of 4.7, while 18 of OSU's experimental cultivars exceeded this value. Similar to our previous field trial, 'Patriot' was one of the worst performing cultivars under the greenhouse screening method. The top-performing cultivar ('2014-4x2') showed minimal shade avoidance response (etiolation), while the worst-performing cultivar ('2014-29x19') developed a 'stemmy' and etiolated growth habit under heavy shade (Fig. 2 and 3). Results suggest the greenhouse method can be used to quickly identify shade tolerant genotypes from large numbers of experimental units, and that the OSU germplasm collection shows promise for development of a new interspecific hybrid bermudagrass cultivar having enhanced shade tolerance.

Future Expectations
The greenhouse screening trial will be repeated in spring 2018 to verify results from the first run. Findings from the greenhouse trials will be compared to those from a field trial in order to validate the method and further work towards development of a new cultivar. Field plots dedicated for this project have laid fallow for a full year and will be prepared for planting of 75 genotypes, including industry standards, in spring 2018. The plots will be established under ambient conditions. Plots will be subjected to shade conditions as early as mid-summer in order to start the selection pressure. The cultivars will be planted in a nearby non-shaded plot in order to verify performance is related to shade treatment and not general poor adaptation.

Summary Points:

- 75 bermudagrass genotypes have been screened for shade tolerance under greenhouse conditions.
- Several of these genotypes expressed similar or better shade tolerance to the current industry standard TifGrand bermudagrass.
- All 75 genotypes will be planted in the field in spring 2018 for validation of greenhouse screening methods.

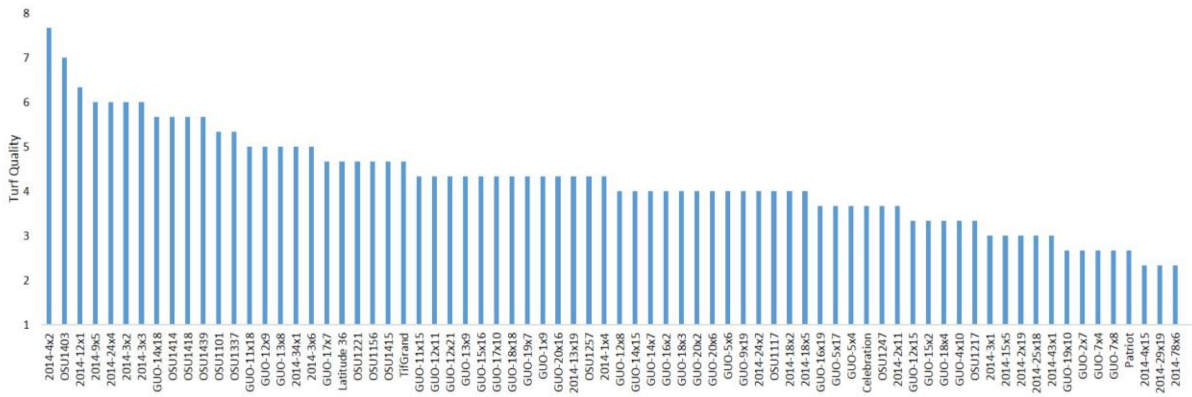


Fig. 1. Turf quality of experimental bermudagrasses under 4-months of heavy shade in a greenhouse.

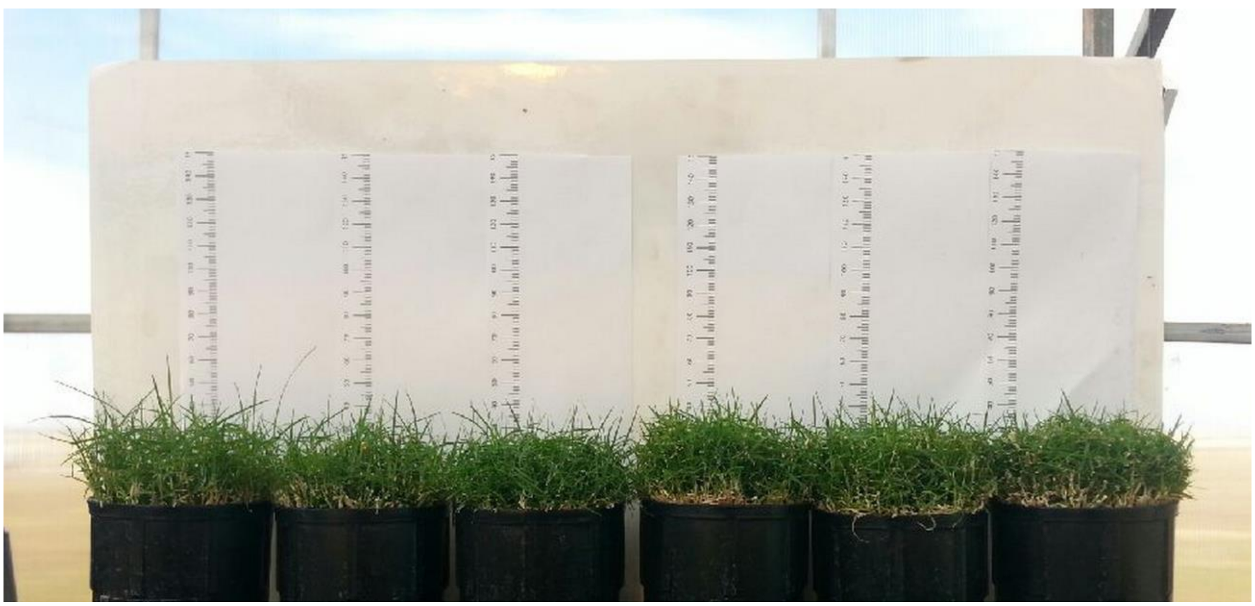


Fig. 2. Top performing entry ‘2014-4x2’ under heavy shade (left) and full sun (right).

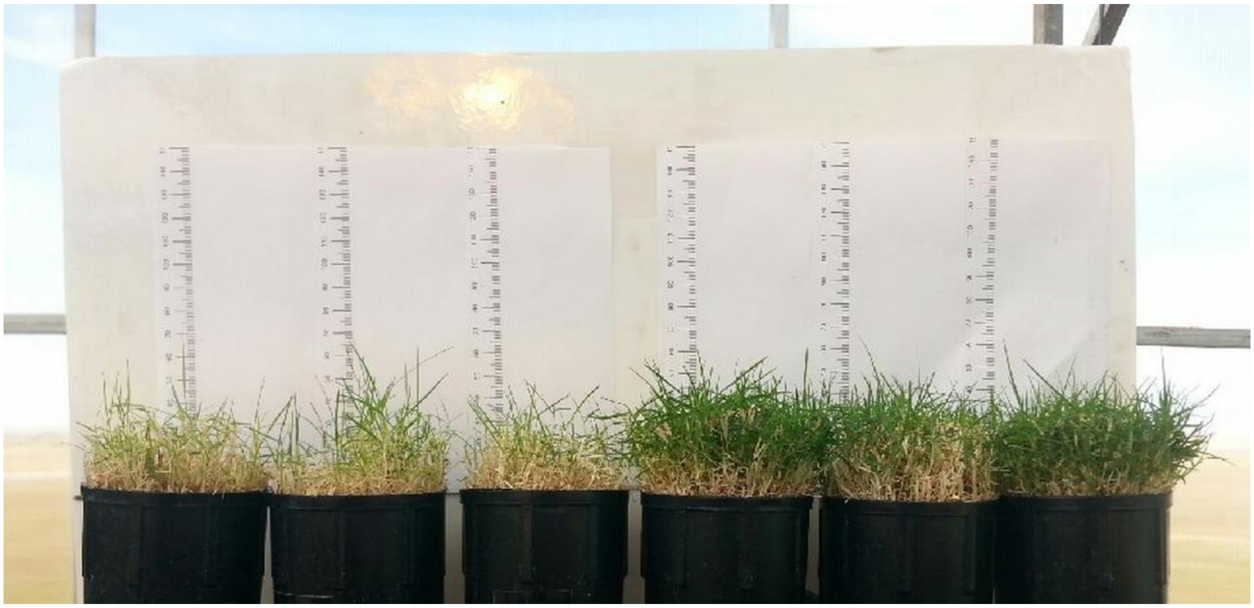


Fig. 3. Poor performing etnry ‘2014-29x19’ under heavy shade (left) and full sun (right).

2017-21-631

Improvement of Bermudagrass, Zoysiagrass, and Kikuyugrass for Winter Color Retention and Drought Tolerance

Adam J. Lukaszewski and James H. Baird
University of California, Riverside

Objectives:

1. Develop bermudagrass, kikuyugrass, and zoysiagrass turf-type genotypes with improved winter color retention and drought tolerance for Mediterranean and arid climates.
2. Utilize Diversity Arrays Technology (DArT) markers to aid in breeding efforts and marker-assisted selection.
3. Develop techniques to reduce kikuyugrass ploidy level to diploid by androgenesis in order to reduce aggressiveness and improve turf quality and playability characteristics.

Start Date: 2017
Project Duration: 5 years
Total Funding: $250,000

Summary

Warm-season or C4 turfgrass species including bermudagrass, zoysiagrass, and kikuyugrass are much better adapted to heat, drought, and salinity compared to cool-season grasses, but they go dormant during winter months making them less desirable choices for lawns, athletic fields, and golf courses. Clear differences in winter color retention, drought tolerance, and water use efficiency exist among warm-season grasses, and within individual species, which indicates that genetic improvements are possible. Our objectives are to develop improved genotypes of these three species with emphasis on winter color retention and drought tolerance for Mediterranean and arid climates.

Bermudagrass

In addition to existing collection of six *Cynodon* species (over 100 accessions), a collection of bermudagrass genotypes from the University of Florida (195 accessions) and Oklahoma State University (350 accessions) was planted in 2016 and maintained during 2017. The collection is continuously supplemented with samples collected locally, or donated to us by others. All collection accessions, along with hybrids obtained in last few years are being screened for color retention and turf quality. To increase genetic variability of bermudagrass accessions from UCR, genotypes from our collection were intercrossed (detached tiller crosses and open pollination). New crossing blocks were also established in May 2017. Spikelets from ca. 150 accessions from the UCR collection and from crossing blocks were harvested for establishment and selection next year. Accessions with latest dormancy and the earliest green-up will be intercrossed, on the assumption that the next generation hybrids may show reduced dormancy period. To support traditional selection of bermudagrass accessions and establish the parentage of the existing hybrids, marker-assisted selection using Diversity Arrays Technology (DArT) was included. DNA of 181 accessions was extracted and sent for genotyping.

Twelve of the most promising hybrids produced in earlier years were chosen for further evaluation in replicated plots across several climatic zones in California (University of

California, Riverside (Riverside, Inland Southern California); Coachella Valley (Thermal, Low Desert) and Fairfax (Northern California)). These are being compared with four widely used or new cultivars: Bandera, Santa Ana, TifTuf and Tifway. Plots were established on May 22 in Riverside; June 14 in Coachella Valley; and June 22 in Fairfax. Dynamics of establishment were measured using Digital Image Analysis (DIA) and turf quality is being evaluated after obtaining full cover. Tested accessions and hybrids showed different growth dynamics in different locations. UCR hybrid, TP 6-3 showed high turf quality, as evaluated in Riverside (UCR) and Coachella Valley. All hybrids and accessions tested in Riverside and Coachella Valley have demonstrated turf quality ratings of 6 (minimally acceptable) or higher and are comparable to commercial cultivars in this study. Quality of tested bermudagrasses in Fairfax was lower, however, quality evaluation there started later because of slower growth. Additionally, recovery after scalping was evaluated for 58 hybrids and accessions. Recovery time varied from 11 to 35 days. Along with intercrossing and selection for winter color retention and turf quality, drought tolerance of bermudagrass hybrids will be evaluated next year.

Kikuyugrass

Accessions of kikuyugrass from California show relatively little variation, therefore our work in 2017 was focused on increasing genetic variability. A collection of 103 available genotypes representing the greatest genetic diversity was established. Seeds of kikuyugrass (unknown origin) were germinated and young plants were selected for dark green color, slower growth rate and finer texture. So far, 439 plants were retained. This number will be further reduced by selection for better winter color retention. Best selections will be included in the collection and evaluated on small plots.

Another attempt was made to generate haploids of kikuyugrass. Protocols for material collection and stress application to induce the switch from the gametophytic to sporophytic pathway of microspore development were tightened up. In this last effort, some 13,000 anthers were plated and while androgenic response was observed, on a scale wider than in the first attempt in 2016, no haploids have been produced. An attempt will be made to generate haploids in different seasons; perhaps the microspores will be more amenable to manipulation than in peak summer.

Observations of pollination and self-incompatibility of kikuyugrass have started in October 2017 on 18 genotypes. This is done to better understand the pollination mechanisms and to help in breeding efforts. For this purpose flowers are self- and cross-pollinated and observations of seeds development will be performed.

Accessions from the collection were used in preliminary drought tolerance assessment, which showed considerable variation for the character. One accession remained green for over 100 days of drought.

Zoysiagrass

A large collection of zoysiagrass genotypes from the University of Florida (155 accessions) and Texas A&M (219 accessions) was planted in 2016 and maintained during 2017. Collection was supplemented with 14 UCR hybrids obtained from breeding program conducted by Dr. V. B. Youngner and V. A. Gibeault, which resulted in releasing cultivars ‘El Toro’, ‘De Anza’ and ‘Victoria’. At present there are no binding observations of this material.

Summary Points

- Dr. Marta Pudzianowska joined our team as a postdoctoral scholar on this project.
- The rage of genetic variation of bermudagrass, kikuyugrass and zoysiagrass has been expanded by addition of new accessions and expanding existing collections.
- Hybridization of existing UCR bermudagrass accessions continued, with emphasis on genotypes possessing desirable winter color retention, early spring green-up, and drought tolerance. A large amount of seed was produced; its germination rate is yet to be determined.
- New replicated trials across several climatic zones in California have been established to evaluate 12 of our most promising bermudagrass hybrids in comparison to cvs. Tifway, Santa Ana, TifTuf, and Bandera.
- Protocols and best culture media for androgenesis of kikuyugrass were tested and selected. Some progress toward successful androgenesis was evident but no haploids have been produced so far.

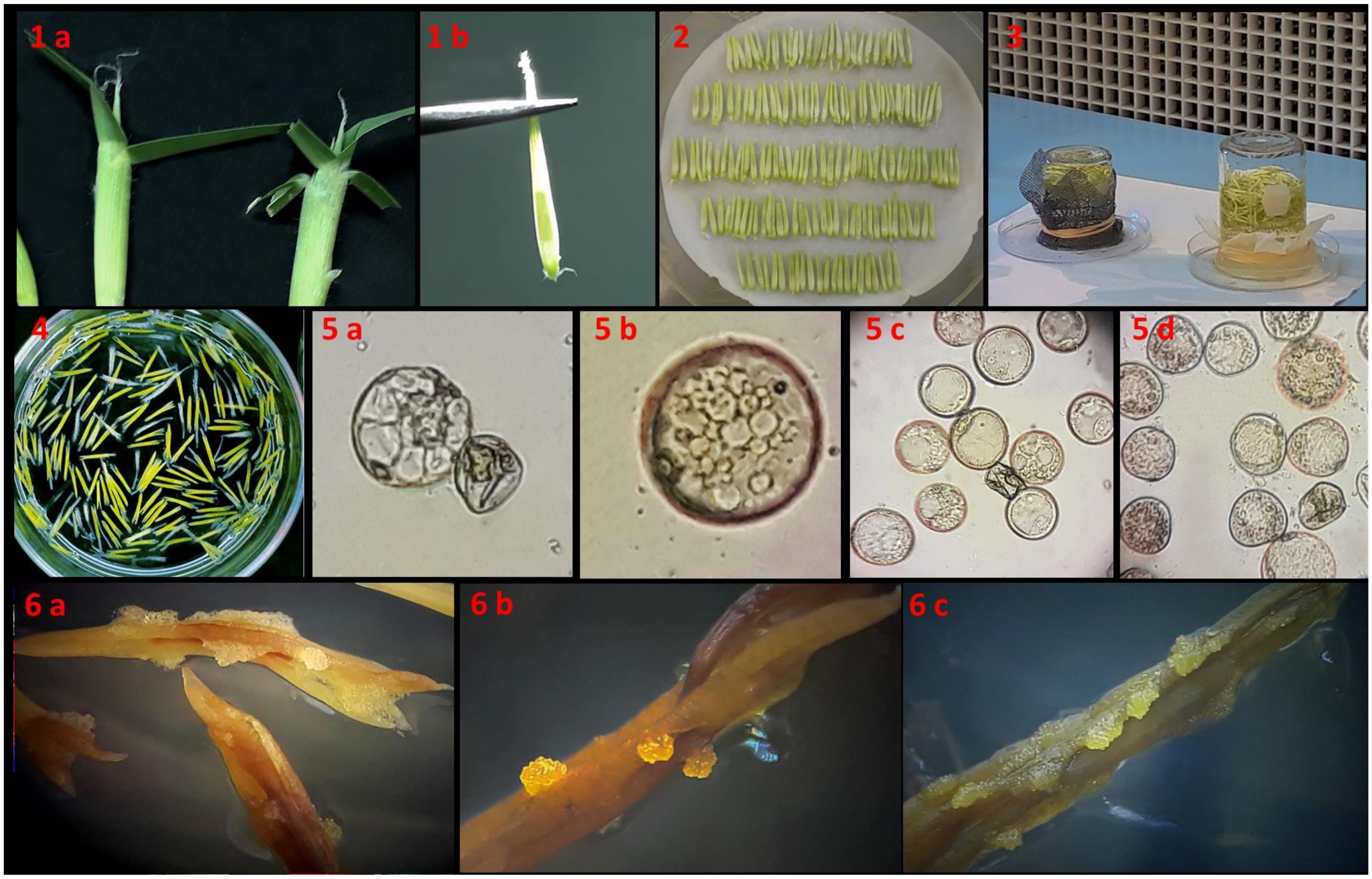


Figure 1. Various stages of attempting androgenesis in kikuyugrass. (1a) flower buds in the appropriate stage – stigma are approximately 5 mm in length; (1b) anthers in the appropriate stage – close to the bottom of the bud. (2) anthers on moist paper in petri dishes; (3) bud sterilization; (4) anthers during pre-treatment in a liquid solution (5a-c) embryogenic microspores; (5d) microspores with starch grains; and (6a-c) multicellular structures on the surface of anthers.

2003-36-278

Title: Buffalograss breeding and genetics

Project leader: Keenan Amundsen

Affiliation: University of Nebraska-Lincoln

Objectives: The primary objective of this study is to develop, through selection and plant breeding, buffalograss suitable for golf course fairways, tees, and roughs.

Start date: 2017

Project duration: Continuous

Total funding: $30,000

Summary:

The turfgrass sciences program at the University of Nebraska-Lincoln (UNL) is developing buffalograss [*Buchloë dactyloides* (Nutt.) Engelm. syn. *Bouteloua dactyloides* (Nutt.) Columbus] suitable for use on golf courses. Buffalograss has exceptional heat, drought, and low temperature tolerance and is a model low-input warm-season turfgrass species. The UNL buffalograss breeding program sponsored a plant collection trip led by graduate student Collin Marshall to collect buffalograss from the southern and western areas of the primary buffalograss growing region (Figure 1). The collection trip yielded 140 new entries that may serve as new sources of pest resistance, abiotic stress tolerance, or turfgrass performance traits. The collection is currently being propagated in anticipation of the 2018 growing season, when turf performance and plant morphology will be documented for the field-grown plants. Under greenhouse management, morphological differences among the collection are already apparent including leaf texture, genetic color, canopy density, canopy architecture, gender expression, stolon proliferation, and stolon internode length (Figure 2). In addition, a commercial DNA extraction kit is being used to extract total genomic DNA from each entry. From existing high throughput sequence data, genetic markers suitable for variety discrimination will be developed and tested on the new collection, elite material from the breeding program, and named cultivars.

Pest resistance and turfgrass quality have been the priority of the buffalograss breeding efforts at UNL, further capitalizing on the innate drought, heat and cold tolerance of the species. We are in an annual cycle of establishing crossing blocks, evaluating progeny, identifying top performing populations, seed increases, and advanced line evaluations. Our newest advanced evaluation trial is managed at 5/8" mowing height and most accessions are performing as good as or better than the standard entries. Several accessions retain green color and canopy density late into the fall (Figure 3). Late season color and canopy density following summer are important attributes that impact the market appeal of buffalograss and for all turfgrasses used on golf courses.

In addition to our breeding efforts, we are continually refining buffalograss establishment and management practices. As an example, buffalograss is slow to germinate. We are working to develop turf type blue grama that could be used in a mixture with buffalograss because it is aesthetically

compatible with buffalograss and because it germinates significantly faster. Similarly we have tested mixing buffalograss with other grasses to reduce plot establishment time. During the 2017 growing season, we experimented with the use of annual ryegrass, which we chose because it should naturally thin out over time allowing the buffalograss to fill in without the need for herbicides. At the end of the growing season we found that the annual ryegrass plots had poor quality (Figure 4). Our annual ryegrass seeding rates (1# or 3# per 1,000 sq. ft.) were likely too high, resulting in poor buffalograss establishment in the first year. More research is needed to optimize seeding rates, for this to be a viable establishment method for turfgrass managers. We are applying both development and management strategies develop improved buffalograss cultivars and also optimizing management practices to make managing those new (or existing) cultivars easier.

Summary points:

1. UNL buffalograss germplasm collection was expanded with 140 new entries
2. Elite buffalograss breeding lines have exceptional turfgrass performance
3. Blue grama compared to annual ryegrass mixtures with buffalograss are preferred to achieve a diverse and uniform turf

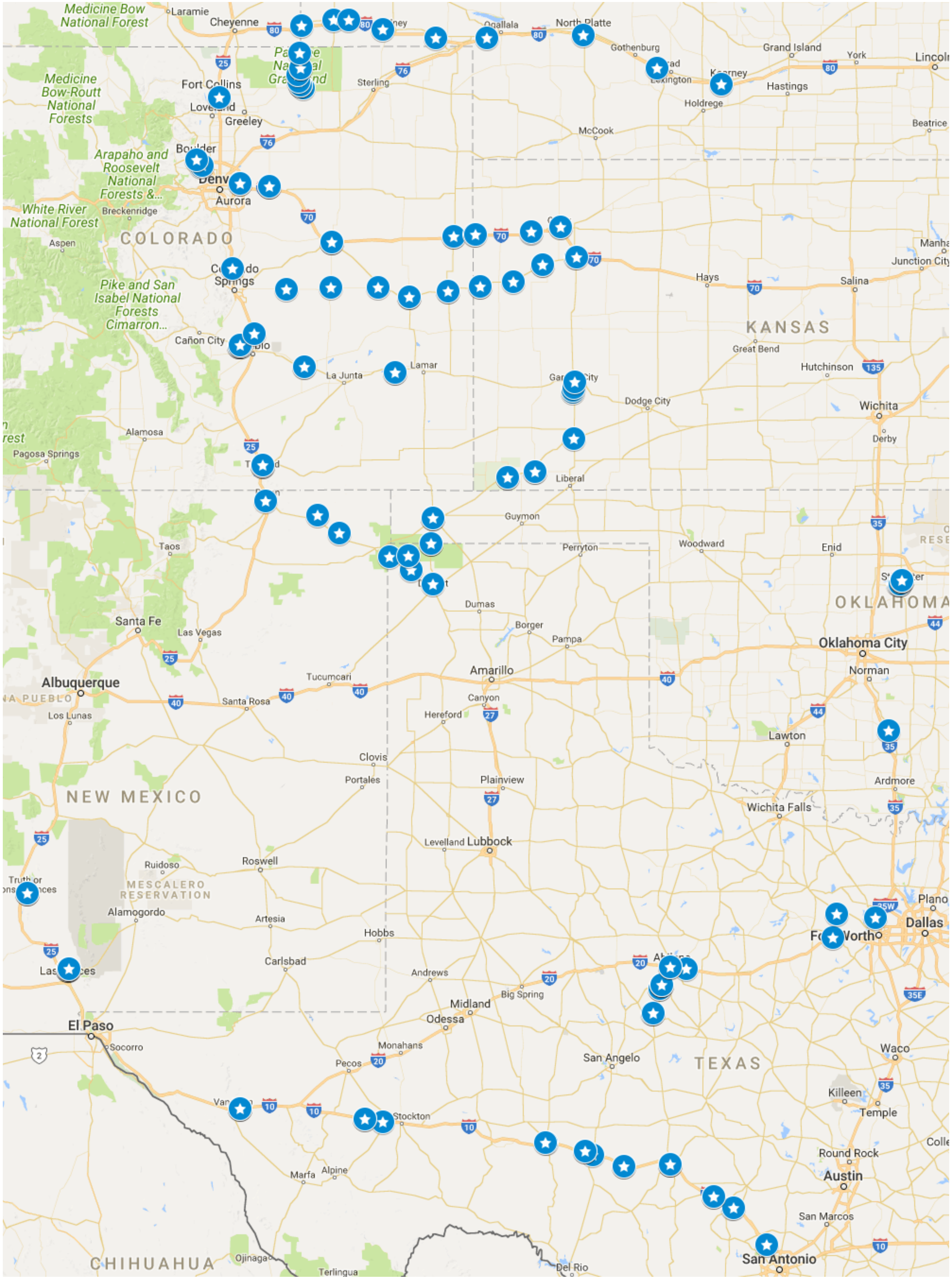


Figure 1. Google map indicating the location of GPS tagged sites of buffalograss collected during the summer of 2017.

Figure 2. Buffalograss accessions being propagated in the University of Nebraska-Lincoln greenhouse facilities. The accessions were collected from the southern and western areas of the primary buffalograss growing region during the summer of 2017.

Figure 3. Late fall color retention of elite buffalograss breeding material. Photo taken on October 18th, 2017.

Figure 4. Evaluation study to test the use of annual ryegrass as a mixture with buffalograss. Monostands of buffalograss germinated slower, but had better turf quality at the end of the growing season (upper outlined plot) compared to plots containing a mixture with annual ryegrass (lower outlined plot).

2016-09-559

Title: Breaking Seed Dormancy in Buffalograss

Project leader: Keenan Amundsen and Elizabeth Niebaum

Affiliation: University of Nebraska-Lincoln

Objectives:

The primary goals of this research are to identify the mechanisms of buffalograss seed dormancy and develop/test alternative methods for breaking dormancy.

Start Date: 2016

Project duration: 3 years

Total funding: $60,710

Summary:

Buffalograss [*Buchloë dactyloides* (Nutt.) Engelm. syn. *Bouteloua dactyloides* (Nutt.) Columbus] has a strong seed dormancy response, common among many native grasses with potential for turf use (Figure 1). In the 1940's, the use of potassium nitrate as a seed treatment to overcome buffalograss seed dormancy was proposed. Treating buffalograss seeds with potassium nitrate followed by storing the seed wet at low temperature is the preferred treatment to overcome seed dormancy by buffalograss seed producers. The seed treatment generally increases germination from <20% in untreated seeds to >85% once treated. The mechanism by which potassium nitrate breaks buffalograss seed dormancy is not understood. The December, 2016 cover story of HortScience describes how potassium nitrate increases seed hydration and initiates germination, and was our lab's first investigation into understanding the role of potassium nitrate in breaking seed dormancy. This research project is taking a multifaceted approach to explore alternate seed treatments that may be more cost effective for seed producers, molecularly understand the mechanisms of seed dormancy in buffalograss, and apply traditional breeding methods to overcome seed dormancy mechanisms.

We are currently testing different seed treatments to break dormancy, which consist of soaking 100 burs in potassium chloride, potassium nitrate, or sodium chloride solution for 48 hours, or acetone for 24 hours. Following the seed treatment, the seed is dried for one day before either storing the seed for a five week chill period at 5°C prior to transferring them to a germination chamber or directly transferring them to a germination chamber without the cold treatment. Once transferred to the chamber, percent germination was collected weekly over four weeks. Percent dormancy was calculated by subtracting the total germinating seeds for each treatment from 100 (Figure 2). Seed viability was not tested, so dormant seed in this study includes dormant and non-viable seed. All treatments tested so far significantly reduce seed dormancy, suggesting the chemical may not be as important as the soaking process. Once seed treatments and seed lots are identified giving consistent results, samples will be collected for transcriptomics and hormone profiling to determine the role and timing of expression of important genes conferring either dormancy or germination.

In addition to seed treatments, recurrent phenotypic selection breeding strategies are being used to remove seed dormancy. Two approaches are currently being used. One approach is designed to select seeds that germinate within 14 days in the absence of any seed treatment, allow those to grow to maturity and intermate, and collect seed, repeating this process for several generations. Early generations from this approach had reduced seed dormancy suggesting the mechanism is under genetic control. Dormancy returned to a higher percentage in subsequent generations. Buffalograss burs, sold as seed, typically contain 3 to 5 caryopses. It is possible that even if one caryopsis germinates early, the others may retain dormancy making it difficult to overcome dormancy through breeding. We are continuing this approach to see if we can increase germination/decrease dormancy within a buffalograss population. Alternatively, a modified approach is being applied whereby once early germinating seedlings are identified, seeds are dissected to remove the other caryopses, accelerating the selection process for early germinating types with reduced dormancy.

Research was also started to understand maternal effects on seed dormancy. Buffalograss seed producers report variable success with the potassium nitrate treatment for breaking seed dormancy, occasionally requiring multiple treatments to break dormancy. The stronger dormancy response in a given year may be caused by environmental factors during seed development. Buffalograss flowers throughout the growing season and it is possible that the length of time on the mother plant may impact the dormancy response. We harvested seed on July 17th, August 2nd and 16th, and September 5th, 2017. Over the winter, germination tests will be done on treated and untreated seed from each harvest date to better understand if harvest timing date influences seed dormancy. Other factors like pest pressure, available moisture, temperature during seed maturation may also influence dormancy.

Together this data will help resolve buffalograss seed dormancy mechanisms and best management practices (seed treatments or field production management) to reduce the impact of seed dormancy.

Summary points:

1. Commercially, buffalograss seed dormancy mechanisms are overcome by a potassium nitrate seed treatment.
2. Soaking burs is more important than the solution used to break buffalograss seed dormancy.
3. Field-based breeding methods have potential for overcoming seed dormancy issues in future seeded buffalograss cultivars.

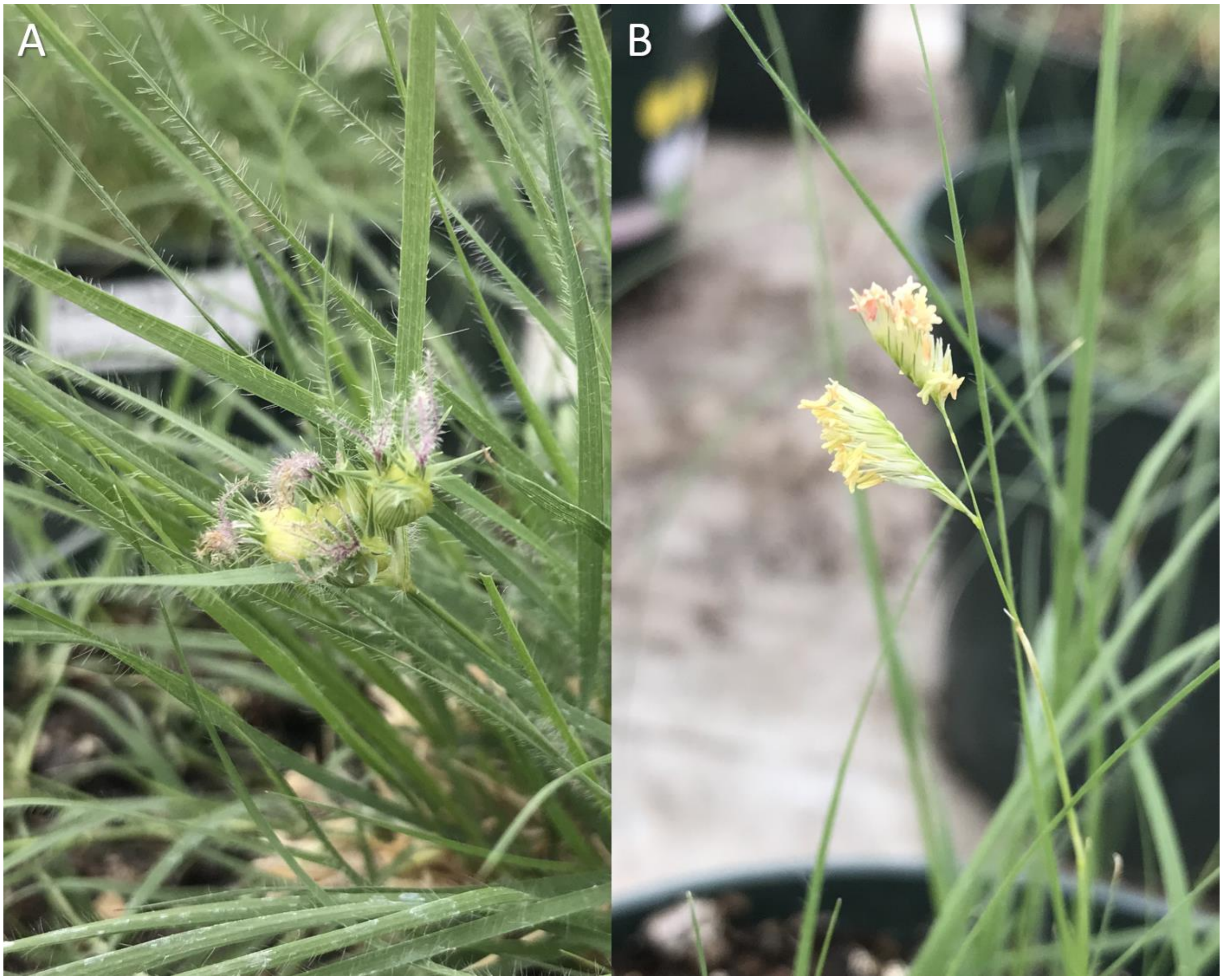


Figure 1. Female (A) and male (B) inflorescence of buffalograss, an important dioecious U.S. native turfgrass species.

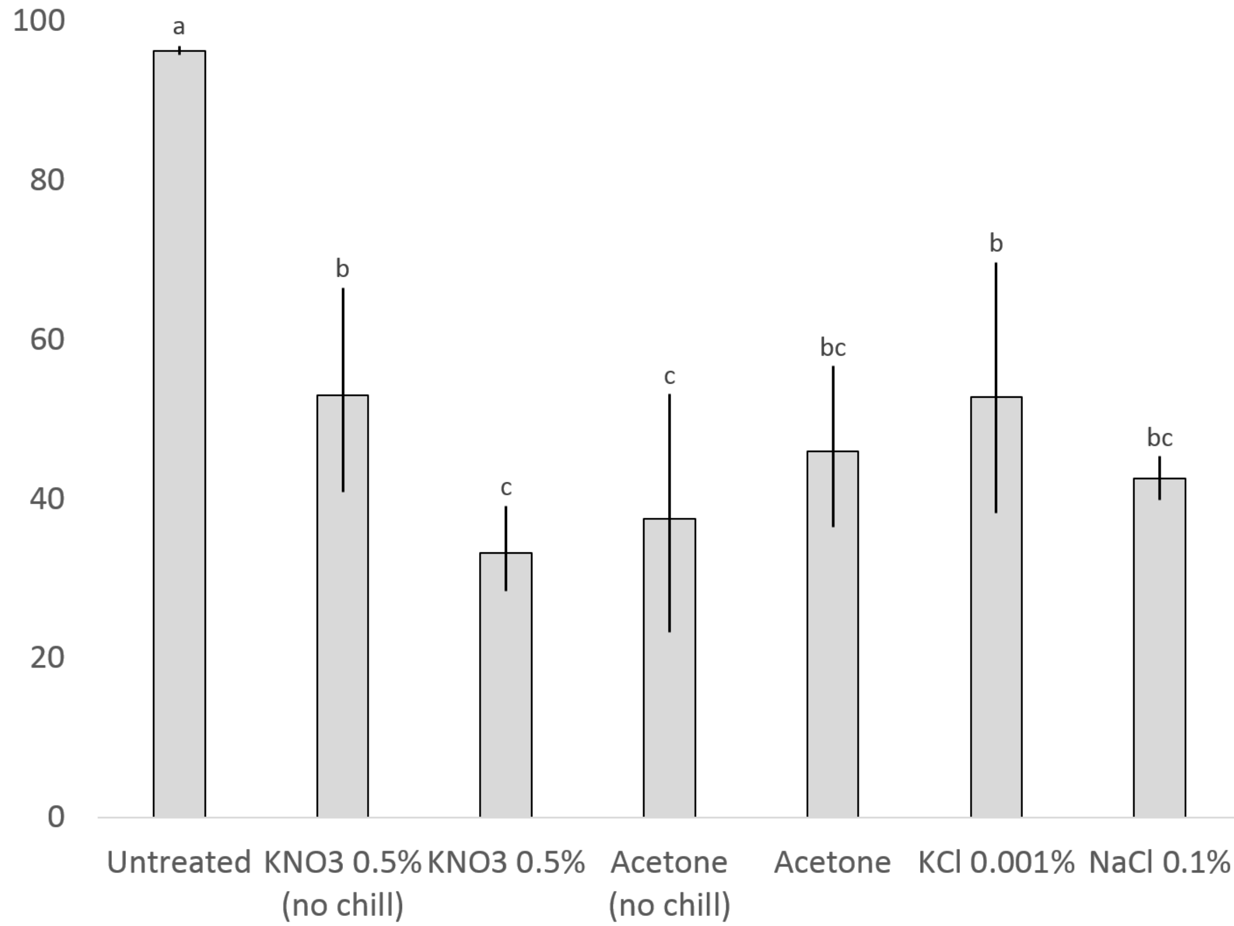


Figure 2. Dormancy of buffalograss following chemical treatments applied to break dormancy (based on 100 seeds). Error bars show standard deviation among four replications and letters indicate statistical groupings based on Fisher's LSD.

2007-16-357

Project Title: Genetic Improvement of Prairie Junegrass

Project leader: Eric Watkins

Affiliation: University of Minnesota

Objective:

1. Determine the genetic potential of native prairie junegrass germplasm for use as low-input turfgrass.

Start Date: 2007
Duration: ten years
Total Funding: $100,000

Prairie junegrass (*Koeleria macrantha*) is a native, perennial, prairie grass that has demonstrated characteristics that are desirable in low-input turfgrass situations. Several of the accessions we have evaluated maintain adequate turfgrass quality under non-irrigated and unfertilized conditions, though the species does have several deficiencies when grown as a turf (Figure 1). The species also exhibits a slow vertical growth habit which would lead to a reduced mowing requirement. In the last year, we examined a subset of our prairie junegrass collection based on our previous research on ploidy, turfgrass quality and seed production characteristics.

Seed production remains one of the principle limitations of prairie junegrass as a viable turfgrass species in the United States. We have found vast differences in seed production between accessions (Figure 2); in fact, top performing lines can produce ten times as much seed as lower performing lines. These poor performing accessions do not produce enough seed to be economically viable, but because of the variability we have seen in our breeding program, we should be able to improve this trait. Additionally, turfgrass quality is highly variable within the species, with the European collections demonstrating the best mowing quality and lateral spread and the collections from North America exhibiting poor quality. Ideally, we would utilize positive traits from both European (turf quality) and North American (seed production) types. We have so far been unsuccessful in making deliberate crosses resulting in viable seed between European collections and the North American collections; one reason for this is differences in the ploidy. Higher quality prairie junegrass from Europe is often tetraploid and the plants from North America in our collection are diploid. In order to address this problem, we have decided to manipulate prairie junegrass ploidy using chemical mutagenesis. The technique has been widely used in other turfgrass species such as zoysiagrass and perennial ryegrass to increase the total number of chromosomes.

Although colchicine (a chemical commonly used for this type of project) treatment has been used often in other species, the specific protocol must be adapted for each species with an experiment to determine the recovery rate of plants with the desired ploidy. Early in 2017, we treated seedlings from a diploid ecotype originally collected in Minnesota with colchicine for three durations: 24, 48 and 72 hours. Colchicine prevents the formation of microtubules during cell division resulting in unreduced daughter cells. In our case, this means that the colchicine-treated plants should have the same number of chromosomes as the tetraploid plants from Europe. Tetraploid plants often have enlarged morphological characteristics such as flowers, leaves, and stomata and an increased number of chloroplasts compared to their diploid counterparts. Our initial results show slight differences in the length of stomata on the leaf surface between the plants treated for 72 hours and the untreated plants (Figure 3). We will examine the number of chromosomes in the root tips of the plants so that we can verify the actual ploidy in the treated plants and using flow cytometry as a higher throughput screening for ploidy.

We will use any tetraploid plants that we recover from this population to make deliberate reciprocal crosses between plants from North American and Europe collection. We hope to recover viable seed from those crosses so that we can introduce the turfgrass quality traits from European germplasm into the Minnesota ecotypes while maintaining economically viable levels of seed production. If successful, this project will move us much closer to a high quality, low-input prairie junegrass cultivar that could drastically reduce inputs in sustainable landscapes such as golf course roughs.

Summary Points:

- Seed production remains an important target for genetic improvement efforts in prairie junegrass.
- Ploidy differences between European and North American collections prevent combining useful traits from these populations.
- We used colchicine to overcome the ploidy barrier between the two collections, and future research will focus on verification of ploidy.

Figure 1: Prairie junegrass is often slow to establish and some accessions suffer from leaf rust disease.

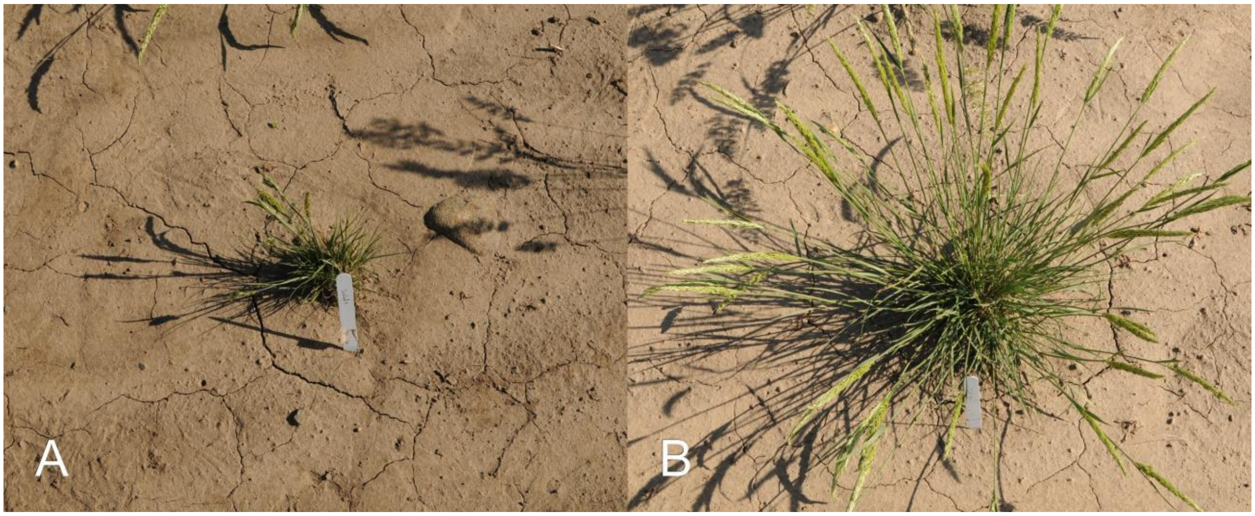


Figure 2. Seed production representative differences between an accession from Ireland (left, A) and an accession from Iowa (right, B). Images were taken on the same day during late spring in the first growing season after establishment.

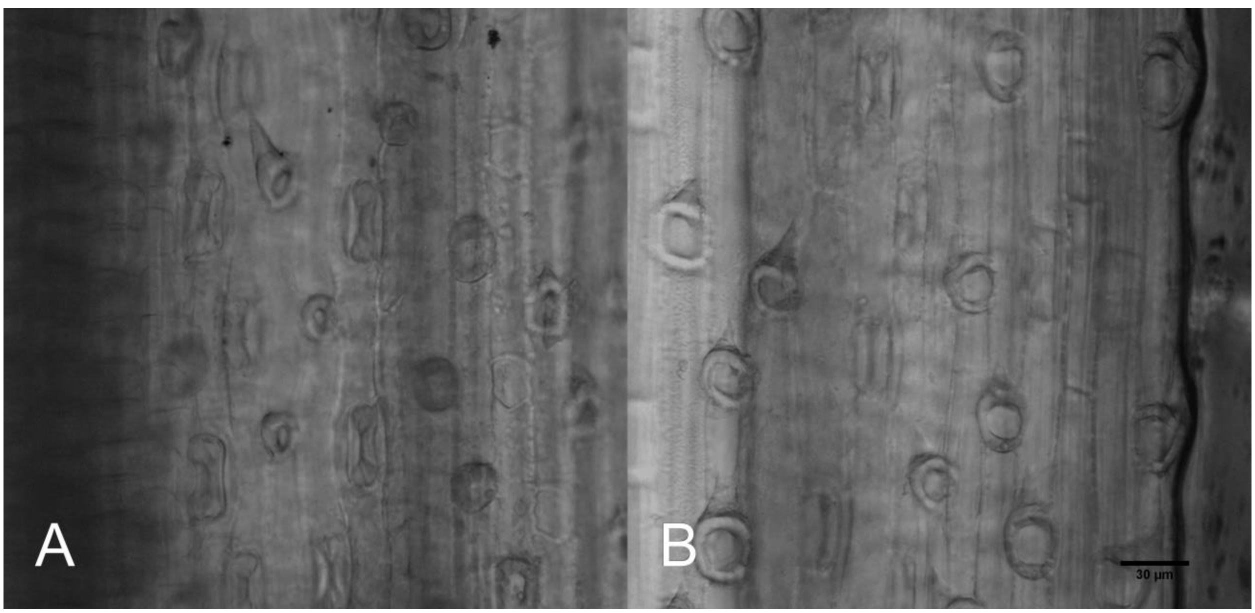


Figure 3. Stomatal length is an indicator of ploidy levels within a plant species. Left (A): potential tetraploid plant with an average stomatal length of $33\mu m$. Right (B): diploid plant with an average stomatal length of $30\mu m$. Images were taken of the abaxial leaf surface near the midpoint of the leaf with magnification of 400x.

2016-04-554

Development and Release of Turf-Type Saltgrass Variety
Yaling Qian and Tony Koski
Colorado State University

Start date: 2016
Project duration: 3 years
Total funding: $90,000

Objectives:

1. To increase the materials (accessions) selected from the source nursery and the first and the second generation nurseries, further develop breeder's fields, and collect data and prepare document for release of elite vegetative saltgrass varieties;
2. Continue to evaluate several seeded lines for potential release; and collect data and prepare document for potential release of seeded saltgrass varieties;
3. To establish field plots made up of progeny from elite parents and from seeds harvested from the third cycle of crossing block for advancement of saltgrass development.

Inland saltgrass is indigenous to western North America, it is adapted to specific niches of alkaline and saline soils. The planting of saltgrass on roughs and possibly even on fairways could help golf courses conserve potable water because of its tolerance to lesser quality water (reclaimed or saline waters) while maintaining acceptable turf quality and providing a playing surface. Inland saltgrass has value for use as turfgrass and/or a revegetation plant in areas that commonly have high soil salinity levels.

Material Increase and Evaluation: Three pairs of males and females were selected and increased to 1000 plugs each. These materials were transported to a turfgrass seed company for on-site evaluation of seed production via a material transfer agreement. These lines were planted to strips in three isolated fields. We expect that the evaluation of seed production of these fields can be achieved in 2020, three years after planting.

Efforts are in progress in rescuing and increasing plant materials. About 15-20 clones from the second-generation nursery were selected and increased. These saltgrass accessions were produced through several breeding cycles. Some of these increased materials were planted in the field in June 2017 for evaluation. Data on spread, establishment, growth, and general turf characteristics are collected. If performances of these lines are acceptable following the next several years of evaluation, these lines will be further supplied to the interested parties for potential release.

Two inland saltgrass accessions that have potential for turf and revegetation use have been established from sprigs and evaluated in the field. Data on turf quality, disease incidence and growth were collected. One line had better quality and stronger rhizomes than the other. Both lines maintained an average turf quality rating between 6 and 8 with 6 as the minimal acceptable rating for the quality and color. Rust was seen in July to September. Two lines differ dramatically in the severity of rust infection with one line almost immune to rust infection. Without mowing, the plants had a 16 to 18 cm maximal height.

Seed Production and Evaluation of Seeded Lines: The elite saltgrass accessions selected out of the second-generation nursery were planted in open pollination crossing blocks to evaluate seed production, survival, and spread. Seed production was insignificant the first 2 years after planting. Three years after planting, seed production was more substantial. Seed yield was determined by hand harvesting a 1 square foot area, hand threshed, and weighed to get seed yield for each mother clone. Nine different elite female accessions produced seed, and five females never produced seeds. Seed production in four different females was within 450 to 500 kg/ha. Female number 5 yielded at roughly 740 kg/ha, while number 2 had the highest yielding clone at nearly 1,045 kg/ha. Numbers 2 and 3 were the only two females that produced seed in all four replications (Figure 1). Five out of 14 females reaching commercial seed production levels in our research plots shows promise for commercial seed production. In June, 2017, the second-generation elite accessions were again planted in 4 replicated crossing blocks.

Four potential seeded lines have been established in the field for evaluation. Due to limited availability of seeds, these testing plots are relatively small. These lines will be evaluated for several years for trait stability and turf quality. If these plots prove to have acceptable turf quality and trait persistence, they will have potential to be released to interested parties.

Cycle 3 Breeding Effort: In a continuing effort of the development of turf-type saltgrass, we started an evaluation of the third generation. Seeds from the third generation crossing block were harvested. Individual seeds were stratified and germinated in the greenhouse in containers to generate saltgrass plugs. The single seed plugs were planted in field plots in the spring of 2017 (Picture 1). A total of ~300 clones for the third generation of saltgrass are under evaluation. After planting, plugs were monitored biweekly on percent coverage, grass height, shoot density (number of tillers per unit area), disease incidence, and turf quality. The first year data indicated that some lines perform better than the others.

Summary points:

1. Materials were increased. Three 3 pairs of males and females have been planted in the field for commercial seed production evaluation.
2. Five out of 14 selected elite saltgrass females reached commercial seed production levels in the research field evaluation and showed promise for commercial production.
3. Seeds of the third generation crossing block were harvested, processed, and planted for cycle 3 field evaluations. The first year data indicated that some lines perform better than the others.

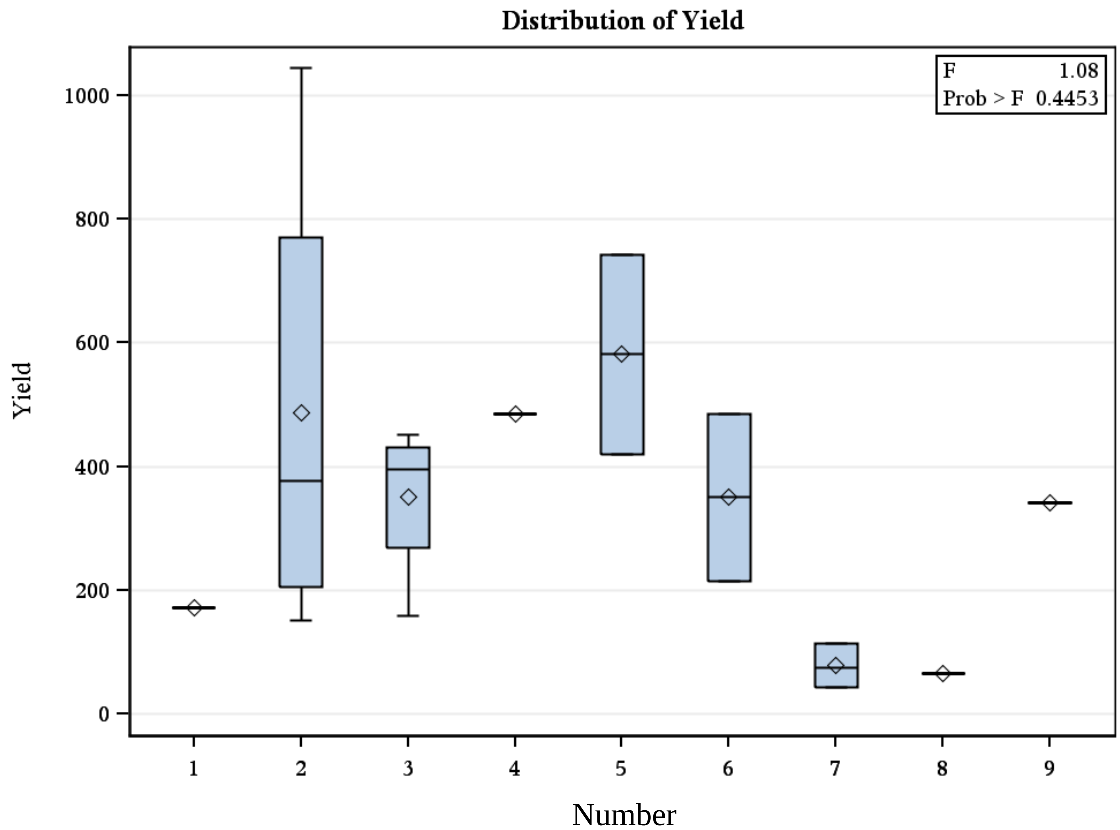


Figure 1. Seed yield (kg/ha) of flowering females in crossing blocks. Number on x-axis corresponds to female clones producing seed for that female.

Figure 2. Cycle 3 field plots.

2016-05-555

Improved Wheatgrass Turf for Limited Irrigation Golf Course Roughs

Joseph G. Robins and B. Shaun Bushman

USDA ARS Forage and Range Research, Logan, UT 84322

Project Objective(s):

1) Evaluate performance of elite wheatgrass turfgrass populations for turfgrass quality in monoculture and mixture conditions.
2) Characterize the effect of mowing height and irrigation replacement on wheatgrass turfgrass quality.

Start Date: 2015

Project Duration: 3 years

Total Funding: $40,440

As demand increases for western U.S. water resources, their availability for landscape irrigation, including golf courses, will become more limited. While player expectations and gameplay require high performing turfgrass for playable areas of courses, there remains the possibility of using grass species with lower quality for the less-used areas of the rough and out-of-bounds areas. This would allow superintendents to manage these areas with lower inputs, including minimal to no-irrigation water, depending on the species used.

The wheatgrass species are well-adapted to this type of scheme. The wheatgrasses are native to semi-arid to arid regions of Eurasia and North America. These regions are characterized not only by aridity, but also by extremes in temperature and grazing intensity. Thus, they are species that are potentially well-suited for low-maintenance turfgrass situations. In their natural conditions, the wheatgrasses possess low turfgrass quality and show limited response to inputs of fertilizer and irrigation when managed as turfgrass. However, this may be a plus to golf course management where limitations on fertilization and irrigation may be a positive.

The USDA (Logan, UT) turfgrass breeding program works on four different wheatgrass species. These are crested, intermediate, thickspike, and western wheatgrasses. Crested and intermediate wheatgrass are native to Eurasia, but both possess a long history of use in the western U.S. for site stabilization and forage production on dryland pastures and rangeland. Thickspike and western wheatgrass are native to western North America and are rhizomatous species with the potential to produce loose sods. The USDA breeding efforts for turfgrass in these species has focused on truly low-maintenance situations, such as roadsides and recreational properties, where almost no management will be used. However, these populations may be well-suited for use on less-used areas of golf courses.

In fall 2016, we established plot of experimental turfgrass populations of these four species. Each species was grown either in monoculture, or in two- or three-way mixes with the other wheatgrass species or with other cool-season grasses, Kentucky bluegrass and hard fescue. The plots established well in 2016 and treatments and data collections began in spring 2017. Aside from wheatgrass populations (mixes), the treatments were a 2 x 2 factorial of mowing height and irrigation level. The mowing heights were 3 inches and 2 inches. The irrigation levels were 50% evapotranspiration replacement and no supplemental irrigation. In 2017, we mowed plots to the corresponding mowing height on a weekly basis. We also applied sufficient irrigation to replace 50% of the evapotranspiration rate on a weekly basis. We collected data weekly by taking digital images of each plot.

We completed data collection for the year in October. We are now processing digital images to convert them to quantitative data. Once finished, we will complete the analysis for the 2017 data. We will take another year of data in 2018. At the completion of the study, we will publish a peer-reviewed scientific journal article and have the information to make recommendations to turfgrass managers for improved wheatgrass turfgrass management.

- Completed year 1 of data collection.
- Preliminary data analysis and results available in the next few months.
- Will complete study in 2018.

Figure 1. The USDA (Logan, UT) turfgrass breeding program works on four different wheatgrass species. These are crested, intermediate, thickspike, and western wheatgrasses.

Figure 2. The USDA breeding efforts for turfgrass in these species has focused on truly low-maintenance situations, such as roadsides and recreational properties, where almost no management will be used. However, these populations may be well-suited for use on less-used areas of golf courses.

2017-33-643

Title: Optimizing seed production and stand establishment of two minimum-input turfgrass species

Principal Investigator: Steven Smith
School of Natural Resources and the Environment,
University of Arizona, Tucson, AZ 85721

Objectives:

1. Determine optimum seed production management for sprucetop grama and curly mesquite native desert grasses.
2. Determine low-maintenance native grass establishment methods for out-of-play areas on golf courses.

Start Date: 2017
Project Duration: Two years
Total Funding: $26,190

This research builds on prior USGA-supported projects that demonstrated potential turfgrass utility for two grass species native to southern Arizona: sprucetop grama (*Bouteloua chondrosioides*) and curly mesquite (*Hilaria belangeri*). This research also resulted in selected germplasm of these species that tolerates regular mowing in spaced-plant nurseries. The current research would provide answers to key remaining questions related to the use of these germplasms in commercial turfgrass plantings at elevations below about 1000 m (3281 ft) in the Southwest. This will involve results from seed production experiments begun in 2014 at two locations in Tucson (elevations: 699 and 717 m), and focus on basic agronomy, harvest, conditioning and yield. It will also involve greenhouse experiments on seed germination, seeding rate, and sod establishment. This will lead to field demonstrations of stand establishment under commercial turfgrass management conditions.

Because of their reduced water requirements, use of the species studied could benefit golf courses that maintain playable (mowed) primary roughs, secondary rough areas (mowed or not), and large-acreage facilities that maintain turf as a mowed cover. No research with these species has addressed seed production or stand establishment under turf management conditions.

This research will address remaining questions related to the commercial utility of sprucetop grama and curly mesquite as minimum-input turfgrass species in commercial plantings in the Southwest. Based on our findings, selected genotypes derived from previous USGA-supported research could be released as cultivars. Results of this work would be delivered via scientific presentations and refereed journal articles as well as in popular, industry, and trade outlets.

I. Context and relevance of this research

This research builds on prior USGA-supported projects that demonstrated potential turfgrass utility for two grass species native to southern Arizona: sprucetop grama (*Bouteloua chondrosioides*, BOCH), and curly mesquite (*Hilaria belangeri*, HIBE). This research also resulted in selected germplasm (clones) of these species that tolerates regular mowing in spaced-plant nurseries. The current research project would address key remaining questions related to the use of these germplasms in commercial turfgrass plantings at elevations below about 1000 m (3281 ft) in the Southwest. This will involve results from seed production experiments begun in 2014 at two locations in Tucson (elevations: 699 and 717 m), and focus on basic agronomy, harvest, conditioning, and seed yield. It will also involve greenhouse experiments on seed germination, seeding rate, and sod establishment. This will lead to field demonstrations of stand establishment under commercial turfgrass management conditions.

II. Research Objectives

a. Seed production

1. Review and formally describe procedures used in plots at Tucson Plant Materials Center (BOCH) and Campus Agriculture Center (HIBE) since 2014 to:
   i. Establish and maintain seed production stands.
   ii. Harvest, condition, and store seed.
2. Establish germination test protocol and use this to evaluate viability and post-harvest dormancy in seed lots produced in 2014-2017.
3. Produce estimated yields of pure live seeds.

b. Stand establishment and management

4. Optimize broadcast seeding rate under greenhouse conditions by assessing plant and stand development with periodic clipping.
5. Establish plot-scale demonstration plantings in the field and manage to promote sod development.

III. Methodology and timetable

a. Seed production (2017-2018)

Working with Heather Dial (TPMC) we will use records of seed production in 2014-2017 to describe formal agronomic protocols for seed production for both species (Objective 1). We will similarly develop protocols for seed harvest, conditioning, and storage, and germination testing (Objective 2). Using the latter protocol over the period 2017-2019 will permit assessment of post-harvest seed dormancy and changes in viability in storage (Objective 3). Using data on recovery of post-conditioning pure live seeds from the seed production plots will permit estimation of seed yields (Objective 3).

b. Stand establishment and management

1. Greenhouse experiments (2017-2018)

We will determine optimal broadcast seeding rate (Objective 4) in greenhouse experiments in a standard artificial growing medium (Sunshine mix 4:sand in 3:1 volume ratio). Seed used will be conditioned field-grown bulks of 'Santa Rita' BOCR and 'Taber' HIBE. Experiments will be conducted in 1020 trays (11" x 21.4" x 2.44" = 235 in^2) with 1-cm headspace and 5 mm of seed coverage. Initial experiments will involve seeding rates of 1, 2, and 4 PLS/in^2 for each species. Greenhouse temperatures and day length will be based on those common in early-August in Tucson (high: 36.7°C, low: 23°C, day length: 13.5 hrs.). As seedlings develop leaves/tillers in excess of 15 cm in length, plants will be clipped by hand to approximately 7.5 cm (3"). Data will be recorded weekly on emergence, tiller development, cover, and turf quality. Each species will be included in separate simultaneous experiments, with each organized as randomized complete block design with seeding rate as the independent variable.

2. Field demonstration plantings (2018-2019)

Based on findings from greenhouse experiments, we will establish demonstration field plantings with multiple plots (>2 m^2 = 21.5 ft^2) of both species. This will occur in summer 2018 at the Karsten Turfgrass Research Facility at the University of Arizona in Tucson. Plots will be established with both native species (populations: Santa Rita and Taber) and standard bermudagrass entries as controls in a single experiment using a randomized complete block design with three replications. Irrigation and mowing will be conducted so as to optimize performance of the native grasses. Plots will not be over-seeded to permit evaluation of cool-season performance of the native species. Turf quality and persistence will be evaluated regularly through summer 2019.

Figure 1. Sprucetop grama planted in August 2012 at the University of Arizona, Tucson, AZ. Individual plants were mowed at three inches and flood irrigated once every six weeks. Researchers are now determining the optimum seed production and establishment methods of experimental cultivars.

2. Integrated Turfgrass Management

Turfgrasses developed for use on golf courses require management practices that provide quality playing surfaces while conserving natural resources and protecting the environment. Projects should focus on conserving natural resources by reducing the use of water, pesticides, fertilizers, and energy. The objectives of these studies include the following:

- Develop cultural practices that allow efficient turfgrass management under unique conditions, such as deficit irrigation, marginal quality water, drought, poor quality soils, and shade
- Determine the range of adaptability and stress tolerance of turfgrasses
- Evaluate direct and interacting effects of two or three cultural practices, like irrigation, mowing, fertilization, cultivation, compost utilization, and organic matter accumulation (thatch)
- 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 use natural resources more efficiently and reduce costs, with minimal impairment of playing quality conditions or aesthetic appeal. We encourage regional cooperation among researchers where similar climatic and soil conditions exist.

Topic **Pg.**

2015-15-530

Title: Excessive Winter Crown Dehydration Affects Creeping Bentgrass Cold Hardiness

Project Leaders: William Kreuser and Darrell Michael

Winter desiccation injury observed in the northern Great Plains was particularly widespread during the winter of 2013-2014. The loss of turf left many golf course superintendents re-evaluating their winter desiccation prevention plans. However, a scientific backing to support agronomic decision-making regarding desiccation prevention is lacking in the literature. Since winter desiccation injury is likely in the future, it is important to understand how desiccation prevention treatments influence the winter survival of turfgrass by sustaining crown moisture content and improving spring recovery.

While no preventative practices can guarantee complete survival of turf, several of the tested treatments can reduce desiccation pressure and increase the likelihood of survival. The impermeable covers tested in this study consistently provided the greatest level of crown moisture content retention regardless of location. However, the recovery results varied greatly between years at Mead. In 2014-2015 the turf quality declined when freezing temperatures injured the turf following cover removal whereas this was not observed in 2015-2016 where temperatures remained above freezing following cover removal. Both the permeable cover and sand topdressing treatments also effectively sustained crown moisture contents throughout the winter at both sites and both years. The sand topdressing and permeable cover recovered similarly to the impermeable cover by the end of the study, but at a slower rate. Interestingly, the slight reduction in crown moisture content from the impermeable cover did not result in freezing injury following cover removal in 2014-2015. It is very likely that turf under the impermeable cover lost significant cold hardiness from soil warming and heat accumulation, and pre-maturely deacclimated. The turf under the permeable cover and sand topdressing were less effected by heat accumulation and retained a greater level of cold hardiness.

While the use of both covers typically resulted in quicker recovery in the spring, their labor requirements to employ limit their uses while aggressive sand topdressing provides a labor effective means of sustaining crown moisture content in desiccating conditions for large scale applications. Sprayable products were ineffective at sustaining crown moisture content in harsher desiccating environments. When desiccation pressure was less severe at Axtell in 2015-2016, the use of an anti-transpirant did result in an acceptable turf quality while many other treatments did not.

Since complete survival is highly dependent on the winter environment, a plan must be prepared in the event of turf loss. This thesis evaluated several commonly practiced techniques superintendents implement to ensure rapid recovery such as germination blankets and fertilizer programs. Surprisingly, the results indicate that these practices are not as effective as previously believed. Germination blankets did not result in accelerated emergence or quicker re-establishment. It has been shown that germination blankets can increase soil temperatures and accelerate re-establishment in some instances, but due to the low sun-angle and short day lengths observed in the spring, solar-induced soil heating was likely limited. Aggressive fertilization is also believed to accelerate re-establishment but in this study, the practice did not result in the anticipated results. Pre-existing nutrient sources present in the soil may have supplied adequate fertility for young seedlings.

While the results from this thesis answer many questions regarding the effectiveness of desiccation prevention treatments and maximizing re-establishment of putting greens from superintendents and in the literature, many questions remain. Specifically, future studies investigating the relationship between crown moisture content and cold hardiness of creeping bentgrass (*Agrostis stolonifera* L.) would provide more clarity when selecting desiccation prevention treatments. Understanding the ideal crown moisture content range which maximizes cold hardiness allows superintendents to select desiccation prevention treatments which minimize pressure from both desiccation and freezing temperatures. Since practitioners are lacking the necessary tools to accurately measure crown moisture content, diagnostic tools should be developed to which will allow managers to visually estimate crown moisture content and viability of turf crowns. Additionally, annual bluegrass (*Poa annua* L.) is often considered to be more susceptible to desiccation and freezing temperatures. Identifying crown moisture contents in which desiccation injury occurs in annual bluegrass as well as how annual bluegrass' crown moisture impacts cold hardiness would improve our understanding of how and when turf dies. Similarly, superintendents could formulate winter management plans around ensuring ideal crown moisture contents in which desiccation pressure is reduced while cold hardiness is maximized.

Summary Points:

•Impermeable covers, permeable covers, and sand topdressing consistently increased crown-moisture retention during winter, and recovery in spring was greatest with impermeable covers.

•Sprayable products did not improve crown-moisture retention when desiccation pressure was most severe, but the anti-transpirant used improved quality under milder conditions.

•Germination blankets and fertilizer are commonly used in early spring to encourage recovery following desiccation injury, but were not effective strategies in this research.

•Sand topdressing requires fewer labor hours compared to installing and removing covers, and may be preferred on golf courses where labor is limiting.

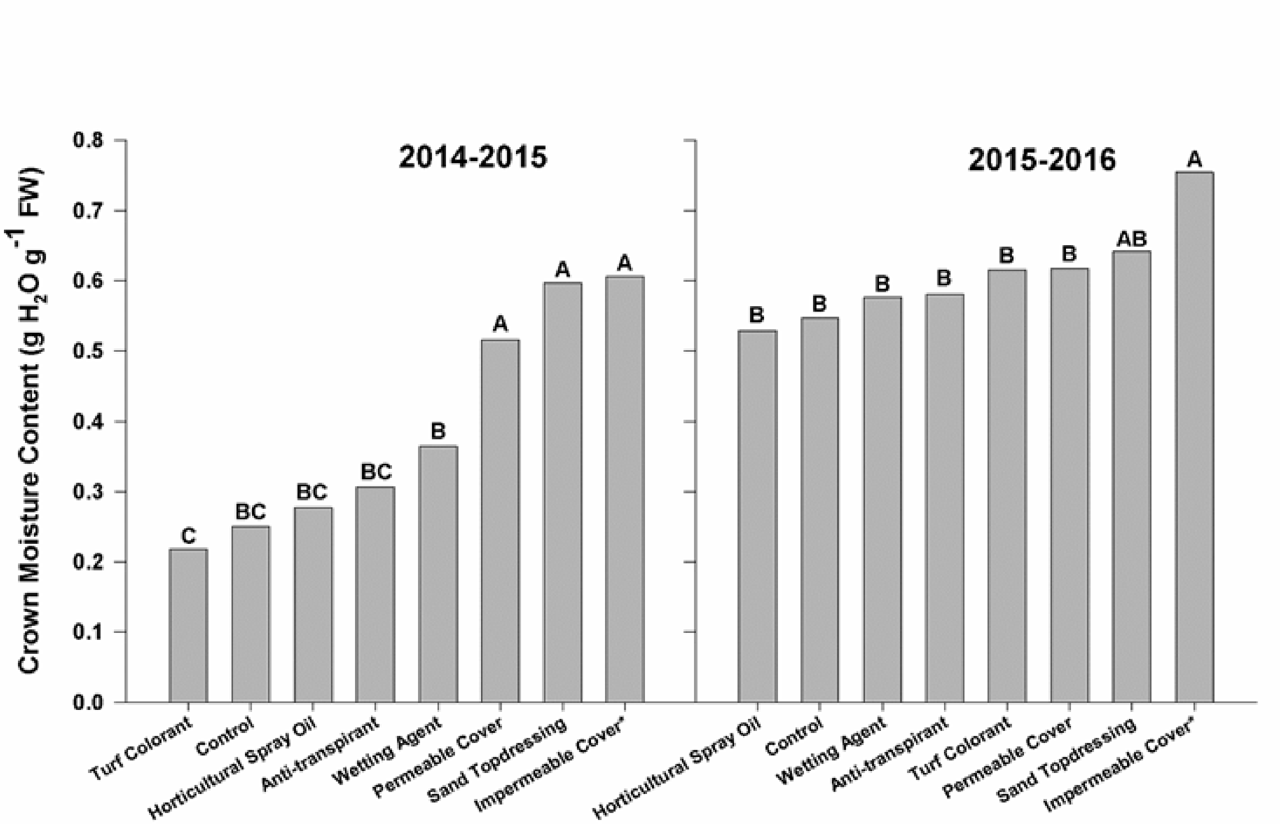


Figure 1. Crown moisture content as affected by spray-applied and cover treatments in Axtell, NE 13 March, 2015 and 2016 (p<0.001). Different letters above bars within a year denote a statistical difference at the 0.05 probability level. *White impermeable cover.

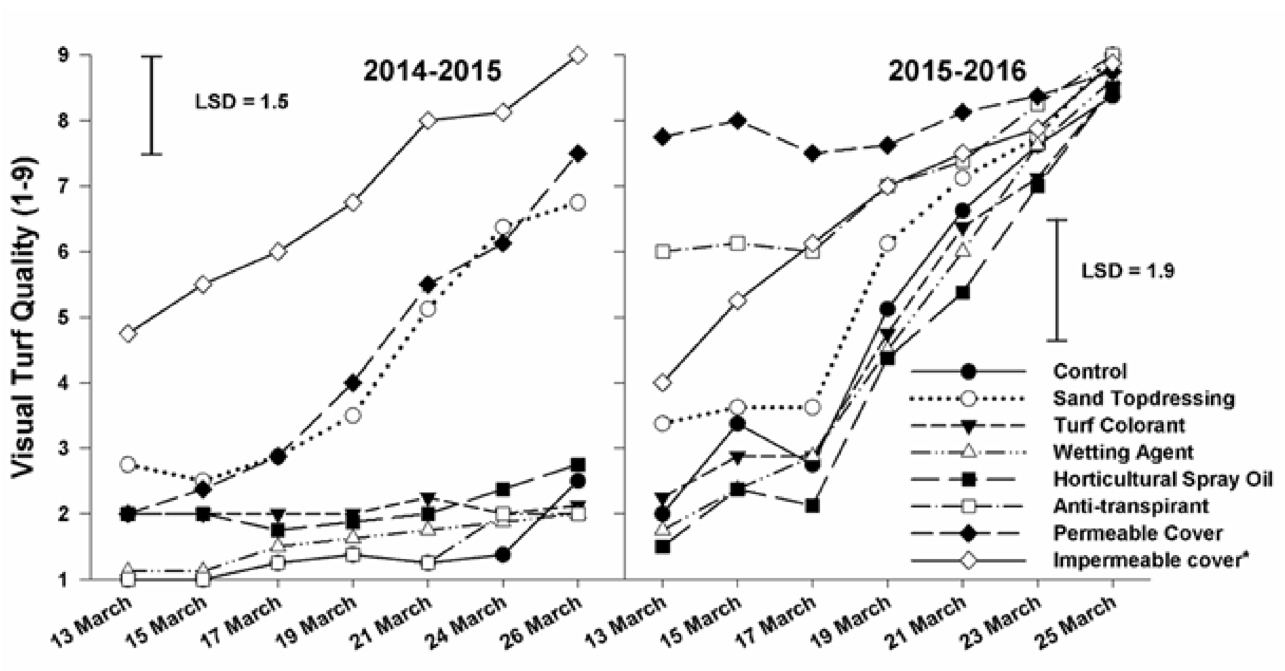


Figure 2. Visual turf quality as affected by spray-applied and cover treatments in Axtell, NE after removal of covers. Samples were evaluated in the greenhouse for recuperative capacity and rate of green-up (p<0.001). *White impermeable cover.

2016-07-557

Minimum Daily Light Integral Requirements for Warm-Season Fairway/Tee and Rough Cultivars: Mowing Height and Growth Regulator Interactions

Benjamin Wherley, Zhaoxin Chen, and Russell Jessup
Texas A&M University Department of Soil & Crop Sciences

Maintaining turf in shade is a significant management challenge for golf course superintendents. Environmental differences with regard to month of the year, shade sources, intensity, duration of shade, or hours of direct sunlight make it difficult to specify a minimum light requirement in terms of hours/day that can extend across various situations. Rather than responding to a number of hours of direct sunlight or percent shade, plants respond to the cumulative daily total number of photons (measured in moles/sq. meter/day) received within the photosynthetically active wavelengths (400-700 nm), termed daily light integral (DLI). The limited amount of turfgrass DLI research that has been conducted in the past has primarily involved greenhouse experiments or has been focused on ultradwarf bermudagrass.

A two-year field study was conducted over the 2016/2017 growing seasons in College Station, TX, under replicated treatments offering 0 to 90% reductions in photosynthetic photon flux (PPF). Objectives of the study were to 1) determine minimal DLI requirements for 10 zoysiagrass and bermudagrass cultivars commonly used on golf courses, 2) determine how minimal DLI requirements change seasonally (spring, summer, and fall months), 3) determine effects of fairway & rough cutting height (0.75” vs. 2”) on minimal DLI, and 4) determine impacts of Trinexapac-Ethyl (TE) on minimal DLI requirements.

A 15,000 sq. ft. irrigated shade research facility has been constructed in 2015 at the Texas A&M Turfgrass Field Laboratory. Turfgrasses utilized in this project are shown in Table 1. Two parallel studies are being conducted: A ‘rough study’ conducted at 2” mowing heights, and a fairway study managed at 0.75” mowing heights. Both studies are arranged in a completely randomized design with 4 replicate plots per treatment and 6 density-neutral shade levels (0, 30, 50, 70, 80, 90% photosynthetic photon flux reduction) as the whole plot factor. Shade structures cover plots throughout the year, including winter months, and are only removed for short periods for routine maintenance and data collection. Plots were established in July 2015, with grasses provided 6-weeks to establish under full sun conditions before shade structures were moved onto plots. Turf quality, digital image analysis of percent green cover, NDVI, and rooting data were measured monthly. Polynomial regression was used to determine minimal DLI thresholds for acceptable Turf Quality in each entry at the end of the project. Two-year average DLI for the summer month periods (June-Aug) are provided in Table 2. These DLI were also calculated for Spring (March-May) and Fall (Sept.-Nov.) periods with similar regression analysis performed. In this report, two-year average Summer DLI data have been provided for all cultivars at both fairway and rough mowing heights. The following are some of the key findings from this analysis:

- Summer DLIs were measured to be similar between the two years. In year 1 (2016), DLIs produced by the shade treatments were 5.8, 8.6, 11.7, 20.9, 27.9, and 47.6 mol m-2 d-1 for the 90, 80, 70, 50, 30, and 0% (Full Sun) shade treatments, respectively. For year 2 (2017), summer DLIs were 5.4, 8.7, 12, 21.1, 27.9, and 46.2 mol m-2 d-1 for the 90, 80, 70, 50, 30, and 0% (Full Sun) shade treatments, respectively (Table 2).
- During Summer months, DLIs for Fairway Height turf were highest for bermudagrass cultivars and lowest for zoyiagrass cultivars. Trinexapac-Ethyl reduced DLI requirements by ~0.5 to 2 mol m^{-2} d^{-1} in bermudagrasses and by ~3 to 7 mol m^{-2} d^{-1} in zoysiagrasses (Figure 1).
- Without TE, Fairway bermudagrass cultivars ranked as follows, from lowest to highest Summer DLI requirement: Latitude 36 < Celebration < TifGrand < Tifway. With TE, bermudagrass ranked as follows, from lowest to highest

Summer DLI requirement: Latitude 36 < TifGrand < Celebration < Tifway (Figure 1).

- Without TE, Fairway zoyisagrass cultivars ranked as follows, from lowest to highest Summer DLI requirement: Zorro < Zeon < Palisades < Geo < JaMur. With TE, zoysiagrass ranked as follows: Zorro < Zeon < JaMur < Palisades < Geo (Figure 1).
- At Rough Height, cultivars expressed a much wider range of Summer DLI requirements, from as low as 11.75 to 32 mol m^{-2} d^{-1}. At Rough Height, Summer DLI ranked as follows for the bermudagrass cultivars: Celebration < Latitude 36 < Tifway < TifGrand. Zoysiagrass cultivars ranked as follows: Zorro < Zeon < Palisades < JaMur (Figure 2).
- At Rough Height, minimal DLI required for acceptable Turf Quality in Zorro and Zeon zoysiagrass (11.75 and 13.25 mol m^{-2} d^{-1}, respectively) were lower than that required for Palmetto St. Augustinegrass (15.5 mol m^{-2} d^{-1}) (Figure 2).
- Minimal DLI required for acceptable Turf Quality was noticeably lower for all cultivars for the Spring and Fall periods (Data not shown)

Table 1. Species, Cultivars, and Origin of entries included in the Texas A&M shade study. St. Augustinegrass was included only in the rough height study as a shade tolerant check.

Species	**Cultivar**	**Origin**
Bermudagrass	Tifway	University of Georgia
	TifGrand	University of Georgia
	Latitude 36	Oklahoma State University
	Celebration	Sod Solutions
Zoysiagrass	Zeon	BladeRunner Farms, Inc.
	Zorro	Texas AgriLIFE Research
	Palisades	Texas AgriLIFE Research
	JaMur	BladeRunner Farms, Inc.
	Geo	Sod Solutions
[1]St. Augustinegrass	Palmetto	Sod Solutions

[1] Palmetto St. Augustinegrass was included as a shade tolerant check at the rough mowing height only.

Table 2. Mean daily Light Integrals (DLI) within each of the shade treatments during the summer months (June, July, August) months for the 2016 and 2017 seasons.

	DLI (mol m^{-2} d^{-1})	
	2016	**2017**
Full Sun	47.6	46.2
30% Shade	27.9	27.9
50% Shade	20.9	21.1
70% Shade	11.7	12.0
80% Shade	8.6	8.7
90% Shade	5.8	5.4

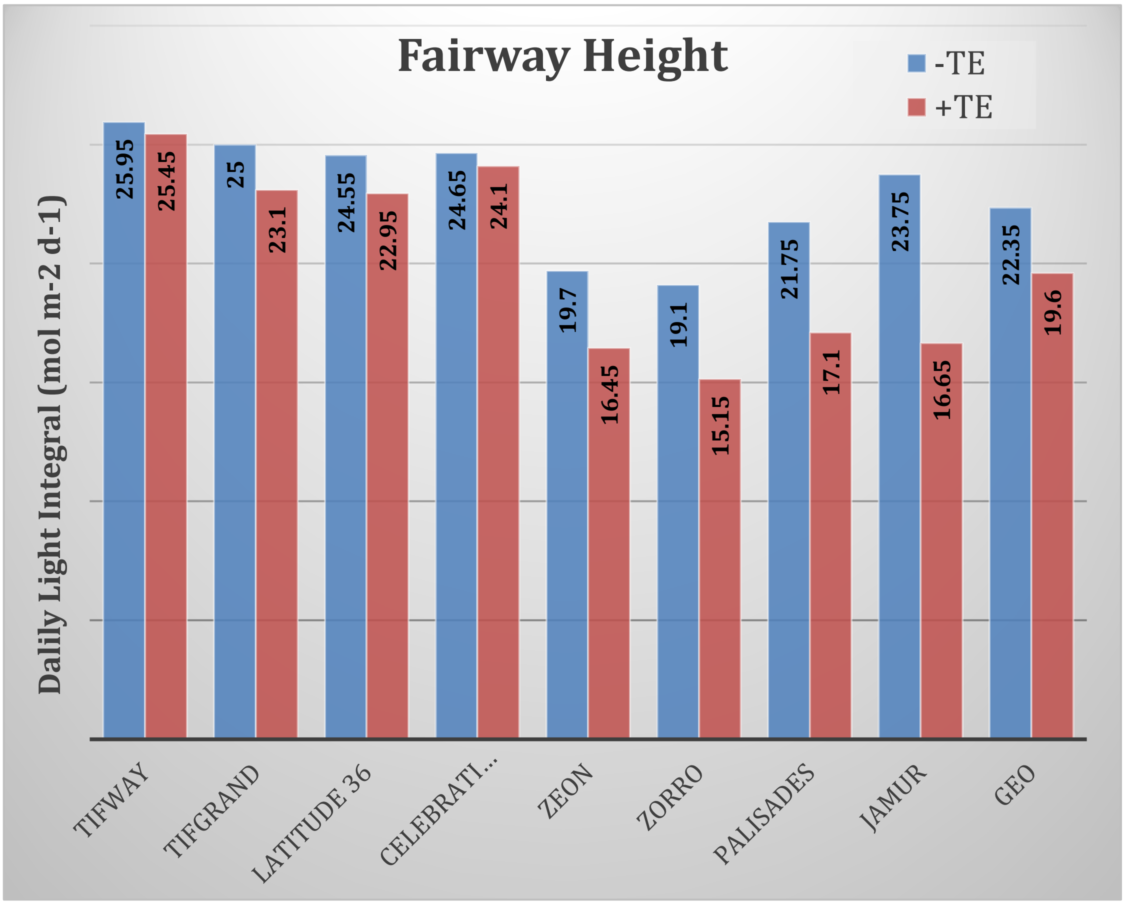


Figure 1. Two-year average minimal Daily Light Integrals required to maintain minimally acceptable Fairway Turf Quality during summer months with and without Trinexapac-Ethyl (TE). Data are averaged over the 2016 and 2017 summer months (June, July, and August).

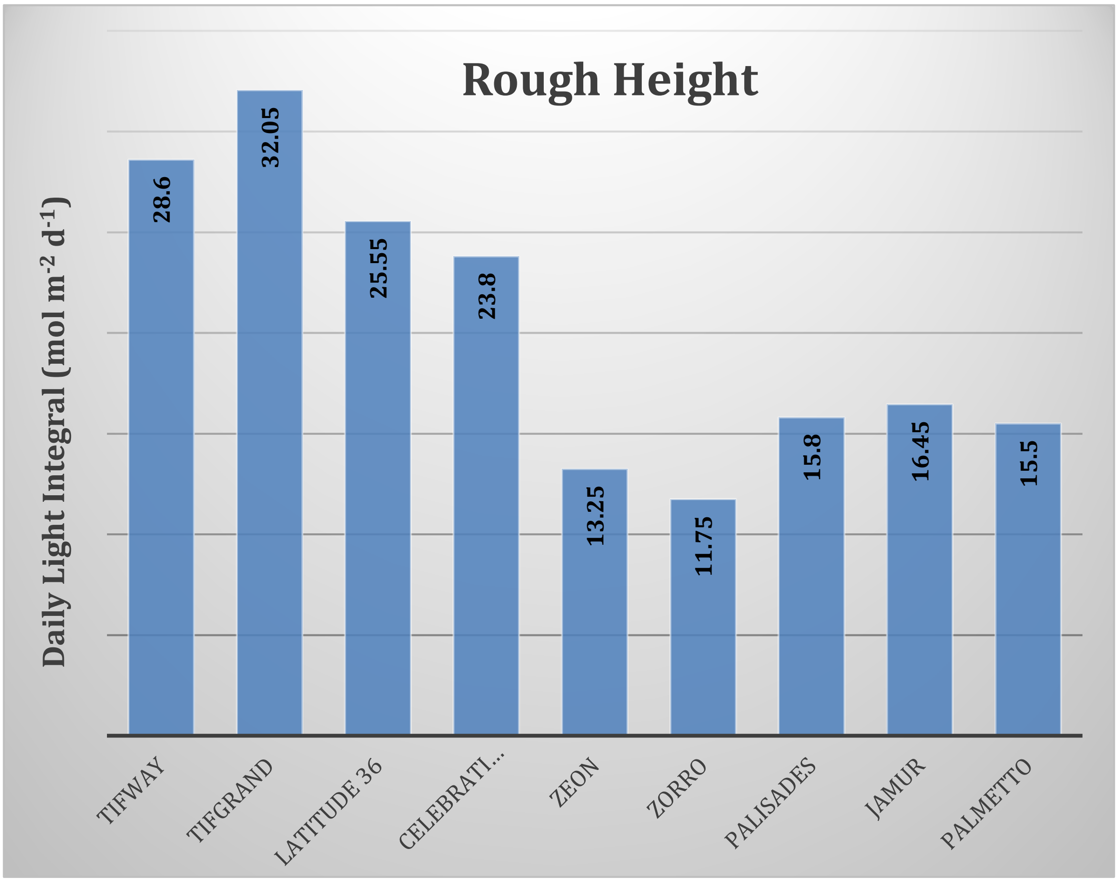


Figure 2. Two-year average minimal Daily Light Integrals required to maintain minimally acceptable Rough Height Turf Quality during summer months. Data are averaged over the 2016 and 2017 summer months (June, July, and August).

Figure 3. Image of the Texas A&M Research Field Laboratory shade study facility with shade structures in place.

2016-10-620

Title: Determining Precise Light Requirements for Various Turfgrass Systems

Project leader: Travis R. Russell, Douglas E. Karcher, and Michael D. Richardson

Affiliation: University of Arkansas, Fayetteville

Objectives:
1) Estimate seasonal DLI requirements for various warm-season turf types present in a golf course fairway/tee setting.
2) Compare estimated DLI values from Objective 1 to estimated DLI requirements of comparable turfgrass systems (cultivar and mowing height) in a standardized field research setting.

Start Date: 2016
Project Duration: 2 years
Total Funding $15,080

Summary

Introduction

A decrease in photosynthetically active radiation (PAR) caused by tree shade is often detrimental to turfgrass quality. The cumulative amount of PAR photons delivered over one day is termed the daily light integral (DLI) with units of mol / m^2/ d. The DLI measurement is an effective method to determine the light requirements of warm-season turfgrass types in a standardized research setting, however this is a labor intensive process and typically requires multiple seasons to complete. No published research has attempted to evaluate DLI values *in situ* on the golf course, where existing tree shade is obviously limiting turfgrass growth. It may be possible develop methodology for quickly determining a minimum DLI requirement for various turfgrass types in existing turfgrass landscapes, where there is an obvious gradient of high to low turf quality caused by tree shade.

Methods

Four warm-season cultivars were selected for evaluation at area golf facilities (Table 1). For each cultivar, two independent shaded sites were identified for DLI measurement. Quantum light sensors were installed in four positions along a line transect in each shaded site (Fig. 1). Daily light integrals (mol / m^2/ d) were then determined over a 6 day period at each site in 2017, measuring PAR on 15 min intervals at each sensor position. Concurrently, visual turfgrass quality was evaluated at each sensor position. Multiple turfgrass plugs from each site were extracted and transplanted at to standardized shade research setting at the Arkansas Agricultural Research and Extension Center in Fayetteville. Plugs were established in full sun conditions for one month and then varying levels of shade stress were applied using moveable shade structures (Fig. 2). Quantum light sensors were mounted under each of the shade cloth treatments, and PAR was recorded for the duration of the study. The PAR light measurements were summed to calculate DLI values under each shade treatment for monthly and seasonal averages. The turf was evaluated using visual turfgrass quality ratings, which were recorded every two weeks during the study. Visual ratings were based on evaluation of turfgrass cover, color, density, and uniformity using a 1 to 9 scale with 1 representing dead turf and 9 representing dark green, healthy turf. Any turfgrass quality rating below 6 was deemed unacceptable turfgrass quality. Critical DLI values necessary to attain acceptable quality were then estimated for each cultivar in using non-linear regression, both in the research setting and *in situ.*

Results

In the standardized research setting when evaluated over two growing seasons, 'Cavalier' zoysiagrass had the lowest critical DLI requirement at 18.5 mol / m^2 / d and 'Meyer' zoysiagrass had the highest at 27.8 mol / m^2 / d (Fig. 3) when maintained under golf course fairway conditions. However, in the golf course setting, the critical minimum DLI values estimated for 'Cavalier' and 'Meyer' were 24.6 and 22.6 mol / m^2 / d, respectively (Fig. 4), which did not agree well with the research setting values. In addition, the critical minimum DLI value estimated for common bermudagrass was surprisingly low at 11.5 mol / m^2 / d in the golf course setting, compared to 26.8 mol / m^2 / d in the research setting. It is likely that seasonal variable shade and tree root competition contributed to relatively poor critical minimum DLI estimates in the golf course setting.

Summary Points

- The following minimum DLI requirements (mol / m^2 / d) were determined from multiple seasons of season-long shade stress when maintained under fairway conditions:
  - **22.8 for 'Astro-DLM' bermudagrass**
  - **26.8 for common bermudagrass**
  - **18.5 for 'Cavalier' zoysiagrass**
  - **27.8 for 'Meyer' zoysiagrass**
- Minimum DLI values determined from observations in the golf course setting were not consistent to those obtained from the standardized research setting.
- Additional work is needed to develop an efficient method to determine DLI requirements in an established turfgrass landscape.

Table 1. Location sites of four turfgrass types under evaluation when estimating a minimum DLI requirement in an existing landscape.

Turfgrass	Golf Course	Location
'Astro-DLM' bermudagrass	Shadow Valley Golf Club	Rogers, AR
Common bermudagrass	Bella Vista Golf Club	Bella Vista, AR
'Cavalier' zoysiagrass	Blessings Golf Club	Johnson, AR
'Meyer' zoysiagrass	Shadow Valley Golf Club	Rogers, AR

Figure 1. Quantum light sensors placed along line transect in shaded areas on golf courses. Positon 1 = full turfgrass coverage, 2 = slight turfgrass decline, 3 = extensive turfgrass decline, 4 = complete turfgrass failure.

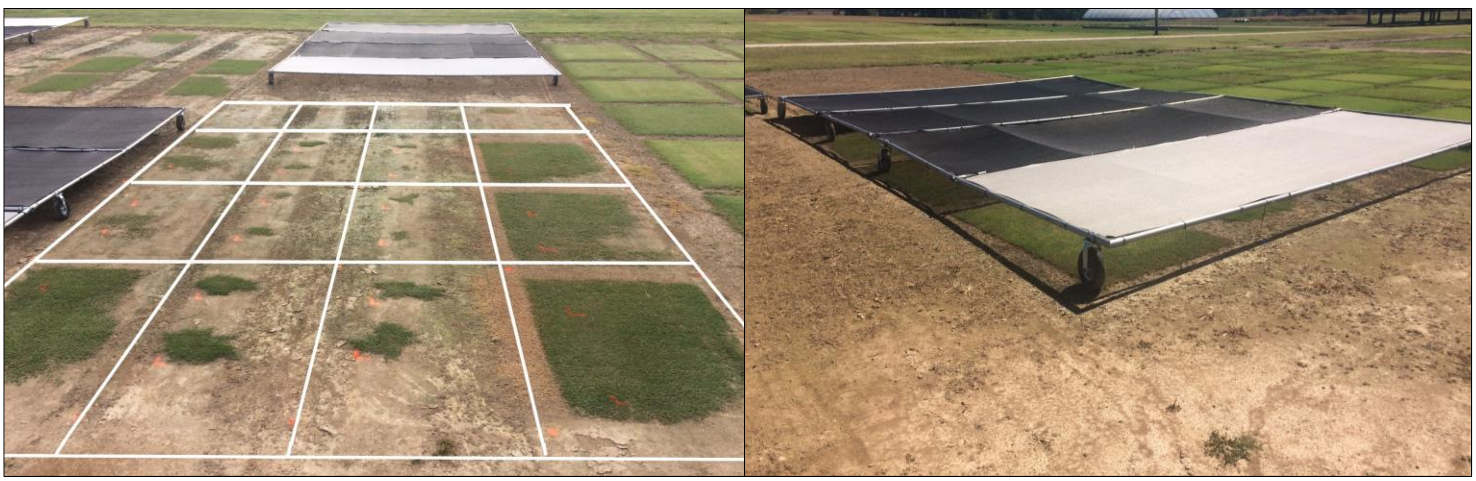
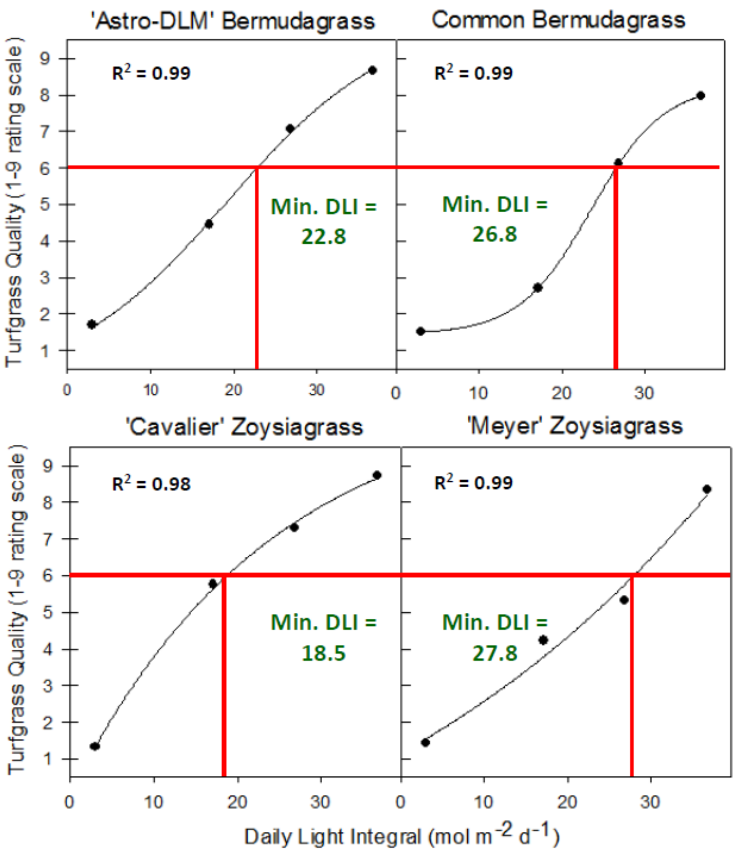


Figure 2. Turfgrasses from each golf course site transplanted to a standardized research setting under shade structures applying continual 22, 40, 60, or 90% shade.



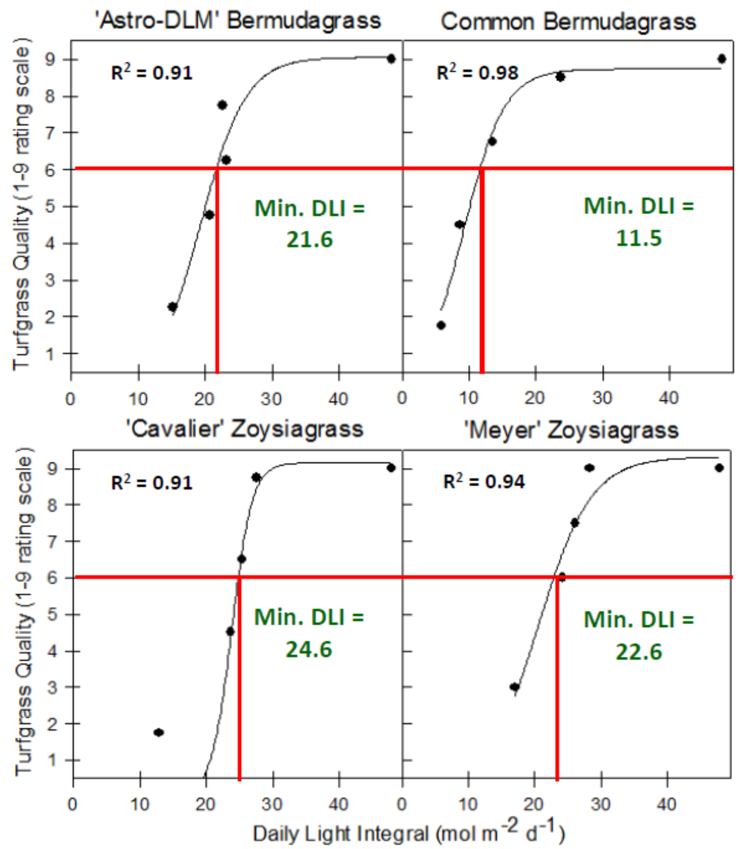


Figure 3. Visual turfgrass quality response of warm-season turfgrasses in standardized research setting under 22, 40, 60, and 90% continual shade from May-September 2017. Visual quality rated on 1-9 scale. Red lines indicate minimum acceptable quality and estimated minimum DLI requirement.

Figure 4. Turfgrass quality response of warm-season turfgrasses in golf course fairway/tee setting under estimated season long daily light integral (mol m^{-2} d^{-1}) regimes present at each site. Visual quality rated on 1-9 scale. Red lines indicate minimum acceptable quality and estimated minimum DLI requirement.

2016-10-560

Reducing ultradwarf bermudagrass putting green winter injury with covers and wetting agents

Michael D. Richardson, Douglas E. Karcher and Eric J. DeBoer. University of Arkansas, Department of Horticulture, Fayetteville, AR 72701

As ultradwarf bermudagrass (*Cynodon dactylon x Cynodon transvaalensis*) putting greens move further north in the transition zone, there is an increased risk of sustaining winter injury from low temperature exposure and crown desiccation. The benefits of utilizing covers for winter protection are well-documented but there are significant labor costs associated with covering and uncovering greens during the winter to allow for play during favorable weather. While the current recommendation is to cover bermudagrass greens when the low temperature is forecasted to drop to -4 °C or 25 °F (O'Brien and Hartwiger, 2013), it may be possible to lower this forecasted temperature, resulting in fewer covering events, reduced labor costs and more days open for play.

Localized dry spot (LDS) is a common problem on sand-based putting greens and can lead to desiccation of the turfgrass crown and even death of the plant. Symptoms of LDS are easily recognized when turf is actively growing but may not be apparent while the turf is dormant. Wetting agents are commonly applied during the growing season to combat effects of LDS but little information exists on the effects of a late-fall/early-winter wetting agent application on winter survival and spring green-up of ultradwarf bermudagrass.

Objectives:

- Examine predicted low-temperature thresholds for covering Tifeagle, Champion, and Mini-Verde ultradwarf bermudagrass putting greens
- Investigate the effects of a late-fall wetting agent application on soil moisture and winter survival of ultradwarf bermudagrass

Materials and Methods:

This trial was conducted at the Arkansas Agricultural Research and Extension Center in Fayetteville, AR. The treatments included three ultradwarf bermudagrass cultivars ('Champion', 'Mini-Verde', and 'Tifeagle'), five cover treatments based on forecasted low temperatures (-4.0, -5.6, -7.8, or -9.4 °C and an uncovered control), and two wetting agent treatments (Revolution applied at 1.9 ml m^{-2} on Dec. 6, 2016 and an untreated control) The experimental design was a strip split plot, where cover treatments were applied as strip plots across cultivars and cover x cultivar plots were further split with the wetting agent treatments (Photo 1). Results from the first year of the trial (2015-2016) were summarized in the 2016 USGA Research Summary and data from the second year (2016-2017) of this trial are summarized in the current report. This research will be continued for a third season, during the 2017-2018 winter.

Results:

Fayetteville, AR experienced a more typical winter season in 2016-2017, and several days of extreme low temperatures (-15 °C) were experienced (Figure 1).

- As seen in Year 1, 'Tifeagle' and 'Mini-Verde' experienced less winter injury and better spring greenup than 'Champion' (Figures 2 and 3, Photo 2)
- Uncovered plots of all cultivars experienced complete winterkill (Figure 3, Photo 2)

- The use of protective covers enhanced spring green-up and recovery for all cultivars and there were minimal differences in any of the cover treatments (Figure 3, Photo 2)
- A late season wetting agent application did not affect spring green-up of ultradwarf greens in Year 2 (data not shown), but would still be recommended as a precaution again winter desiccation.
- Using lower temperature thresholds to place covers significantly reduced the number of covering events that occurred in 2017 and resulted in more days that the course would have been open for play (Table 1). These reductions could potentially save thousands of dollars in labor costs for a golf course each year and increase revenue by keeping the course open for play on more days in the winter season (Table 1).

Photo 1. Overview of the trial site, showing the various cover treatments stripped across the three cultivars of ultradwarf bermudagrass.

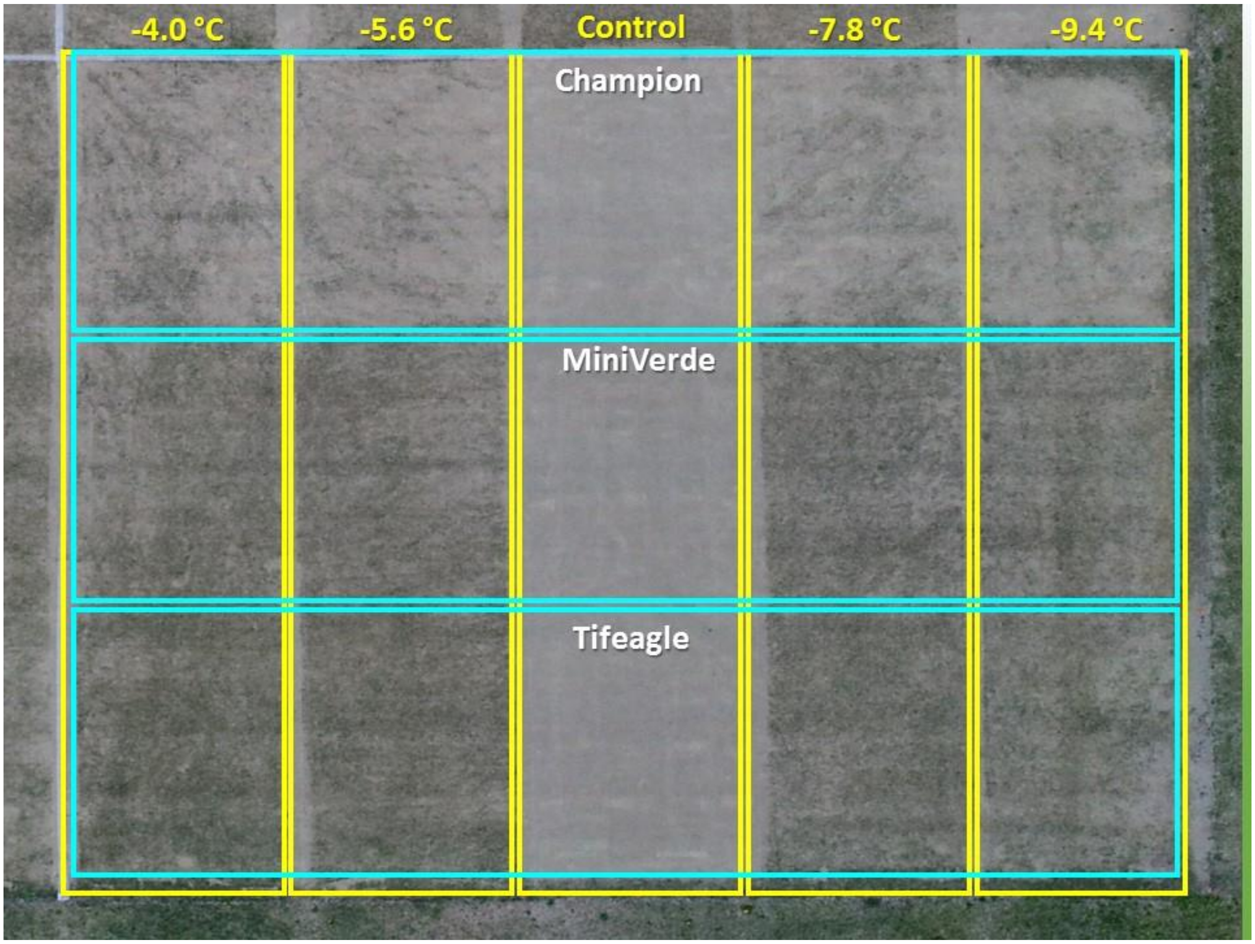


Photo 2 – Spring greenup of three ultradwarf bermudagrass cultivars exposed to various predicted low-temperature, cover thresholds – Photo taken on 18 April 2017.

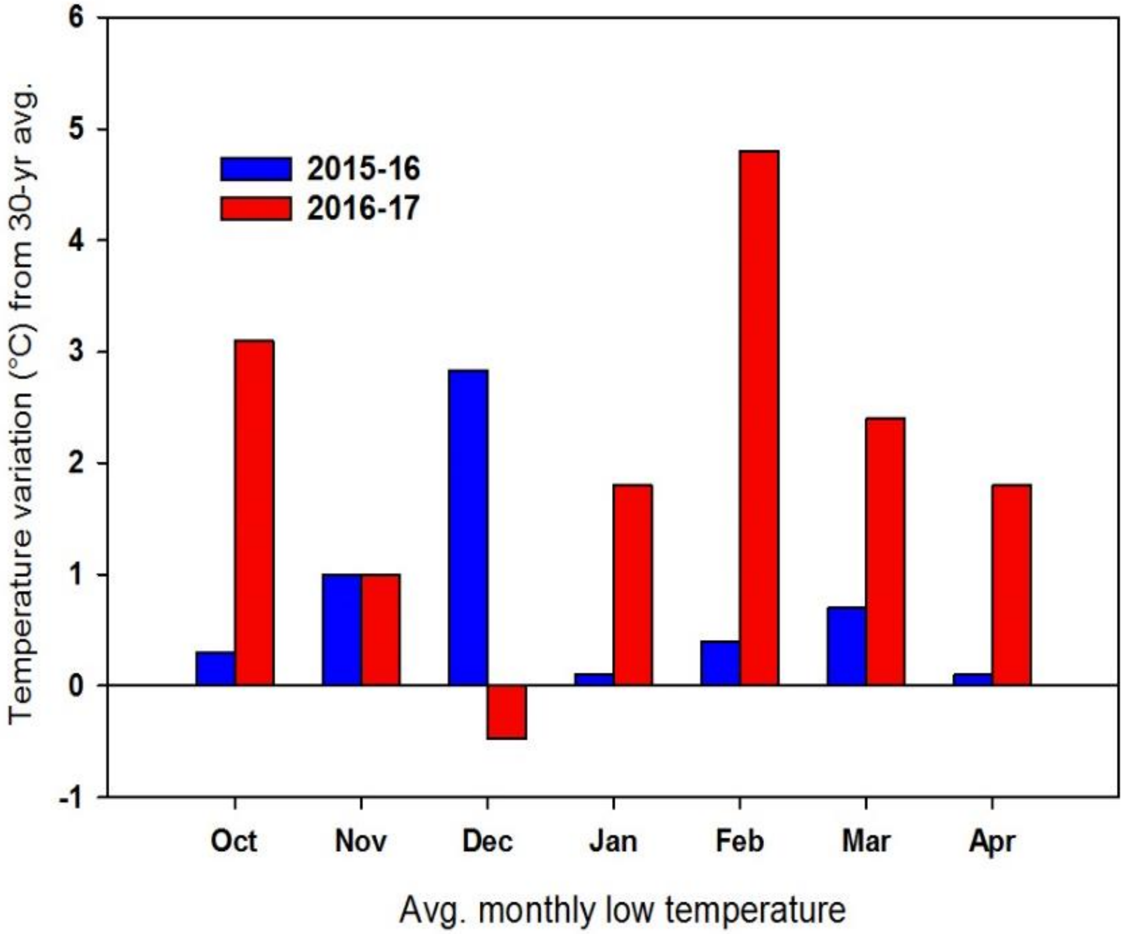


Figure 1. Average monthly low temperature deviation from the 30-yr average in Fayetteville AR during the months of the study.

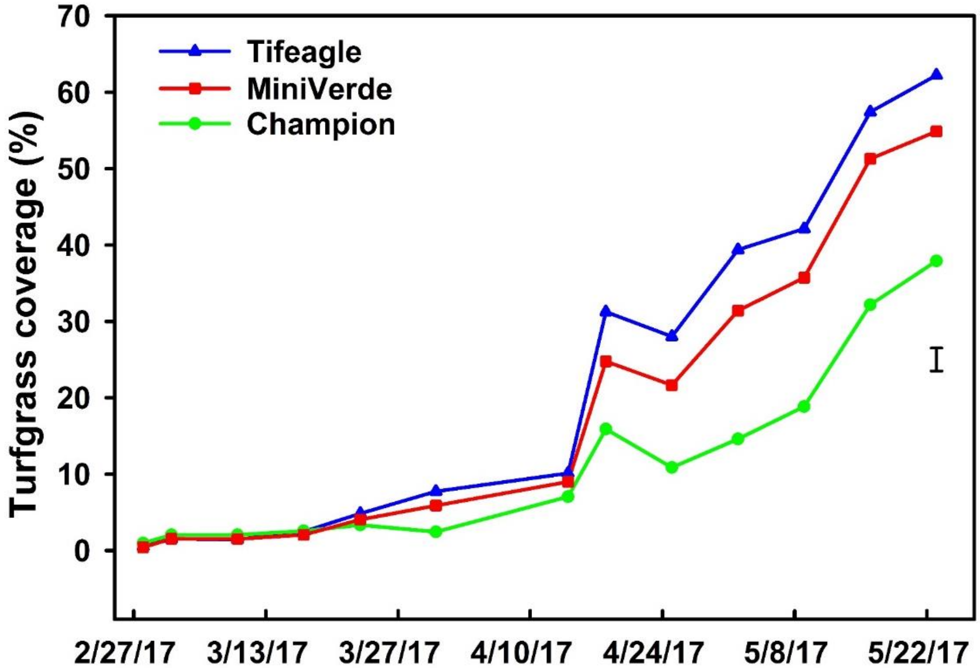


Figure 2 – Effect of cultivar on winter injury and spring greenup of ultradwarf bermudagrass in Spring 2017. Error bar represents the least significant difference (P<0.05) for comparing treatments.

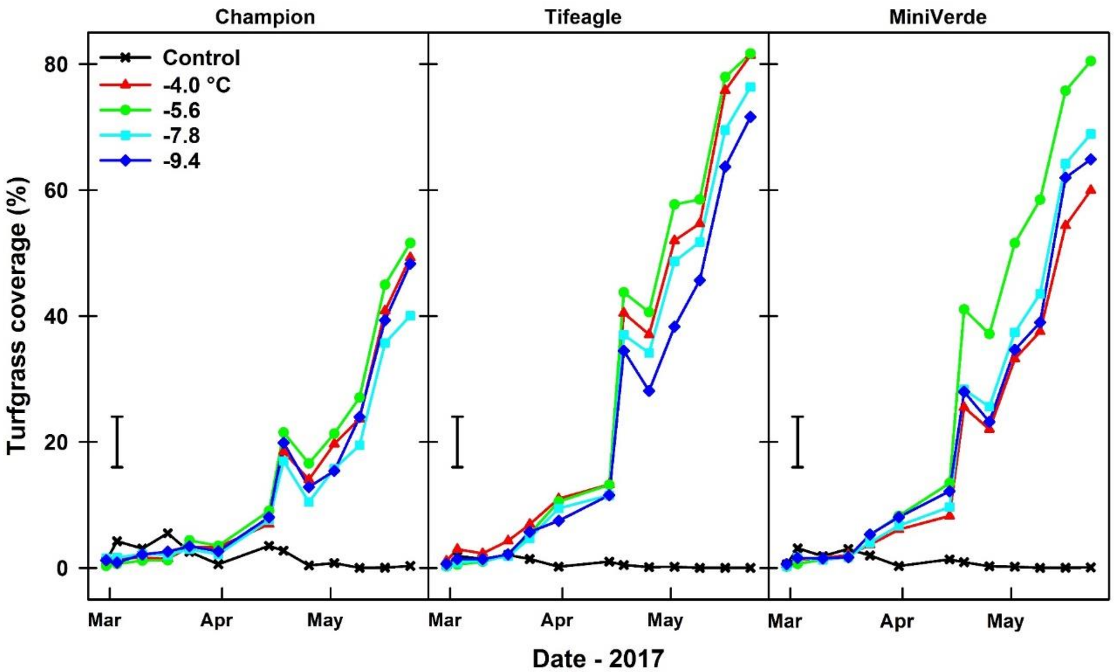


Figure 3. Cultivar by cover treatment interaction on spring greenup of ultradwarf bermudagrass greens in Spring 2017. Error bar represents the least significant difference (P<0.05) for comparing treatments.

Table 1. A two-year summary of the effects of modifying cover temperature thresholds on number of covering events, total days covered, and increased days open for play in Fayetteville AR.

Cover Treatment	Number of Covering Events (2 yr total)	Total Days Covered	Potential Savings†	Increased days open for play
-4.0 °C	18	60	-	-
-5.6 °C	14	53	$2,968	7
-7.8 °C	6	28	$8,904	32
-9.4 °C	4	19	$10,388	41

† Potential labor savings were calculated based on the estimated labor costs associated with deploying and removing covers developed by Jared Nimitz at the Peninsula Club in Cornelius, NC.. Mr. Nimitz has tracked labor for over 5 years and associated an average labor cost of $742 for each covering and uncovering event.

2017-15-625

Modeling GA Production Improves Prediction of Turf Growth and PGR Performance

Jacob Fuehrer and William Kreuser

University of Nebraska-Lincoln

Intro

Annual nitrogen fertilizer regimes for cool-season turf species have historically been based off of bimodal growth curves found in textbooks. These growth curves show highest growth in the spring and the fall. Recent research has indicated that at low temperatures, nitrogen uptake is reduced. This has led to reduced late-fall nitrogen recommendations. Another point of interest was summer nitrogen fertilization. Current growth potential models predict the magnitude of growth and when to fertilize based off of optimal temperatures for photosynthesis. These models currently do not have any scientific research to support them. Also, we have observed growth in some field studies that contradicts this model.

Research Question & Objective

- How is clipping yield affected by nitrogen fertilizer response and temperature in three cool season species?
- Quantify the effect that temperature and nitrogen response has on clipping yield from three turf species during the growing season.

Materials & Methods

We tested three cool-season species, 'L-93' Creeping bentgrass (1.3 cm HOC), 'Nu Destiny' Kentucky Bluegrass (5.1 cm HOC), and '5-Iron' Perennial Ryegrass (5.1 cm HOC). The species were started as plugs taken from the East Campus Turf Plots on the UNL campus. The plugs were grown in 10 inch black Cone-tainers. The plugs were grown in two Environ growth chambers with average air temperatures at 20C and 30C. Light intensity, humidity, and day length were all kept the same. The four nitrogen fertilizer treatments tested were 0, 0.6, 1.2, and 2.4 g m^{-2}. The plugs were acclimated to their respective chambers for three weeks and fertilized with 0.5 g m^{-2} N the first two weeks of acclimation. Nitrogen treatments were applied weekly. Clippings were collected, dried, and weighed weekly starting two weeks after treatments began and continuing for four weeks.

Results

We found that as nitrogen rate increased, clipping yield also increased for all three species. Although there were differences between the species in regards to nitrogen rate response. Creeping bentgrass and Kentucky bluegrass were much more sensitive to nitrogen increases as compared to perennial ryegrass. We also observed a much greater response to nitrogen in the cool (20C) growth chamber as compared to the hot (30C) growth chamber. Average weekly clipping yield at the high nitrogen rate was nearly double in the cool chamber than the hot chamber. Lastly, we found that perennial ryegrass was much more sensitive to temperature than creeping bentgrass and Kentucky bluegrass (Figure 1). Perennial ryegrass had about 4x the growth in the cool chamber as compared to the hot chamber while creeping bentgrass showed very little difference in mean weekly clipping yield between the chambers.

Conclusion

We can conclude that temperature and nitrogen fertilizer do play a role in clipping yield. Clipping yield increased with nitrogen rate but the amount of response decreased from cool temperature to warm temperatures. The magnitude of these responses differed among the three species as well. Perennial ryegrass was much less sensitive to nitrogen rate and much more sensitive to temperature than creeping bentgrass and Kentucky bluegrass. More testing will be needed to observe growth at other temperatures.

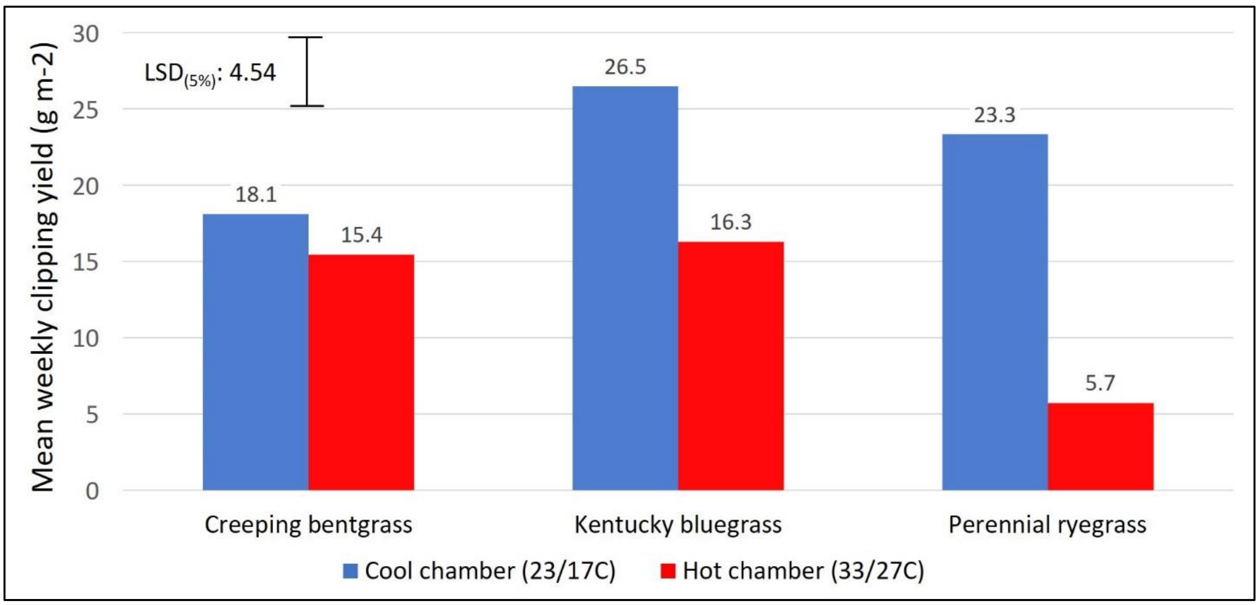


Figure 1. Three cool-season species mean weekly clipping yield in each growing environment.

2017-20-630

Title: Chemical Priming to Improve Annual bluegrass Responses to Ice Stress

Project Leaders: Emily Merewitz and Kevin Frank

Affiliation: Michigan State University

Objectives:
1) Evaluate whether chemical priming and Primo applications influence winter survival and spring green up rates in Michigan in 2017 and 2018 (field experiment)

2) Determine whether chemical priming and Primo applications affects annual bluegrass performance under no ice and ice stress conditions (freezer experiment)

Start Date: 2016
Project Duration: Two years
Total Funding: $20,000

Summary Text:
Priming of plants means that a given treatment makes plants more prepared to take on a subsequent stress. Information from controlled research studies available on priming chemicals for turfgrass species in response to abiotic stress is lacking. Plant priming with salicylic acid (SA) and jasmonic acid (JA) could potentially boost the systemic acquired resistance (SAR) or induced systemic resistance (ISR) pathways, respectively. Both JA and SA are either already in turf products or have potential to be in turf products. These are two pathways that are primarily associated with plant defense of biotic stress but are also involved in promoting tolerance to abiotic stresses. CIVITAS Pre-M1xed is also said to have an ISR stimulating effect on plants. In our previous work funded by the USGA, we have found that this CIVITAS product was beneficial to annual bluegrass survival of ice cover. CIVITAS treated plants had a higher level of the fatty acid linolenic acid, a precursor to JA, than control plants (Laskowski et al, 2018). In that same study, PGRs such as Primo showed some evidence of decreasing ice tolerance of annual bluegrass; however, not on all days measured. This study aims to determine whether priming of annual bluegrass with CIVITAS Pre-M1xed, SA, and JA in combination with PGR treatment improves or inhibits winter survival and spring green-up under natural field conditions and ice stress tolerance in simulated controlled conditions.

All chemical treatments began on 2 June 2017 and were applied every two weeks through 4 August 2017, and then once more on 30 October 2017 based on CIVITAS program recommendations for use in the summer and fall months. All treatments were applied with a pressure-calibrated backpack sprayer (63.3-gal a^{-1} at 275 kPa) equipped with four flat fan nozzles (DG8002 DS, Teejet Technologies, Wheaton, IL.). The treatments were:1) Control 2) Primo (0.125 fl oz/1000ft^2) 3) CIVITAS Pre-M1xed (8 fl oz/1000ft^2) 4) JA (2mM) 5) JA (0.5mM) 6) SA (20µM) 7) SA (10µM) 8) CIVITAS Pre-M1xed + Primo (8 fl oz/ 1000ft^2 + 0.125 fl oz/1000ft^2) 9) JA + Primo (2mM + 0.125 fl oz/1000ft^2) 10) JA + Primo (0.5mM +0.125 fl oz/ 1000ft^2) 11) SA + Primo (20µM +0.125 fl oz/1000ft^2) and 12) SA + Primo (10µM +0.125 fl oz/1000ft^2). Commonly measured turf evaluation parameters were measured in the field on all

plots including turf quality, the dark green color index (DGCI), normalized difference vegetation index (NDVI).

After only one year of data, CIVITAS or CIVITAS + Primo had the greatest turf quality when compared to the untreated control. On several dates and for turf quality, NDVI and DGCI, CIVITAS and Primo, JA and Primo, and SA and Primo treatment combinations had improved values compared to control plots and Primo alone (only for DGCI). Testing the effects of all treatments on the survivability of annual bluegrass under ice cover or no ice cover in the low temperature growth chamber is currently being conducted. Fatty acid analysis will be evaluated following the completion of the growth chamber treatments.

Summary Points:

- Chemical priming hormone treatments alone (JA only, SA only) appear to have no significant effect on experimental measurements in the field when compared to the untreated control
- When Primo was added to chemical priming hormones a synergistic effect of increasing DGCI was observed when compared to the untreated control and when compared to Primo alone on several dates.
- Civitas and Civitas + Primo had the greatest turf quality and DGCI during the summer and into the fall on several dates.

Literature Cited

Laskowski, K., K. Frank, and E. Merewitz. 2018. Chemical Plant Protectants and Plant Growth Regulator Effects on Annual Bluegrass Survival of Ice Cover. Journal of Agronomy and Crop Science. *Under Review*.

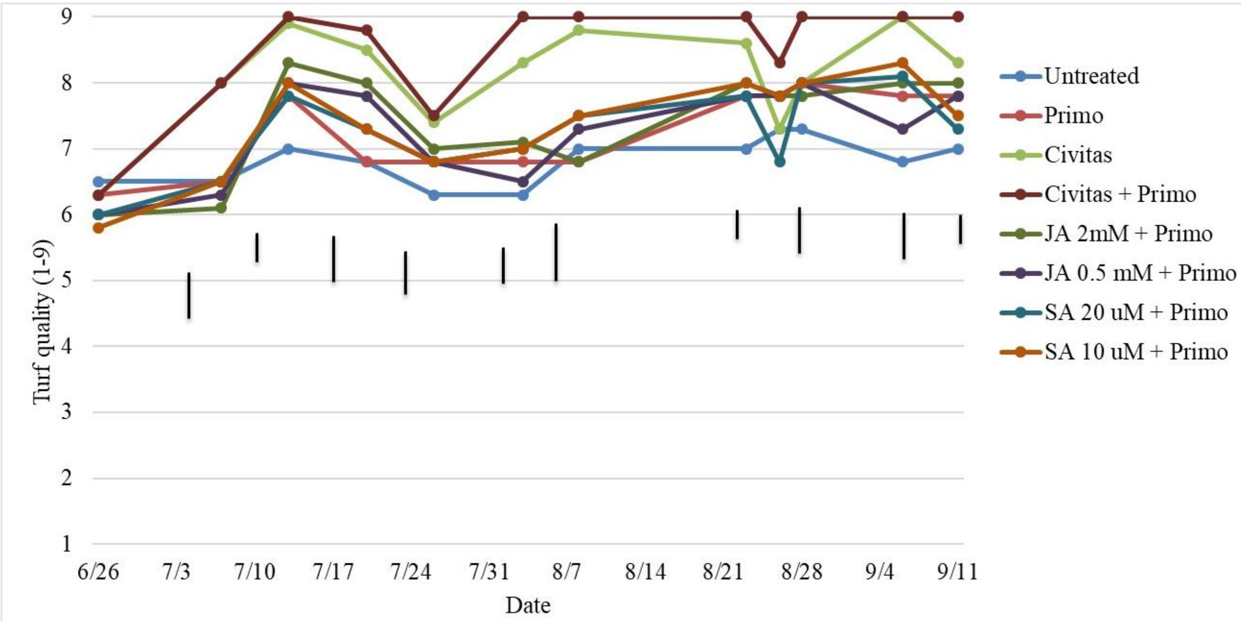


Figure 1. Turfgrass quality (1–9 scale with 1 (poor) and 9 (best), with 6 being acceptable) of annual bluegrass under chemical priming treatments in 2017. Bars represent Fisher's protected least significant difference at $P \leq 0.05$ for the comparison of means on each date.

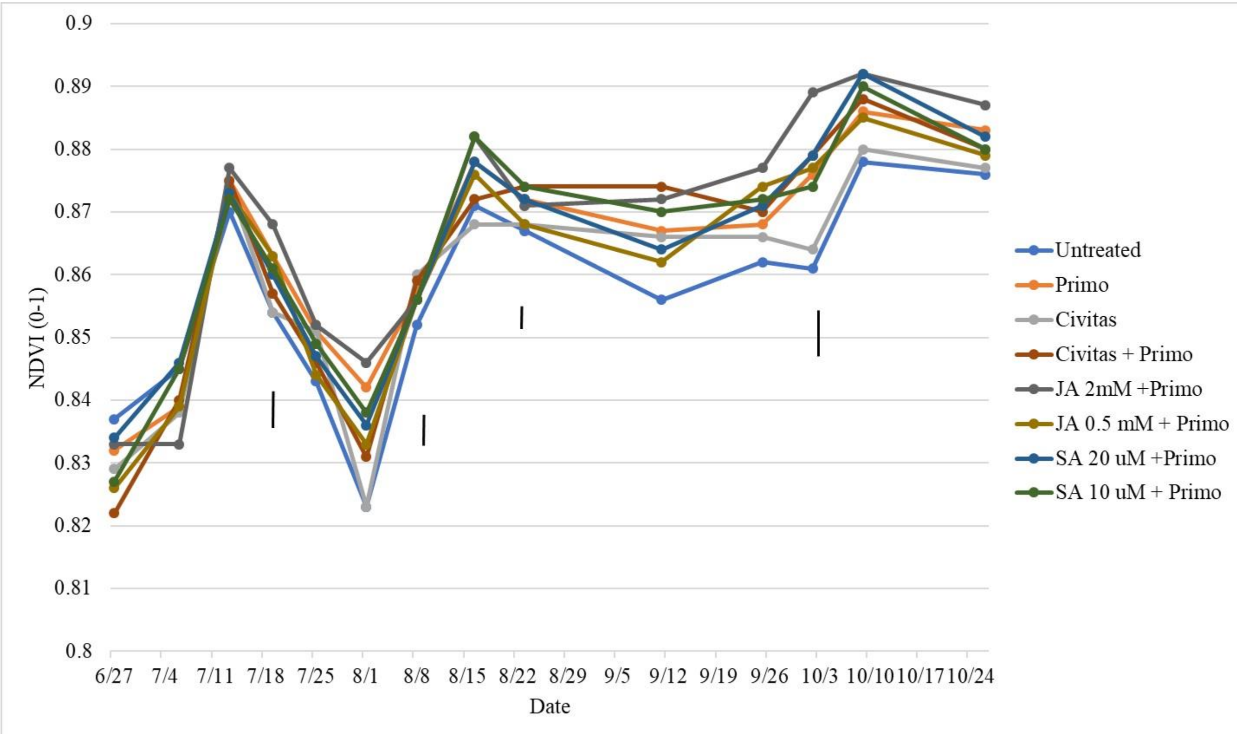


Figure 2. Normalized difference vegetation index of annual bluegrass under chemical priming treatments in 2017. Bars represent Fisher's protected least significant difference at $P \leq 0.05$ for the comparison of means on each date.

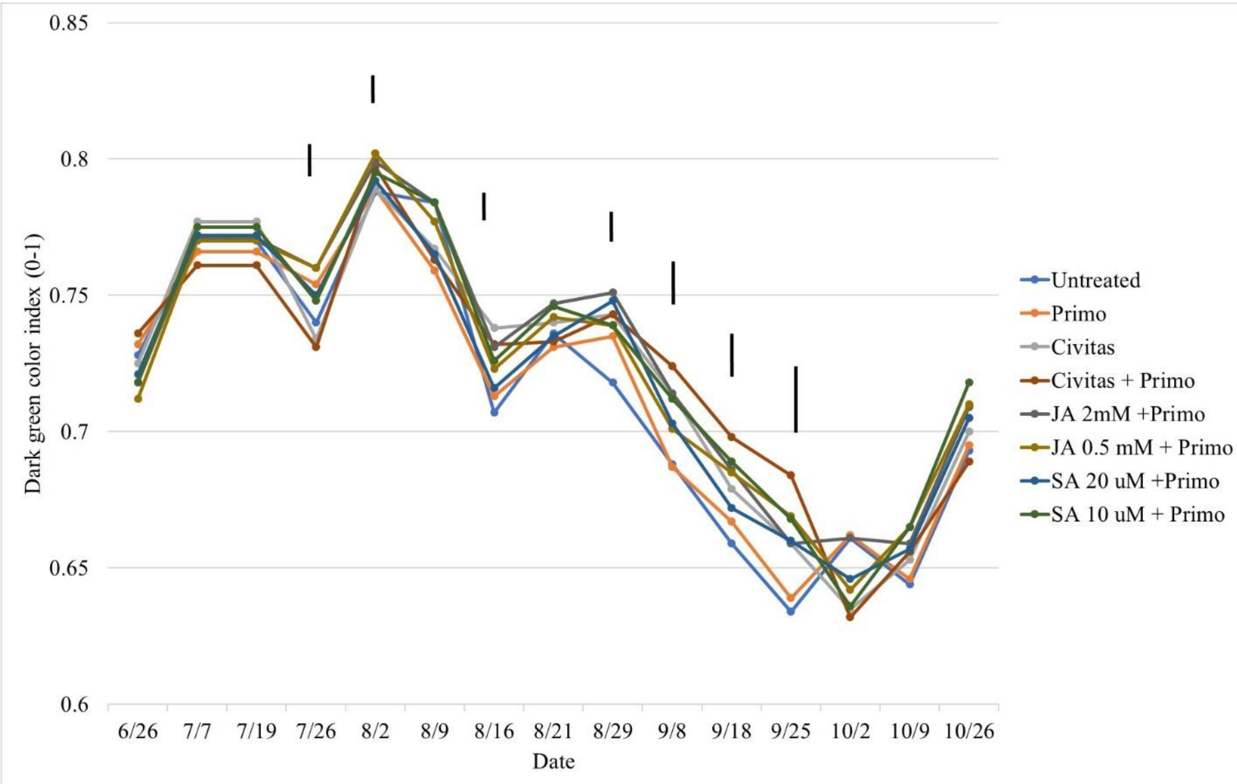


Figure 3. Dark green color index of annual bluegrass under chemical priming treatments in 2017. Bars represent Fisher's protected least significant difference at $P \leq 0.05$ for the comparison of means on each date.

2015-18-533

Title: Response of Seven Seeded Low Maintenance Grasses to Less than Optimum Irrigation.

Project Leader: David Kopec
Affiliation: University of Arizona
Objectives: Determine turfgrass performance of seven seeded low maintenance grasses when irrigated with different ET replacement values.
Start Date: May 2017.
Duration: 1 year – as USGA project

KEY BULLETS:

- During the peak period of drought in mid-July, the following grasses produced a minimal turf surface (NTEP quality of at least 4.0= no less than 80% green plot cover, utility turf) at the lowest ET replacement values: Jackpot bermudagrass (25%), Wrangler bermudagrass (25%), and SunDancer bufflaograss (25%).

- During the peak period of drought in mid-July, the following grasses produced a nominal turf surface (NTEP quality of at least 5.0= just less than fully acceptable conditions for fairway, but acceptable for secondary rough otherwise) at the lowest ET replacement values: All three buffalo grasses (35%), Jackpot and Wrangler bermudagrass (35%).

SUMMARY*:*

On a per unit ground basis, many golf courses have undergone reductions in turf areas, based on identifying areas which have minimal player contact, and overall hole-changing and rating considerations.

With these concepts in mind, a study was established in 2015 to evaluate commercially available seeded-type low maintenance grasses that could be used on golf course landing zones and other areas which would otherwise be in out-of-bounds areas, or in areas that receive lesser amounts of traffic. If such grasses afford a suitable grass cover (as opposed to weeds, soil, or hardscapes) and have the added benefit of doing so under less than standard irrigation amounts for existing turfs, then this too would be another successful component of water savings of turf. As such, four cultivars of low

maintenance bermudagrass, and three buffalograsses (representing three generations of turf-type development) were tested in 2017 using a special field arrangement referred to as a Linear Irrigation Gradient (or LIGA) design.

This special irrigation design applies a continuous gradient of water from the center sprinkler line that decreases in relative amount with distance to end of the sprinkler radius of throw. The LIGA design here applied irrigation replacement amounts at 75, 65, 55, 45, 35, and 25% of reference ET.

The irrigation test started on May 13th and ended on Oct 22nd. The test was irrigated nightly, based on the previous days reference ET (midnight to midnight), from an on-site weather station and a Rain Bird PC irrigation control system.

All plots were mowed at 3.0 inches with a walk behind 22" rotary mower with clippings bagged (to avoid bermudagrass contamination). The test was fertilized with 1/2 lb. of nitrogen/ 1000 ft^2 on 3 occasions as needed using a slow release urea. The plots were observed for living density, absence/presence of any dead turf, all of which were "captured" in the visual assignment of overall turfgrass quality. Using the NTEP visual rating scale, all 168 plots of turf received quality scores on eight evaluation dates from May 27th to October 21st 2017, when short day lengths started to trigger the beginning of fall dormancy.

Results

For each grass, the questions to answer are, what is the ET replacement level that is required to provide a minimal utility turf (4.0 for quality) and that of a nominal low maintenance turf (5.0 for quality).

Table 1 shows the minimum ET required to achieve a utility turf (*4.0 or greater* NTEP quality) at the peak of the drought in July, and at the end of the trial in October 2017. Jackpot and Numex-Sahara did so at 25% ET replacement, while the other five grasses did so at 35%. Note that at the 35% level, all three buffalograss entries had better quality scores than the bermudagrass entries, when achieving the minimum quality requirement of at least 4.0 for a utility turf. To close the trial with the same requirement of at least 4.0 at the end of October, all seven grasses needed 45% ET replacement, as Wrangler bermudagrass and all three buffalograss turfs had slightly better quality than Numex-Sahara, Jackpot, and Cheyenne II as utility turfs.

Table 2 shows the minimum ET required to achieve a nominal quality turf (5.0 minimum NTEP quality) at the peak of the drought in July, and at the end of the trial in October 2017. All three bermudagrass cultivars as well as Jackpot and Wrangler bermudagrass achieved nominal turfgrass quality (*5.0 or greater)* at 35% ET irrigation, while Nu-Mex Sahara and Cheyenne did so at 45%, noting that a slightly higher quality was realized for those two bermudagrass entries when meeting that basic quality requirement. At the end of the trial, all three seeded buffalograss cultivars did so at 45% ET irrigation. All of the bermudagrass cultivars required 55% ET replacement at end of season to close the trial with a minimum quality of 5.0. Nu-Mex Sahara and Wrangler had achieved slightly higher quality scores (6.0) as part of that requirement.

Table 1. ET replacement irrigation level which maintained seven seeded low maintenance grasses at a utility turfgrass quality (***4.0 or greater***) at the peak of drought in in late [July], and at the end of the trial on [Oct 22], 2017. University of Arizona.

		ET replacement Level					
Grass	Cultivar	0.25	0.35	0.45	0.55	0.65	0.75
Buffalograss	Bison		[5.0]	[5.5]			
	TopGun		[5.3]	[5.5]			
	SunDancer		[5.5]	[5.5]			
Bermudagrass	Nu-Mex Sahara		[4.8]	[4.8]			
	Jackpot	[4.0]		[4.8]			
	Cheyenne II		[4.5]	[4.5]			
	Wrangler	[4.0]		[5.5]			

ET replacement value = Percentage of Reference ET(0) from on site weather station using standardized Penman Monteith equation.
Quality: 1=dead, =utility grade, 5=nominal/acceptable for rough, 6=faiway acceptable, 9=best possible.
Values are the mean of replications per each grass/ET replacement level combination.
Red value is grass mean quality score during peak drought, blue value is at end of trial, October 2017.

Table 2. ET replacement irrigation level which maintained seven seeded low maintenance grasses at nominal utility turfgrass quality (***5.0 or greater***) at the peak of drought in in late [July], and at the end of the trial on [Oct 22], 2017. University of Arizona.

		ET replacement Level					
		0.25	0.35	0.45	0.55	0.65	0.75
Grass	Cultivar						
Buffalograss	Bison		[5.0]	[5.3]			
	TopGun		[5.3]	[5.5]			
	SunDancer		[5.5]	[5.5]			
Bermudagrass	Nu-Mex Sahara			[6.0]	[6.0]		
	Jackpot		[5.3]		[5.8]		
	Cheyenne II			[6.0]	[5.5]		
	Wrangler		[5.5]		[6.0]		

ET replacement value = Percentage of Reference ET(0) from on site weather station using standardized Penman Monteith equation.
Quality: 1=dead, =utility grade, 5=nominal/acceptable for rough, 6=faiway acceptable, 9=best possible.
Values are the mean of replications per each grass/ET replacement level combination.
Red value is grass mean quality score during peak drought, blue value is at end of trial, October 2017.

Figure 1. Four cultivars of low maintenance bermudagrass, and three buffalograsses (representing three generations of turf-type development) were tested in 2017 using a special field arrangement referred to as a Linear Irrigation Gradient (or LIGA) design, which was audited to estimate the precipitation rate gradient.

Figure 2. This Linear Irrigation Gradient (or LIGA) design applies a continuous gradient of water from the center sprinkler line that decreases in relative amount with distance to end of the sprinkler radius of throw. The LIGA design here applied irrigation replacement amounts at 75, 65, 55, 45, 35, and 25% of reference ET. Note poorer quality at the ends of plots where irrigation was least.

2016-14-564

Low-Input New Groundcover and Native Grass Species for Turfgrass Replacement in the Low Desert

Kai Umeda and Worku Burayu
University of Arizona, 2017

Objectives:
1. Evaluate and compare the adaptation and performance of nativegrasses and alternative groundcovers in the low desert southwest United States as a low input turfgrass replacement in non-play areas of golf courses.
2. Generate local research-based information on the feasibility of growing new groundcovers and the nativegrasses by properly assessing their interactions with insect pests and weeds, water, and fertility requirements.
3. Increase the awareness of stakeholders about the characteristics of nativegrasses and alternative groundcovers for low water use requirements and potential water saving capacity.

Start Date: 2016
Project Duration: 3 years
Total Funding: $45,000
Report Type: Annual, second year report (2017)

Summary Text

The need for low turf maintenance inputs such as fertilizer, pesticides, water, and less frequent mowing has generated interest to evaluate low-input nativegrasses and groundcovers for the landscapes of the southwest United States. This project investigates native grass species and new groundcovers as low input and minimum maintenance plant materials when turfgrass is removed from non-play areas of golf courses or other landscapes. The study is a multi-year and multi-location set of field trials consisting of nine grass species, a native forb, and an introduced horticultural groundcover (Table 1). The first was initiated in May 2016 at Camelback Golf Club in Scottsdale, AZ and the second in June 2017 at Briarwood Country Club in Sun City West, Arizona. Small plots for each species treatment measured 6 ft x 6 ft and were arranged in a randomized complete block design with three or four replicates. At Scottsdale, plants were established under sprinkler irrigation receiving an equivalent of 0.35 inch/day for about six weeks. After mid-July, plants were grown receiving an equivalent of 0.24 inch/day. In September, irrigation was reduced to an equivalent of 0.15 inch/day. Beginning in November, irrigation was suspended for the winter and then resumed in mid-April 2017 with an equivalent of 0.15 inch/day. In the second year during 2017, the overall plant quality evaluation data for greenness, percent ground cover and vigor were collected at various intervals during the growing seasons: summer, fall, winter, and spring. At Briarwood CC, field plots were installed with overhead sprinkler irrigation and during 2017, first year data were collected for plant emergence, plant height, and percent ground cover. Data were analyzed using JMP statistical software and means compared using Student's t-test.

Laboratory Germination

In 2017, concurrent with field planting at Briarwood CC, grass species showed varying percent seed germination rates in the laboratory at a room temperature. At one week, *Eragrostis tef* (teff) and *Eragrostis intermedia* (plains lovegrass) had germination rates of over 92% (Figure 1). *Hilaria rigida* (big galleta), and *Bouteloua gracilis* (blue grama) had germination rates of 52.5% and 47.5%, respectively. *Muhlenbergia asperifolia* (alkali muhly), *Sporobolus cryptandrus* (sand dropseed), *Sporobolus airoides* (alkali sacaton) exhibited 15-25% germination. *Bouteloua dactyloides* (buffalograss), *Sporobolus contractus* (spike dropseed), and the forb, *Zinnia acerosa* (desert zinnia), failed to germinate, similar to the 2016 trial.

Field Experiments

A. Briarwood CC

Surface coverage of the plot area and height of plants data are presented in Figure 1. In the field small plots, all plant species except desert zinnia and buffalograss established a stand at Briarwood CC within 12 weeks after seeding (WAS). *Lippia nodiflora* (Kurapia), big galleta, and teff emerged relatively faster and there was better than 80% stand establishment. Blue grama and sand dropseed exhibited 70% plot coverage. Alkali muhly, Alkali sacaton and Spike drop seed covered less than 50% of the surface area. Spike dropseed, sand dropseed, plains lovegrass, and teff grew to a height of more than 24 inches at 12 WAS. Shortest in stature, Kurapia and alkali muhly grew no more than 2 and 10 inches in height, respectively. To increase the awareness of stakeholders about the establishment, characteristics and overall performance of nativegrasses and alternative groundcovers for low water use requirements, a field demonstration was conducted at Briarwood CC on September 15, 2017 (Figure 2)

B. Camelback Golf Club

The second-year performance of nativegrasses and groundcovers for overall quality throughout spring, summer, fall, and winter are presented in Figure 3. Before a mowing in July 2016, all plant species exhibited good visual quality and vigor. After mowing, all of the native grasses performed at varying rates of growth to establish and provide surface area coverage throughout spring (March-May), summer (June-August), fall (September-November) and winter (December-February). In fall, all but buffalograss, sand dropseed and spike dropseed exhibited acceptable visual quality levels (> 6) for greenness. There was a definite difference in color of plants (greenness) among plant species in winter (Figure 4). Kurapia, plains lovegrass, alkali sacaton, alkali muhly, and blue grama, maintained foliar greenness during the winter into spring.

Summary Points

- All plant species, except desert zinnia and buffalograss emerged, survived and established under field conditions at Briarwood CC.
- All of the native grasses exhibited varied growth rates to establish, provide surface area coverage, and overall plant quality throughout spring, summer, fall and winter at Camelback GC.
- Kurapia, plains lovegrass, alkali sacaton, alkali muhly, and blue grama, in that order, performed well to maintain greenness during the fall, into winter, and into spring at Camelback GC
- Overall observations showed that kurapia was very aggressive and vigorous as a groundcover.
- Desert zinnia seed did not germinate in the laboratory or in the field at both locations in both years.
- The evaluations at both sites demonstrated the requirement for an adequate water supply for the establishment and to achieve desirable characteristics of all plant species.

Table 1. List of native grasses and groundcovers evaluated in the low desert Arizona

	Common Name	**Scientific Name**
1	Alkali sacaton	*Sporobolus airoides*
2	Alkali muhly	*Muhlenbergia asperifolia*
3	Blue grama	*Bouteloua gracilis*
4	Buffalograss	*Bouteloua dactyloides*
5	Teff	*Eragrostis tef*
6	Plains lovegrass	*Eragrostis intermedia*
7	Big galleta	*Hilaria rigida*
8	Sand dropseed	*Sporobolus cryptandrus*
9	Spike dropseed	*Sporobolus contractus*
10	Desert zinnia	*Zinnia acerosa*
11	Kurapia	*Lippia nodiflora*

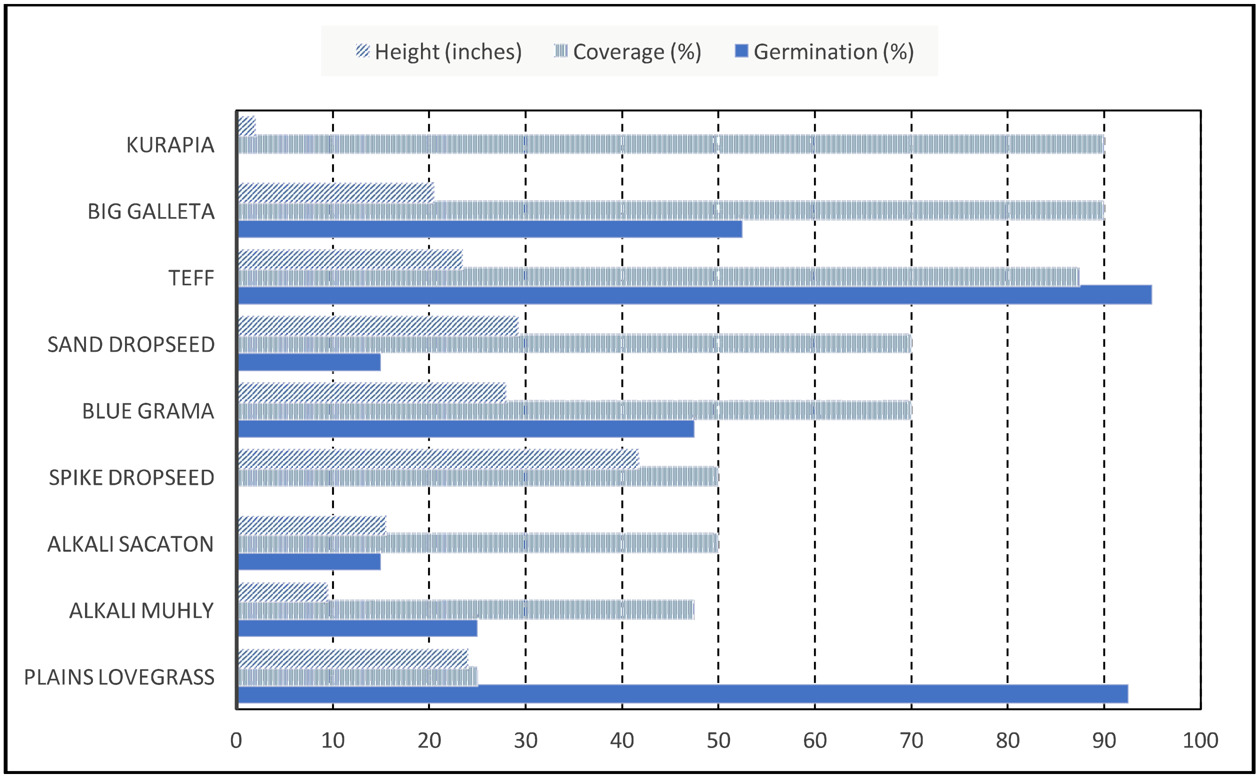


Figure 1. Percent seed germination of grasses in the laboratory at room temperature a week after seeded, ground surface coverage (%) and plant height (inches) of nativegrasses and groundcovers at 12 weeks after planting in the Sun City West, Arizona, 2017. Kurapia was planted as plugs.

Figure 2. Field demonstration of nativegrasses and groundcovers performance at Briarwood Country Club in the Sun City West, AZ on September 15, 2017.

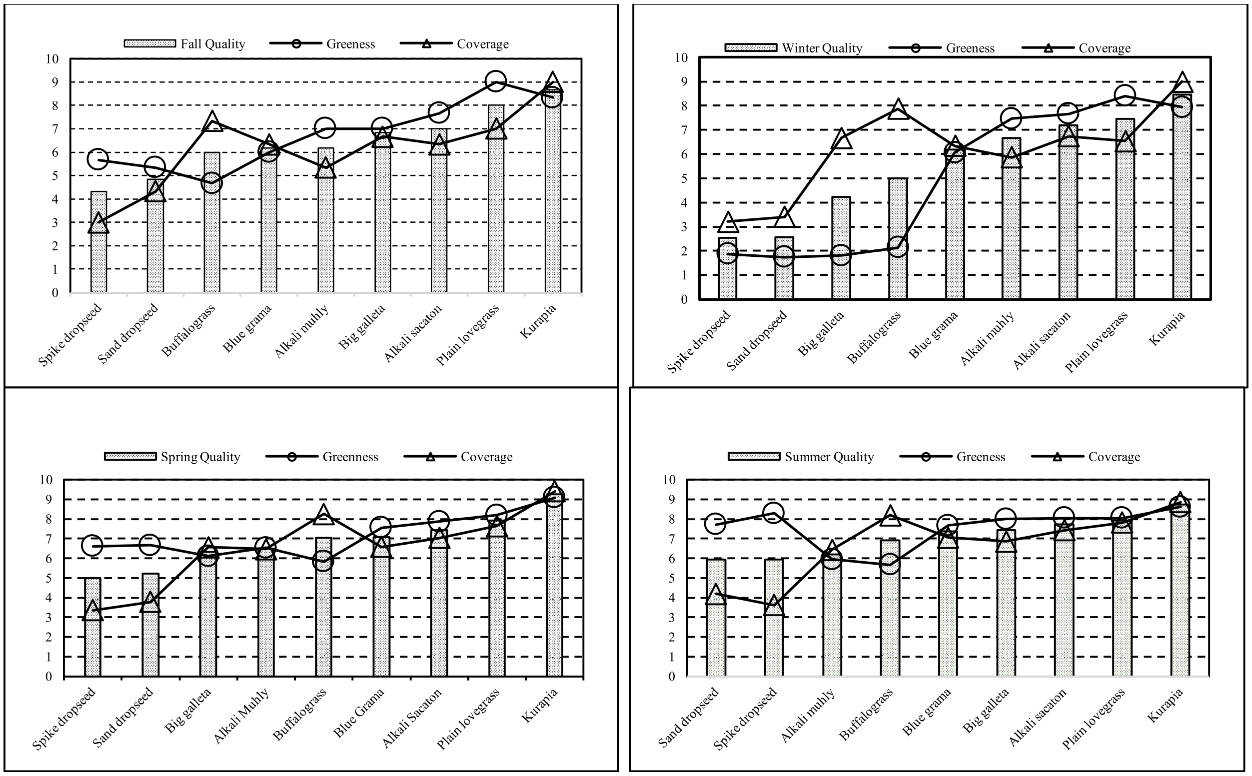


Figure 3. Performance of nativegrasses and groundcovers during fall (0.157 inch/day irrigation), winter (no irrigation), spring (0.157 inch/day) and summer (0.30 inch/day) time at Scottsdale, AZ in 2016-17**.**

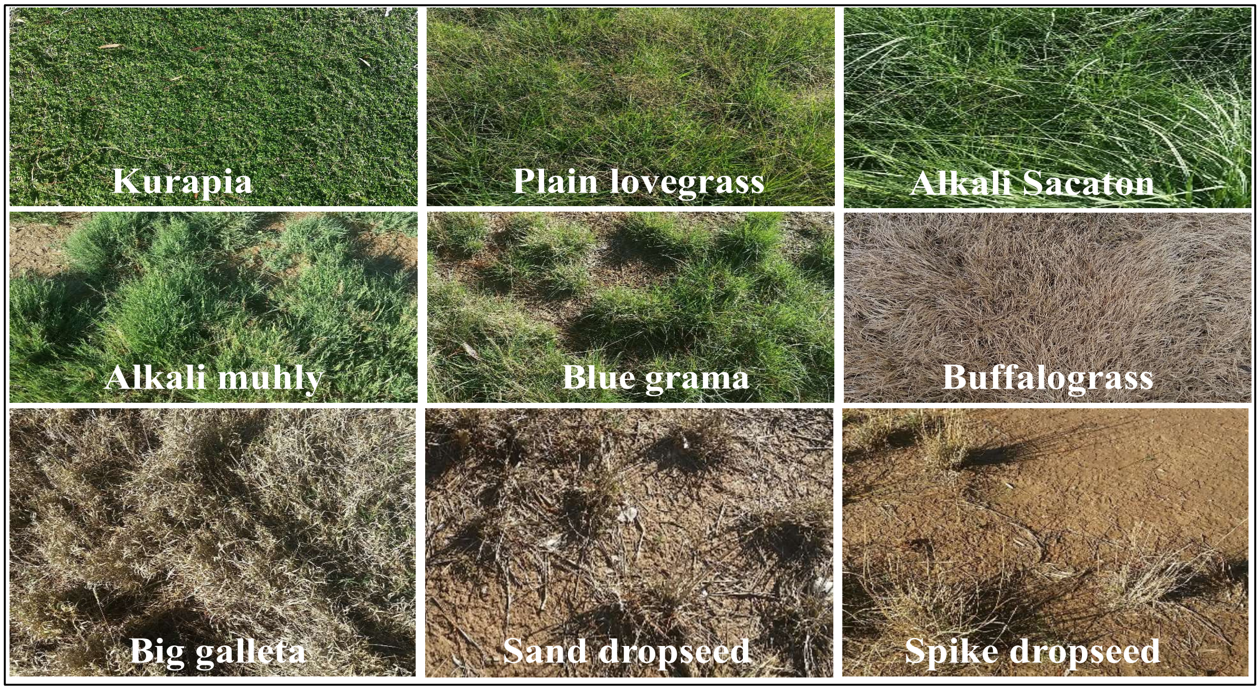


Figure 4. Evaluating quality of nativegrasses and groundcovers in winter at the end of January, 2017 in Scottsdale, AZ. Greenness retained by Kurapia, lovegrass, sacaton, muhly, and grama. No irrigation during the winter.

2017-04-614

Project title: Bermudagrass rough conversion to no-mow, low-input grass area

Project leader: Maggie Reiter

Affiliation: University of California Cooperative Extension

Objectives:
1. Evaluate the performance of low-input, alternatives grasses as an out-of-play area on a Central California golf course
2. Compare establishment rates of those alternative species
3. Test methods for bermudagrass termination
4. Develop best management practices for subsequent weed control

Start date: 2017

Duration: 3 years

Total funding: $50,000

Summary text:
To conserve natural resources, increase economic savings, and comply with legislative restrictions, golf course managers are having to maintain their landscapes at healthy conditions with lower inputs of water, fertilizer, pesticides, and energy. A worthwhile option to reduce inputs is using alternative grass species that perform well under lower-input management. Among golf course turfgrass areas, the rough is the largest component of maintained turfgrass and the most reasonable area to integrate lower-input grasses on a large scope with effective outcomes. Currently, bermudagrass (*Cynodon dactylon*) is the most dominant species on golf course roughs throughout California and the Southwest United States. Bermudagrass is popular for its superior functionality and appearance, but a healthy sward needs regular water, fertilizer, pesticides, mowing, and cultivation. Golf course managers are looking for ways to convert bermudagrass areas, especially in rough areas that are seldom in play and not worth the inputs to maintain. Alternative grass species exist that could provide a minimal-input, naturalized area without impairing playing conditions. However, there are major unknowns associated with the establishment and management of alternative grass species. Little research has been published and golf course superintendents are reluctant to install these species.

The goal of this project is to determine what alternative grass species will perform well and remain playable as an unmowed golf course rough, and to develop best management practices to terminate bermudagrass and establish a healthy, low-input stand of vegetation.

Objectives 1 and 2
Two field trials were established on rough areas of golf courses in Dinuba, CA and San Luis Obispo, CA, to measure the performance of different grasses. Ten cool-season grass species were seeded October 2017 in 3.7 x 1.5 m plots, at a rate of 324 pure live seed m^{-2} (Table 1). Plots were arranged in a randomized complete block with 9 replications at the San Luis Obispo site and 4 replications at the Dinuba site. Field plots were irrigated daily with overhead sprinklers, and no fertilizer was provided. Data was collected for germination with a visual rating on a 1 to 5 scale, with 1 representing no germination and 5 representing maximum germination.

Data from 3 weeks after establishment was subjected to an ANOVA. No significant differences were detected for location or location by species interaction, so locations were combined. Differences were detected among grass species, and means were separated with Fisher's LSD (Figure 1). California brome (*Bromus carinatus*) and purple needlegrass (*Stipa pulchra*) made up the highest-ranked statistical group, with the most germination at rating time (Figure 2). The *Festuca* species and *Agrostis* species performed similarly within-genus, excluding sheep fescue (*Festuca ovina*).

In May 2018, two more field trials will be established on in Dinuba, CA and Parlier, CA, to evaluate 9 warm-season grass species (Table 2). Data will be collected from all trials on germination, plant growth stage, turf quality, pest susceptibility, above ground biomass, density, inflorescence counts, and lodging.

Objective 3
A healthy stand of bermudagrass on an active golf course rough will be subjected to different termination methods in 2018. Treatments for bermudagrass removal will include non-selective synthetic herbicide (glyphosate), non-selective organic herbicide, solarization, sod removal, and scalping. Data will be collected on recalcitrant bermudagrass and other weed invasion.

Objective 4
Best management practices for weed control may depend on the alternative grass planted and the bermudagrass termination method. Therefore, results from Objectives 1, 2, and 3 will be used to design experiments for Objective 4.

Summary points:
- Ten alternative grass species were established at 2 golf course sites in Central California
- All species germinated and differences were detected at 3 weeks after seeding
- California brome and purple needlegrass exhibited maximum germination at 3 weeks after seeding

Table 1. Cool-season grass species seeded fall 2017 on golf courses in Dinuba and San Luis Obispo.

Spike bentgrass	*Agrostis exarata*	*
Dune bentgrass	*Agrostis pallens* 'Camp Pendleton'	*
California brome	*Bromus carinatus*	*
Tufted hairgrass	*Deschampsia cespitosa*	*
Sheep fescue	*Festuca ovina*	
Hard fescue	*Festuca longifolia*	
Molate fescue	*Festuca rubra* 'Molate'	*
Chewings fescue	*Festuca rubra* ssp. *commutata*	
Prairie junegrass	*Koeleria macrantha*	*
Purple needlegrass	*Stipa pulchra*	*

*California native

Table 2. Warm-season grass species to be evaluated summer 2018 at 2 locations.

Purple threeawn	*Aristida purpurea*	*
Buffalograss	*Buchloe dactyloides*	
Sideoats grama	*Bouteloua curtipendula*	*
Blue grama	*Bouteloua gracilis*	*
Bermudagrass	*Cynodon dactylon*	
Weeping lovegrass	*Eragrostis curvula*	
Big galleta	*Hilaria rigida*	*
Deer grass	*Muhlenbergia rigens*	*
Alkali sacaton	*Sporobolus airoides*	*

*California native

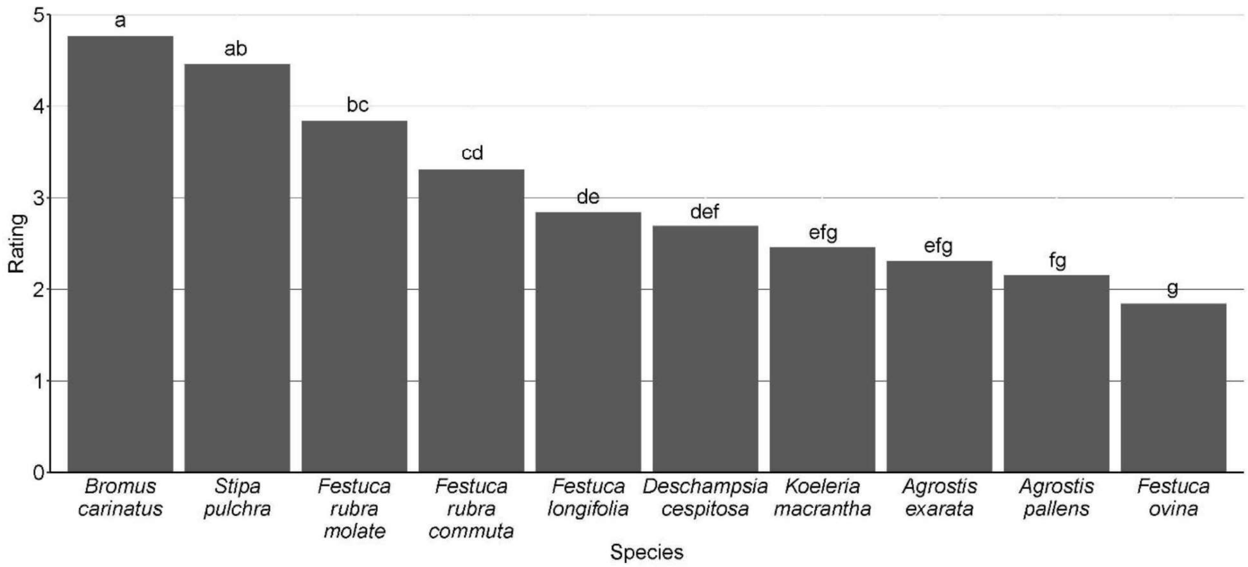


Figure 1. Mean germination rating for each species at 3 weeks after seeding. Bars labeled with the same letter are not statistically different using Fisher's LSD (α=0.05).

Figure 2. California brome (*Bromus carinatus*) plot in San Luis Obispo, 3 weeks after seeding.

2017-06-616

Project Title: Establishment and Maintenance Practices for No-Mow Fine Fescue Golf Course Roughs

Project Leaders: Eric Watkins, Sam Bauer, Andrew Hollman

Affiliation: University of Minnesota

Objective:

Determine optimum seeding rates and biomass removal strategies for no-mow fine fescue.

Start Date: 2017

Duration: 3 years

Total Funding: $44,272

Golf course superintendents are shifting toward the use of fine fescues in roughs and out-of-play areas to reduce management inputs such as water, fertilizer, pesticides, and time. With continued local restrictions and social pressures of input use on turfgrass, we expect this trend to expand. The utilization of unmown fine fescues can result in decreased maintenance costs and display aesthetically pleasing areas throughout a golf course. Since these stands are managed differently than in-play areas, superintendents may be faced with management of different weed species. Slow establishment of fine fescues can also induce weed competition challenges. The density and height of the stands may alter golf ball visibility and ultimately the pace of play (Figure 1). Research that guides superintendents of proper establishment and management of unmown fine fescues is lacking. In this project, we are investigating seeding rates and mowing regimes for optimal weed suppression, golf ball visibility, and aesthetics to reduce management uncertainty.

Establishment of the project began in July of 2017 at the University of Minnesota Turfgrass Research Outreach and Education Center in St. Paul and at Rush Creek Golf Club in Maple Grove, MN. Each location was seeded with ‘Beacon’ hard fescue in a 3 x 4 factorial design with four replications. The two factors include seeding rate based on pure live seed (PLS) (3 levels: 1, 2, and 3 PLS per cm^2) and mowing regime (four levels: spring, fall, spring and fall, and no mowing). At planting, starter fertilizer impregnated with mesotrione was applied at 3.6 x 10^{-3} lb. active ingredient per 1000 ft^2 to reduce weed pressure. Bleaching of fine fescue seedlings was observed but was temporary. Each location was supplied a total of 1.95 lbs. N and 2 lbs. K_2O per 1000 ft^2 during the first two weeks of establishment with split applications, and an additional 0.71 lb. N per 1000 ft^2 was applied at the Rush Creek Golf Club trial in September. The trial areas were mowed at 4 inches in the fall with clippings removed for preparation of data collection and mowing treatments in spring 2018.

During establishment, weed emergence was observed and fine fescue coverage was estimated using grid counts at four time points prior to fall mowing. Plots in St. Paul had significantly more grassy weed coverage and less bare soil than plots in Maple Grove. Prominent weeds at each location also differed (Figure 2). Within each location and coverage category (i.e. broadleaf weed), there were no statistical differences across seeding rates (Figure 3). We expect fine fescue coverage to increase by spring 2018 following the fall mowing and loss of annual weeds. Grid counts and species identification will continue during the following two years.

In 2018-19, we will collect the following data: living fine fescue coverage and weed pressure (grid counts three times each year); seed head density (culm counts in a 1 ft^2 subsample per plot); overall quality; total biomass at each mowing (dry biomass weights of 1 ft^2 subsample per plot); maturity (days after April 1 until seed head is fully emerged); lodging (visual assessment as needed); golf ball lie.

Playability in unmown fine fescues is difficult as it serves as a penalty for unfortunate golf shots. Struggles with locating golf balls may decrease the pace of play and player satisfaction, so an assessment of golf ball visibility in each plot will be performed in the spring, summer, and fall of 2018-19. Digital image analysis will be used to estimate golf ball exposure in each plot. We will drop a red golf ball from a set height into each plot and take a digital image from the top-down. Image analysis will determine the percentage of red pixels in each image to estimate golf ball visibility.

Summary Points

- No-mow fine fescues can serve as a low-input vegetation option in golf course roughs.
- We are determining optimum seeding rates and mowing regimes for maximum quality, weed suppression, and golf ball visibility.
- Estimated fine fescue coverage was similar during establishment for each seeding rate.
- The results from this project will clarify fine fescue rough establishment and management strategies.

Figure 1. Fine fescue no-mow research plots from a previous trial in St. Paul, MN (photo credit: Andrew Hollman).

Common weeds during establishment			
Grassy weeds		**Broadleaf weeds**	
St. Paul	**Maple Grove**	**St. Paul**	**Maple Grove**
Annual bluegrass	Creeping bentgrass	Prostrate knotweed	Pennycress
Fall panicum	Perennial ryegrass	Purslane	Canada thistle
Perennial ryegrass	Fall panicum	Redroot pigweed	Common milkweed

Figure 2: Weed species identified in fall 2017 on plots in St. Paul and Maple Grove.

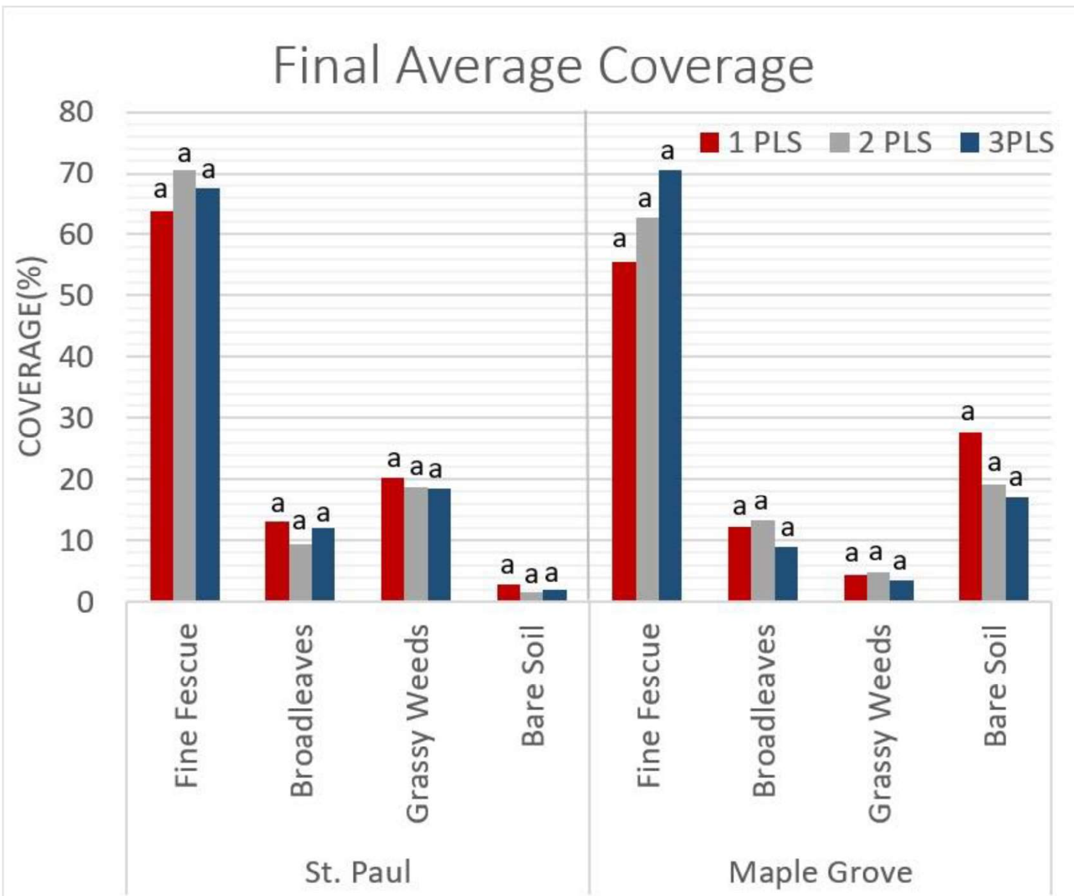


Figure 3: Fine fescue, weed, and bare soil coverage in plots at St. Paul and Maple Grove during fall 2017. Coverage was assessed using the grid-intersect method.

2017-09-619

Title: Smart Tools to Improve and Accelerate the Turfgrass Evaluation Process

Project Leaders & Affiliations:
Ning Wang (PI), Yanqi Wu, Justin Moss, Charles Fontanier, *Oklahoma State University*;
Jack Fry and Dale Bremer, *Kansas State University*

Objectives of the Project:

The ultimate goal of the proposed project is to develop a rapid, quantitative, multi-trait turfgrass quality rating platform to improve the efficiency of turfgrass management in golf courses, accelerate the selection process and improve the selection accuracy of turfgrass breeding.

The specific objectives:

(1) Establish a ground-based platform equipped with low-cost distance camera(s) to collect color-related and height-related traits based on the National Turfgrass Evaluation Program (NTEP) evaluation rating guidelines (Year 1)
(2) Establish a UAV-based platform equipped with a high-resolution RGB camera and a thermal camera for large-scale field screening and stress monitoring (Year 1);
(3) Develop a software package for image and data acquisition, image processing and analysis, statistical analysis, and user interfaces)(Year 1-2);
(4) Validate and optimize the performance of the developed platforms under field conditions using cool-season and warm-season turfgrasses at two locations (Kansas and Oklahoma) (Year 2-3).

Start Date: June 2017

Project Duration: 3 Years

Total Funding: $89,305

Summary: Bermudagrass (*Cynodon* spp.) is the most commonly used turfgrass for golf courses, lawns, parks, and sports fields in the southern USA and throughout tropical and warmer temperate regions in the world. At Oklahoma State University, the turf bermudagrass breeders have been conducting intensive research and field trials to develop new varieties with greater cold tolerance, enhanced turf quality, improved drought tolerance, increased host plant disease resistance, reduced requirements for mowing and fertilization, better shade tolerance, and faster divot recovery rate. Conventional breeding approaches normally take several to more than 10 years to develop a new variety due to the demand of sufficient observations and a large amount of field data to identify and prove the desirable traits. Similarly, quality screening of turfgrass is one of the major and tedious work inputs in golf course management. Current turfgrass evaluation is a *subjective* process based on visual estimates of traits related to turfgrass performance. Visual quality ratings of a turfgrass plot are widely used by turfgrass breeders and researchers. The collected data are highly variable, subjective, and difficult to repeat. The visual quality rating process is also time-consuming and labor intensive.

Recent developments in precision agriculture innovations and data-intensive computational approaches make it possible to accelerate the process of plant breeding with highly precise and accurate-field data acquisition and high-throughput field screening to rapidly quantify the traits of interest and to associate these traits with their genetic and genomic properties. High-resolution vision and spectroscopic systems have been installed on GPS-guided ground vehicles (autonomous or semi-autonomous) and/or unmanned aerial vehicles (UAV) and used in agronomic applications to enable trait specificity at centimeter-level or better. In this project, a field screening system which can collect quantitative data for multiple traits in every turfgrass plot in one field run will be developed to improve the efficiency of the selection and evaluation process, which could potentially result in faster release of better cultivars.

Preliminary study showed that most of the targeted traits of turfgrass could be measured through color directly or indirectly. Some traits could be measured through height or the combination of height and

color. In this project, a rapid, quantitative, multi-trait turfgrass quality and stress evaluation system, which includes a ground-based platform and a UAV-based platform is being developed, which acquires both high resolution RGB (red, green and blue) images and depth images simultaneously. Color-related and height-related traits of turfgrass plants are quantified from the images and displayed to users. Figure 1 shows a project work flow chart including the design components and procedures.

In 2017, a 2015 turf bermudagrass clonal nursery established by the OSU Turf Bermuda Grass Breeding Program on the OSU Agronomy Farm in Stillwater, Oklahoma was used for field testing. A ground-based sensing system was designed, assembled, and installed to an electric golf cart. This sensing system was intentionally designed as an add-on unit, which can be easily attached to any off-road vehicles. Figure 2 shows the current design of the system. The sensing system is mainly based on a range camera, Microsoft Xbox One Kinect (hereafter called Kinect), which provides an RGB color image, an infrared image, and a depth image in one measurement, and a high-resolution RGB camera (GoPro 6) which provides detailed color information of the sample. The sampling rate was set to six frame/second according to the vehicle speed of 3 miles per hour. The determination of the sampling rate of six frame/second was based on the size of hard drive of the laptop (256MB SSD) used. The sampling rate and the vehicle speed can both increase when a larger hard drive is used. With current setup, the quality of images are good enough for processing. The challenging task is to establish appropriate lighting mechanism, which can minimize interferences from sunlight, shadows from the vehicle and surroundings, and others. Two types of LED panels with different wattages and field-of-views were tested under laboratory and field conditions to measure their performance. More tests are needed. Calibration experiments were conducted for the Kinect sensor on distance (height) measurements and color shade measurements (Figure 3). An UAV-based sensing unit was also implemented during a field test in November, 2017. The collected images are being processed.

The next step of the work includes finalizing the design of both the ground-based sensing system the UAV-based sensing system, the selection of lighting unit, and the calibration of the cameras. The data processing and analysis software will also be developed based on the data collected in 2017. The plan is to have a ready-to-go system by the start of the spring 2018 for field evaluations.

Summary Points

1. A ground-based, imaging system for turfgrass evaluation was developed which could be attached on an off-road vehicle, preferably an electric vehicle to implement field data collection.
2. The results from the initial field implementation of the ground imaging system showed that the two selected cameras provided good data for most of the traits of interests. However, the green color shades were hard to differentiate from each other due to interferences from sunlight and shadows of surroundings. A better lighting and imaging system needs to be designed.
3. The UAV-based system provided very good information on the color and size comparison among the samples in the experimental field. A thermal camera may be another add-on to evaluate the stresses.

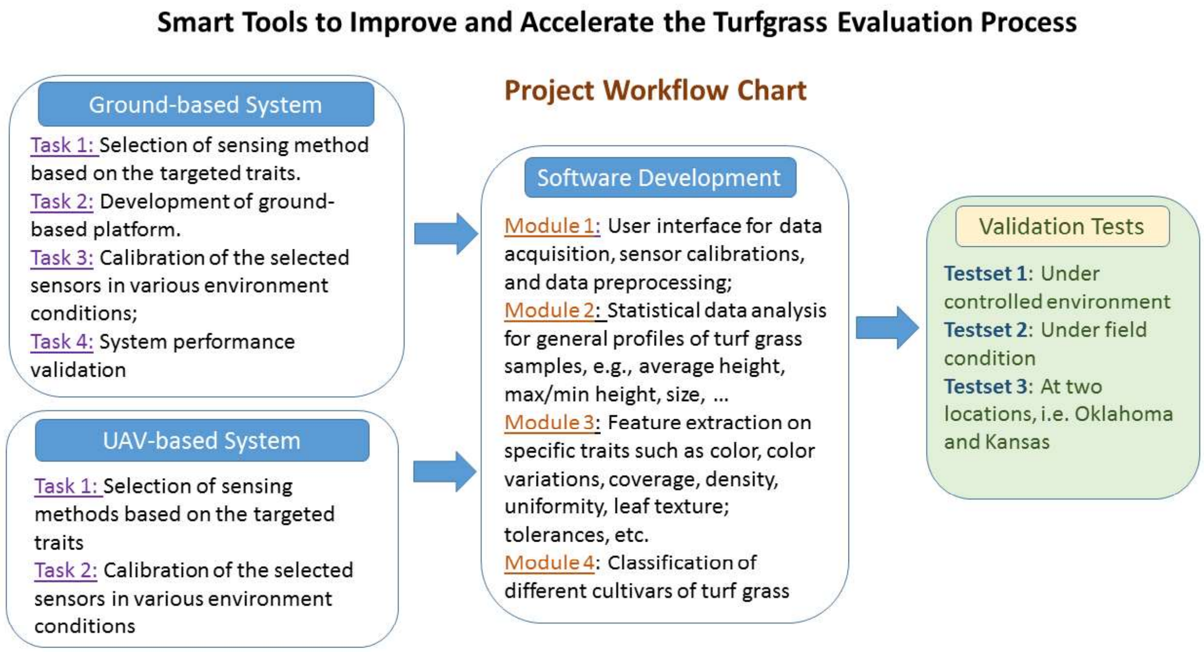


Figure 1. Project workflow chart

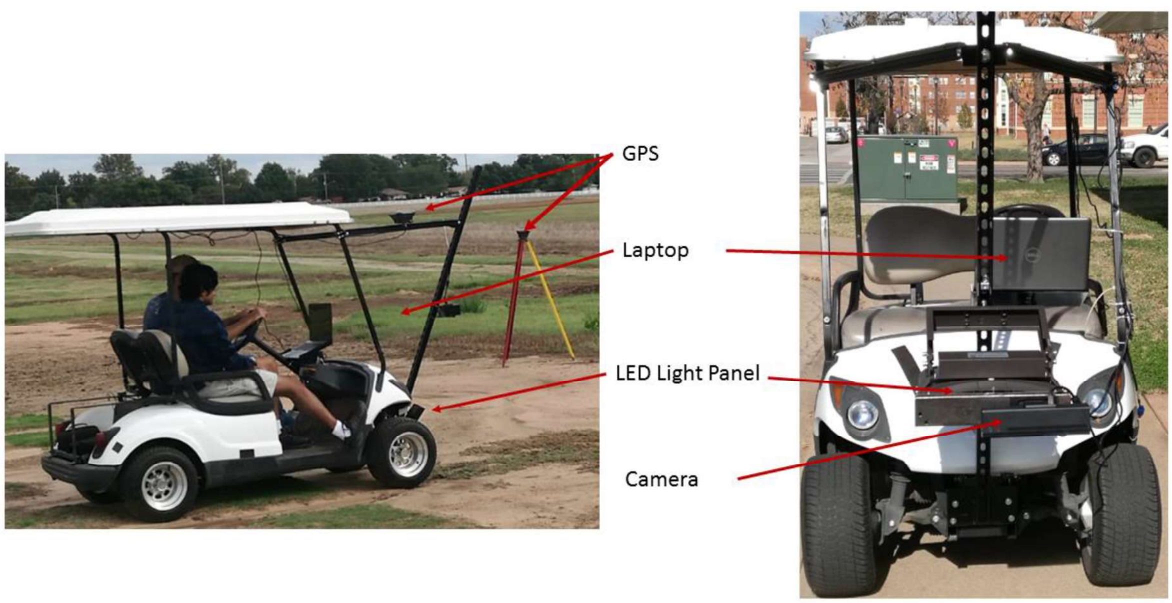


Figure 2. Current ground based sensing system

Figure 3. Camera Color Calibration

2017-13-623

Title: Golfer Perception of Input-Limited Fairway Management in the Northcentral U.S.

Project Leaders: Cole Thompson, Bill Kreuser, and Keenan Amundsen

Affiliation: University of Nebraska-Lincoln

Objectives:
1. Document annual inputs for buffalograss, Kentucky bluegrass, and creeping bentgrass fairways under traditional and input-limited management in the northcentral U.S.
2. Determine the fairway species preference, and expected quality level, for golf course superintendents and professional and amateur golfers when inputs are known and unknown.
3. Link golfer quality expectations to annual management inputs.
4. Determine the combined effects of irrigation regimen and nitrogen fertility on pest incidence, and corresponding total pesticide use in creeping bentgrass, Kentucky bluegrass, and buffalograss fairways.

Start Date: 2017
Project Duration: 3 years
Total Funding: $69,020

Summary text:
Rational
It's commonly assumed that buffalograss (*Buchloë dactyloides*) fairways require fewer management inputs in the northcentral U.S. compared to more commonly used species such as Kentucky bluegrass (KBG; *Poa pratensis*) or creeping bentgrass (CBG; *Agrostis stolonifera*). However, negative opinions of buffalograss are common among golfers and superintendents, despite improved color and density characteristics of recently-released cultivars. Golfers may be more likely to accept buffalograss if management inputs compared to other species are quantified.

Methodology
We established 'Prestige' buffalograss, 'Barvette' KBG, and 'Pure Select' CBG in three plots (20 ft. × 30 ft.) each during 2016 (nine total plots) in Lincoln, NE. These plots are arranged in a randomized, complete block-design, and serve as the whole-plot treatment factor for the experiment. Sub plots are arranged in a 2 irrigation × 3 fertilizer × 2 pest control factorial treatment structure. Irrigation levels are 1) no supplemental irrigation or 2) standard reference evapotranspiration (ETo) replacement (i.e. 80% ET_o for CBG and KBG or 60% ET_o for buffalograss). Fertilizer levels are 1) unfertilized, 2) "standard" fertilizer (1 lb N/1,000 ft^2 in May, Sept., Oct. and Nov. for CBG and KBG; 1 lb N/1,000 ft^2 in June and July for buffalograss), or 3) a threshold program where 0.25 lbs N/1,000 ft^2 is applied when quality approaches an unacceptable level. Pest control levels are 1) untreated or 2) "standard" strategies to control weeds, diseases, and insects. Experimental management began in May of 2017, and diseases were controlled at the first sign of infection in standard pest control plots. We collected visual estimates of turfgrass quality (1-9, where 9=best and 6=minimum acceptable) weekly, counted dollar spot (caused by *Sclerotinia homoeocarpa*) infection centers when present, and mowed individual plots at 0.5 in. when needed based on visual inspection. Additionally, we determined the area under the disease progress curve (AUDPC) for dollar spot in 2017 {AUDPC = $\sum^{ni-1}_{i=1}$ ([y_i + $y(i+1)$] / 2) ($t(i+1)$ - t_i); where i is the order index for sampling dates, n is the number of sampling dates, y is total infection centers, and t is time}.

Preliminary Results

Turf quality

The combined effects of species × irrigation x pest control produced the highest-order interaction that affected average turf quality over the 2017 growing season. Well-watered CBG plots with pests controlled had the highest average quality (7.6), and KBG under similar management had only slightly lower quality (7.1). Unirrigated KBG plots with no pest control (average quality of 6.7) and irrigated buffalograss with or without pest control (average quality of 6.4 in both cases) were in the next statistical grouping. Buffalograss and KBG under other irrigation × pest control treatment combinations averaged acceptable quality over 2017 and CBG that was unirrigated and received pest control did not, but was not statistically different from unirrigated buffalograss with or without pest control. Creeping bentgrass that didn't receive pest control or was unirrigated had significantly lower, unacceptable average quality over 2017. Considering average turf quality and main effects, KBG (6.6) > buffalograss (6.2) > CBG (6.1), plots that were irrigated to ET-replacement (6.6) > unirrigated plots (6.0), standard fertilizer (6.5) > threshold-based (6.3) > untreated (6.1), and plots where pests were controlled (6.6) > untreated plots (6.0). Average quality provides only a snapshot of the effects of treatment combinations, and future analyses of weekly data will provide higher resolution during stressful periods in midsummer.

Pest incidence

Dollar spot was the most prevalent pest in 2017, and the combined effects of species × irrigation x pest control produced the highest-order interaction affecting dollar spot incidence. Dollar spot was most prevalent in well-watered CBG plots without pest control (AUDPC=2152). Well-watered KBG without pest control (AUDPC=826) and unirrigated CBG without pest control (AUDPC=758) were in the next statistical grouping. Dollar spot was never observed in buffalograss under any irrigation x pest control combination (AUDPC=0 in all cases), and CBG or KBG with or without ET-replacement that received pest control were not significantly different (AUDPC=14 to 76). Considering AUDPC and main effects, CBG (756) > KBG (302) > buffalograss (0), plots that were irrigated to ET-replacement (505) > unirrigated plots (200), and plots where pests were not controlled (678) > treated plots (27). The fertilizer main effect was not significant.

Irrigation, Fertilizer, Fungicides, and Mowing

Creeping bentgrass and KBG plots under 80% ET-replacement received 14.3-in. (388,642 gal/acre) of irrigation from 1 May to 29 Nov. 2017, whereas buffalograss plots under 60% ET-replacement received 10.1 in. (274,777 gal/acre). Because this use would exceed 12 million cubic feet annually, our non-residential water costs from the City of Lincoln would be approximately $1.911/unit (748 gal). Therefore, it cost $992.91/acre to irrigate CBG and KBG, and $700.00/acre to irrigate buffalograss in 2017. Because plots were fertilized, treated with chlorothalonil, and mown on a per-plot basis, average expenditures for each are presented at the level of the smallest experimental unit (species × irrigation × fertilizer × pest control) in Table 1. Other fungicides and herbicides were applied in 2017, but we focus on chlorothalonil since dollar spot injury was so prevalent. Average season-long quality and AUDPC values are also presented in Table 1 for reference, but differences are not statistically significant at the level of this highest-order interaction.

Summary Points:

- Drought and dollar spot were the most common detractors of turf quality in 2017, and both disproportionately affected creeping bentgrass compared to other species.
- Chlorothalonil applied at the first sign of dollar spot infection essentially eliminated disease development in creeping bentgrass and Kentucky bluegrass, and only six to eight applications were required on average.
- Creeping bentgrass that did not receive fungicide applications did not average acceptable quality over 2017, regardless of other factors.
- Kentucky bluegrass provided acceptable quality over a range of management scenarios, and can persist in input-limited conditions if transient quality reductions during drought or severe dollar spot infestation are acceptable.
- Buffalograss expenditures were approximately half of other species under the most intense management level. Buffalograss was less affected by input-limited management than other species.
- Our cost analysis is intended only to compare expenditures among species and management scenarios under our experimental conditions, and to quantify general differences for a consumer survey next year. Cost per acre estimates are not intended to predict or suggest the resources needed to manage golf course fairways of species in our study.

Figure 1. A drone image showing replicated whole plots (20 ft. × 30 ft.) of creeping bentgrass (*A*), Kentucky bluegrass (*B*), and buffalograss (*C*) on 10 July 2017. Severe drought stress is visible in unirrigated sub plots (5 ft. × 10 ft.) of creeping bentgrass and Kentucky bluegrass.

Figure 2. Symptoms of injury from dollar spot in sub plots of creeping bentgrass on 22 August 2017. Only plots that received ET-replacement and threshold-based fungicide applications had acceptable quality.

Figure 3. Symptoms of injury from dollar spot in sub plots of Kentucky bluegrass on 22 August 2017. Dollar spot development was low at this time, but severity increased at later ratings.

Figure 4. Sub plots of buffalograss on 22 August 2017. Dollar spot was never detected in buffalograss in 2017.

Table 1. Expenditures and associated quality and dollar spot development of turfgrasses managed under a spectrum of scenarios in Lincoln, NE from 1 May to 29 November 2017.

Species	Irrigation[u]	N Fertilizer[v]			Chlorothalonil[w]			Mowing[x]	Total Cost	Quality[y]	AUDPC[z]
		Lbs (N/1,000 ft²)		Cost ($/A)	(Apps)		Cost ($/A)	(Times)	($/A/Year)		
Creeping Bentgrass	**80%ET$_o$** 14.3 in. 388,642 gal/A *$992.91/A*	Stand.	4.0	*136.36*	Yes	7.3	*373.12*	33.7	*1,502.39*	7.9	32
			4.0	*136.36*	No	0.0	*0.00*	25.7	*1,129.27*	5.9	2315
		Thresh.	0.3	*11.36*	Yes	7.7	*390.08*	30.3	*1,394.35*	7.5	38
			0.9	*31.25*	No	0.0	*0.00*	24.0	*1024.16*	5.8	2148
		Untreat.	0.0	*0.00*	Yes	7.3	*373.12*	29.3	*1,366.03*	7.3	50
			0.0	*0.00*	No	0.0	*0.00*	21.0	*992.91*	5.5	1992
	No supplemental 0.0 in. 0.0 gal/A *$0.00/A*	Stand.	4.0	*136.36*	Yes	7.0	*356.16*	22.0	*492.52*	6.2	149
			4.0	*136.36*	No	0.0	*0.00*	19.0	*136.36*	5.4	563
		Thresh.	1.7	*56.82*	Yes	7.7	*390.08*	20.3	*446.90*	5.6	32
			2.4	*82.39*	No	0.0	*0.00*	19.0	*82.39*	5.1	936
		Untreat.	0.0	*0.00*	Yes	8.0	*407.04*	15.0	*407.04*	5.5	46
			0.0	*0.00*	No	0.0	*0.00*	14.0	*0.00*	5.1	775
Kentucky Bluegrass	**80%ET$_o$** 14.3 in. 388,642 gal/A *$992.91/A*	Stand.	4.0	*136.36*	Yes	6.7	*339.20*	41.7	*1,468.47*	7.5	5
			4.0	*136.36*	No	0.0	*0.00*	37.7	*1,129.27*	6.4	874
		Thresh.	0.7	*22.73*	Yes	6.3	*322.24*	36.3	*1,337.88*	6.7	5
			1.1	*36.93*	No	0.0	*0.00*	38.7	*1,029.84*	6.2	890
		Untreat.	0.0	*0.00*	Yes	6.7	*339.20*	38.7	*1,332.11*	7.1	33
			0.0	*0.00*	No	0.0	*0.00*	38.3	*992.91*	6.2	715
	No supplemental 0.0 in. 0.0 gal/A *$0.00/A*	Stand.	4.0	*136.36*	Yes	6.3	*322.24*	34.3	*458.60*	6.8	12
			4.0	*136.36*	No	0.0	*0.00*	34.3	*136.36*	6.5	376
		Thresh.	1.1	*36.93*	Yes	6.3	*322.24*	36.0	*359.17*	7.0	5
			1.3	*42.61*	No	0.0	*0.00*	32.7	*42.61*	6.3	382
		Untreat.	0.0	*0.00*	Yes	6.7	*339.20*	28.7	*339.20*	6.2	88
			0.0	*0.00*	No	0.0	*0.00*	29.0	*0.00*	5.9	240
Buffalograss	**60%ET$_o$** 10.1 in. 274,777 gal/A *$702.00/A*	Stand.	2.0	*68.18*	Yes	0.0	*0.00*	37.3	*770.18*	6.7	0
			2.0	*68.18*	No	0.0	*0.00*	37.7	*770.18*	6.5	0
		Thresh.	1.7	*56.82*	Yes	0.0	*0.00*	35.0	*758.82*	6.4	0
			2.1	*71.02*	No	0.0	*0.00*	34.7	*773.02*	6.3	0
		Untreat.	0.0	*0.00*	Yes	0.0	*0.00*	34.3	*702.00*	6.1	0
			0.0	*0.00*	No	0.0	*0.00*	35.0	*702.00*	6.3	0
	No supplemental 0.0 in. 0.0 gal/A *$0.00/A*	Stand.	2.0	*68.18*	Yes	0.0	*0.00*	34.0	*68.18*	6.1	0
			2.0	*68.18*	No	0.0	*0.00*	35.3	*68.18*	6.4	0
		Thresh.	2.3	*76.70*	Yes	0.0	*0.00*	32.0	*76.70*	6.1	0
			2.3	*76.70*	No	0.0	*0.00*	31.0	*76.70*	6.1	0
		Untreat.	0.0	*0.00*	Yes	0.0	*0.00*	26.7	*0.00*	5.7	0
			0.0	*0.00*	No	0.0	*0.00*	27.7	*0.00*	5.8	0

[U]Evapotranspiration (ET) replacement was based on standard recommendations for each species. Cost calculation is based on City of Lincoln non-residential water rates for high-volume users of $1.911/748 gallons.

[V]Standard (Stand.) fertilizer was 4, 4, or 2 lbs N/1,000 ft^2/year for creeping bentgrass, Kentucky bluegrass, or buffalograss, respectively. Threshold-based (Thresh.) applications (0.25 lbs N/1,000 ft^2) were made when quality approached an unacceptable level, and values represent a mean over three blocks. Untreated (Untreat.) plots were never fertilized. Urea (46-0-0) valued at $18/50 lbs bag was used for cost calculations.

[W]Chlorothalonil was applied in plots that received pest control (Yes) at 3.25 oz/1,000 ft^2 ($50.88/A) at the first sign of dollar spot infection, and values represent a mean over three blocks. Untreated plots (No) never received an application.

[X]Plots were mown at 0.5 in. when deemed necessary by visual inspection. Values represent a mean over three blocks.

[Y]Turfgrass quality (1-9, where 9=best and 6=minimum acceptable) was visually rated on a weekly basis. Values represent season-long means over three blocks and are not significantly different.

[Z]Dollar spot infection centers were counted when present, and we determined the area under the disease progress curve (AUDPC) for dollar spot in 2017 {AUDPC = $\sum^{n_i-1}_{i=1} ([y_i + y(i + 1)] / 2) (t(i+1) - t_i)$; where *i* is the order index for sampling dates, *n* is the number of sampling dates, *y* is disease severity, and *t* is time}. Values represent means over three blocks.

2017-19-629

Title: Multi-Location Trial to Establish Maintenance Requirements and Performance of New Bermudagrass Cultivars for Fairway Use

Project Leaders: Jason Kruse, Travis Shaddox, Adam Dale, Bryan Unruh, and Kevin Kenworthy

Affiliation: University of Florida

Objectives: Our global hypothesis is that bermudagrass cultivars maintained under fairway conditions differ overall in terms of shade tolerance, wear tolerance, and drought tolerance. To investigate this hypothesis, we will address the following objectives:

1. Determine relative differences in shade, wear, drought and insect pest tolerance of six fairway-height bermudagrass cultivars.
2. Determine the drought response of six fairway-height bermudagrass cultivars under both a Linear Gradient Irrigation System and through deficit irrigation.
3. Determine the minimum nitrogen fertility requirements to maintain acceptable and evaluate the interaction between nitrogen fertilization rate and drought response of six fairway-height bermudagrass cultivars.

Start Date: 2017
Projects Duration: Three years
Total Funding: $45,000

Background

There are several criteria that need to be considered when selecting a bermudagrass cultivar (*Cynodon dactylon* [L.] Pers.; *C. dactylon* x *C. transvaalensis* [Burtt-Davy]) for use on a golf course. Bermudagrass is the primary turfgrass established on golf course fairways in the southern United States because it provides a very dense, green turf cover that is able to tolerate drought and heat as well as a wide variety of soil types, pH, textures, fertilities, and temperatures (Hanna and Maw, 2007). Arguably the most important factor is its ability to withstand injury and re-grow quickly to maintain a high quality playing surface. Selecting a bermudagrass that is genetically able to withstand high amounts of traffic, reduction in light intensity as a result of shade or low light conditions, and maintain quality under reduced irrigation can give turfgrass managers a competitive advantage from the start.

Turfgrass culture is unique from other production agriculture systems. It exacerbates competition for light by attempting to maximize plant population to increase density. When other required components of turfgrass health (water, adequate temperature, nutrition) are met, light interception is the growth-limiting factor. Factors in the turfgrass market often necessitate that turfgrass be grown under lower light conditions. Trees are used on golf courses to increase difficulty and aesthetics for players, but shade cast by a tree canopy can cause lower light levels. Additionally, coastal regions of the US experience reduced light intensity due to heightened levels of water vapor in the atmosphere.

Various leaf-level traits that function together to maximize carbon fixation under low light is known as shade tolerance (Henry and Aarssen, 1997). It can also be seen from a physiological point as the minimum amount of light needed for plant survival. (Valladares and Niinemets, 2008). Shade avoidance denotes architectural traits exhibiting strong vertical growth (Grime, 1966). The term shade avoidance is used in conjunction with shade tolerance to describe different groups of mechanisms that can occur simultaneously or exclusively within a plant under shade stress. In general, physiological changes are associated with shade tolerance mechanisms, while morphological changes are more related to shade avoidance. As these mechanisms are identified as being activated, an increased understanding on how a plant is reacting to shaded conditions can be achieved.

Water resources have become a critically limiting factor for economic growth, and to feed and support an increasing world population. A growing population, urbanization, domestic and industrial usage, and energy production exacerbate the pressure for water demands. There is an estimated 40 million acres of maintained turfgrass in the United States on home lawns, golf courses, sports fields, parks, playgrounds, cemeteries, and highway rights-of-way. Water availability for irrigating turfgrass is becoming limited even in regions where annual rainfall is abundant and periodic droughts occur. Selecting turfgrasses with superior drought resistance could mitigate the conflict between water demand and supply. Efficient selection depends on understanding turfgrass drought responses and characteristics associated with water use. This proper understanding also clarifies the expectation for turf performance under drought.

Water consumption of turfgrass differs both between and within species, and it is influenced by growth rate, evapotranspiration (ET), length of growing season, and cultural practices such as fertilization rate (Biran et al., 1981).

Research on multiple turfgrass species has shown that cultivar (genotype) directly affects insect abundance and pest damage. Turfgrass cultivars often have different pest insect tolerance and resistance, or ability to harbor predatory insects, which directly affects plant health and management inputs. One that harbors more predators and is less suitable to pests can reduce management costs and increase playability. Thus, screening cultivars to promote predatory insect diversity and reduce pest damage is critical to golf course sustainability, particularly once a cultivar is selected for fairway use.

Research has also demonstrated that ground-dwelling predators of key insect pests are often much less abundant on fairways than roughs due to higher management inputs and different turf characteristics (Smitley et al. 1998). If cultivars can be screened that reduce pest pressure and the need for insecticide use, the system as a whole will benefit.

Arguably the most important factor for the long term success of a turfgrass stand on a golf course is its ability to withstand injury and re-grow quickly to maintain a high quality playing surface. As play increases, injury from traffic and divots can accumulate causing a stand of turf to thin, creating an unfavorable, unsafe, and unattractive playing surface. Historically, selection of traffic tolerant cultivars has not been a large field of study, but is becoming essential as more cultivars are developed each year (Trappe et al., 2008; 2010b; Williams et al., 2010).

Research Methodology

Research plots will be established on fumigated sites at each of three University of Florida locations: West Florida Research and Education Center, Jay, FL; Plant Science Research and Education Unit, Citra, FL; and Ft. Lauderdale Research and Education Center, Ft. Lauderdale, FL during the 2016 growing season and will include six cultivars of bermudagrass; two standard cultivars (Tifway 419 and Celebration) or four novel cultivars (TifGrand, TifTuf, Latitude 36, and Bimini).

<u>Experiment 1: General Assessment of Turfgrass Performance – Ft. Lauderdale, Citra, and Jay</u>

Plots at all locations will be evaluated at least monthly to monitor cultivar response to fertility, drought, shade, and wear treatments. Visual ratings will be done using NTEP rating guidelines where a visual rating of 9 equals perfect grass, a 1 equals dead grass and below 6 = non acceptable turfgrass quality. Data may also be collected using digital image analysis of pictures collected using a light box. Instrument ratings (NDVI, thermal, and chlorophyll) will also be used to augment the visual ratings.

<u>Experiment 2: Drought Response – Ft. Lauderdale and Jay</u>

<u>West Florida Research and Education Center – Jay, FL</u>

Grasses will be established on a pre-existing Linear Gradient Irrigation System (LGIS) as described by Zhang et al., 2013. Whole plots will measure 12' X 80' and will be replicated four times. Irrigation rates range from 0 – 120% ET.

<u>Ft. Lauderdale Research and Education Center – Davie, FL</u>

Grasses will be established on 10 x 30 ft plots with four replications to evaluate cultivar response to deficit irrigation and the interaction between deficit irrigation and nitrogen fertilization rate. Two irrigation treatments will be implemented, 50% ET and 80% ET (may be adjusted if needed to preserve canopy), to represent a severe deficit and a typical irrigation program respectively.

<u>Experiment 3: Fertility Requirements – Jay and Ft. Lauderdale</u>

<u>West Florida Research and Education Center – Jay, FL</u>

Nitrogen fertilization treatments (0, 0.25, 0.5, and 0.75 lbs N/1,000 ft2/growing month) will be applied in strips (3' X 80') across the irrigation gradient to investigate the interaction between fertilization rate and drought response among cultivars.

<u>Ft. Lauderdale Research and Education Center – Ft. Lauderdale, FL</u>

Nitrogen fertilization treatments (0, 0.16, 0.33, and 0.5 lbs N/1,000 ft2/growing month) will be applied sub- plots on the deficit irrigation plots (7.5' x 10').

<u>Experiment 4: Wear Tolerance – Citra, FL</u>

Wear tolerance will be determined using a modified Cady wear machine at the PSREU. Wear will be applied two times a week for a period of six weeks during spring and fall of each year. Digital image analysis will be used to quantify declines in turf quality and percent green cover during wear and increases in both parameters during recovery periods.

<u>Experiment 5 – Shade Tolerance and Divot Recovery – Citra, FL</u>

Grasses will be planted into an existing oak canopy to evaluate shade tolerance. Cultivar performance will be quantified using digital image analysis to track green cover. Divots recovery will be evaluated under shaded conditions. Repair from divots in the shade will be quantified using Digital image analysis methodology described by Williams et al., 2011.

<u>Experiment 6 – Playing Surface Response – Jay, FL</u>

Measurements of golf ball lie will be obtained through digital image analysis as described by Richardson et al., 2010. Digital images will be collected on a monthly basis from LGIS plots receiving 70% and 100% ET at 0.5 and 0.75 lbs N/1,000 ft2/growing month.

Experiment 7 – Insect Diversity and Abundance – Citra, FL

We will survey research plots for ground-dwelling insects using 15 mm diameter plastic pitfall traps inserted flush with the soil surface. We will also collect thatch and soil samples to extract soil-dwelling arthropods. To determine cultivar tolerance to pest insects, we will introduce key pests into 30 cm diameter arenas in field plots and evaluate plant damage and insect reproduction, survival, and development.

Expected Outcomes

• Side-by-side comparisons of the four novel bermudagrass cultivars have not been conducted. We expect the information generated from this research to greatly aid golf course superintendents in their selection and management of these new cultivars.
• Results from the irrigation studies will provide water requirement estimates (% ET) at a given level of nitrogen fertility.
• This project will address and eliminate or highlight concerns for Bimini. Which is unknown for its technical merits, but is increasingly being used in south Florida.

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2014-05-494

Evaluating Sand-Capping Depth and Subsoil Influence on Fairway Performance, Irrigation Requirements and Drought Resistance

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A sand-capping research facility was constructed in College Station, TX in summer 2014. Establishment rates of Tifway bermudagrass in plots were inversely proportional to capping depth. While 0, 5, and 10 cm capping depth plots reached full establishment by the end of the 2014 season, 20 cm capping depths did not achieve full establishment until May 2015. This was due largely to differences in surface soil moisture between treatments, which progressively decreased with increasing capping depth.

Over the subsequent two years, turf performance, irrigation requirements, and water and salt dynamics have been closely monitored in relation to capping depths (0, 5, 10, and 20 cm) and subsoil textural treatments (Clay Loam vs. Sandy Loam). Interestingly, irrigation requirements were not found to differ between different capping depths, as plots irrigated 1x weekly generally maintained similar turf cover and quality to plots irrigated 2x weekly (both receiving 60% x reference evapotranspiration). However, overall turf quality and percent green cover was slightly decreased with increasing capping depth both years of the study (Figure 1). Averaging across both 2015 and 2016 seasons, the 0 cm capping depth (topdressed at a rate of 2.5 cm annually) supported ~90% overall green cover; both 5 and 10 cm capping depths supported ~80% overall green cover; and the 20 cm capping depth supported only ~70% overall green cover. Unlike 0, 5, and 10 cm capping treatments, the 20 cm capping depth also exhibited slightly delayed recovery following occasional verticutting and developed hydrophobicity near the thatch surface in year 2. Based on the findings from the establishment year and 2015/2016 seasons, the 5 and 10 cm capping depths seemed to provide better overall Turf Quality and Cover relative to the 20 cm capping depth, however, it is unknown whether these differences will persist long term as root zone organic matter accumulates.

During the 2017 season, a 60-day dry-down period was imposed, with all irrigation to the study terminated to allow for drought stress to be imposed on plots. Given the reduced amount of subsoil root development observed within deeper sand-capping treatments and potential for elevated irrigation water Na (275 ppm) to cause sealing off of subsoil, the dry-down provided an opportunity to observe drought resistance and recovery responses related to sand-capping x subsoil construction. The dry-down was imposed June 10 and continued until August 8, during which evaporative demand was high (reference ET ranged from 0.2 to 0.26"/day) and only 3 appreciable rain events occurred (Table 1; Figures 2 and 3). Soil volumetric water content, as measured by in-ground time domain reflectometry probes buried at the 5 and 15 cm depths in 20 cm capping depth plots, showed a brief spike occurring after these rain events, but was extremely low (3-5%) within the sand-cap for the duration of the dry-down. All treatment plots began the dry-down at ~80-85% green cover on June 13, but gradually declined over the course of the 60-day period to green cover levels of only ~17-24% (Clay Loam) and ~17-27% (Sandy Loam) by July 31. Following resumption of irrigation to plots on August 8, all treatments exhibited rapid bounce back, achieving nearly full recovery levels (~80% green cover) by September 28.

Summary Points

- During establishment year (2014) and initial two growing seasons (2015/2016), the shallower (0, 5 and 10 cm) capping depths supported more rapid establishment, improved turf quality, higher percent green cover, and higher surface moisture relative to the 20 cm capping depths.
- Irrigation of 1x weekly and 2x weekly (each at 60% x ET_o) provided similar levels of turf quality and cover during the 2015/2016 seasons.
- A 60-day dry-down was imposed during the 2017 summer in order to evaluate sand-cap x subsoil treatment effects on drought resistance, recovery, and/or survival.
- By the end of the dry-down, all sand-cap x subsoil treatments had declined from ~80-85% to ~20-25% green cover levels, but rapidly rebounded back to near-full cover levels (~80%+) following resumption of irrigation in early August.

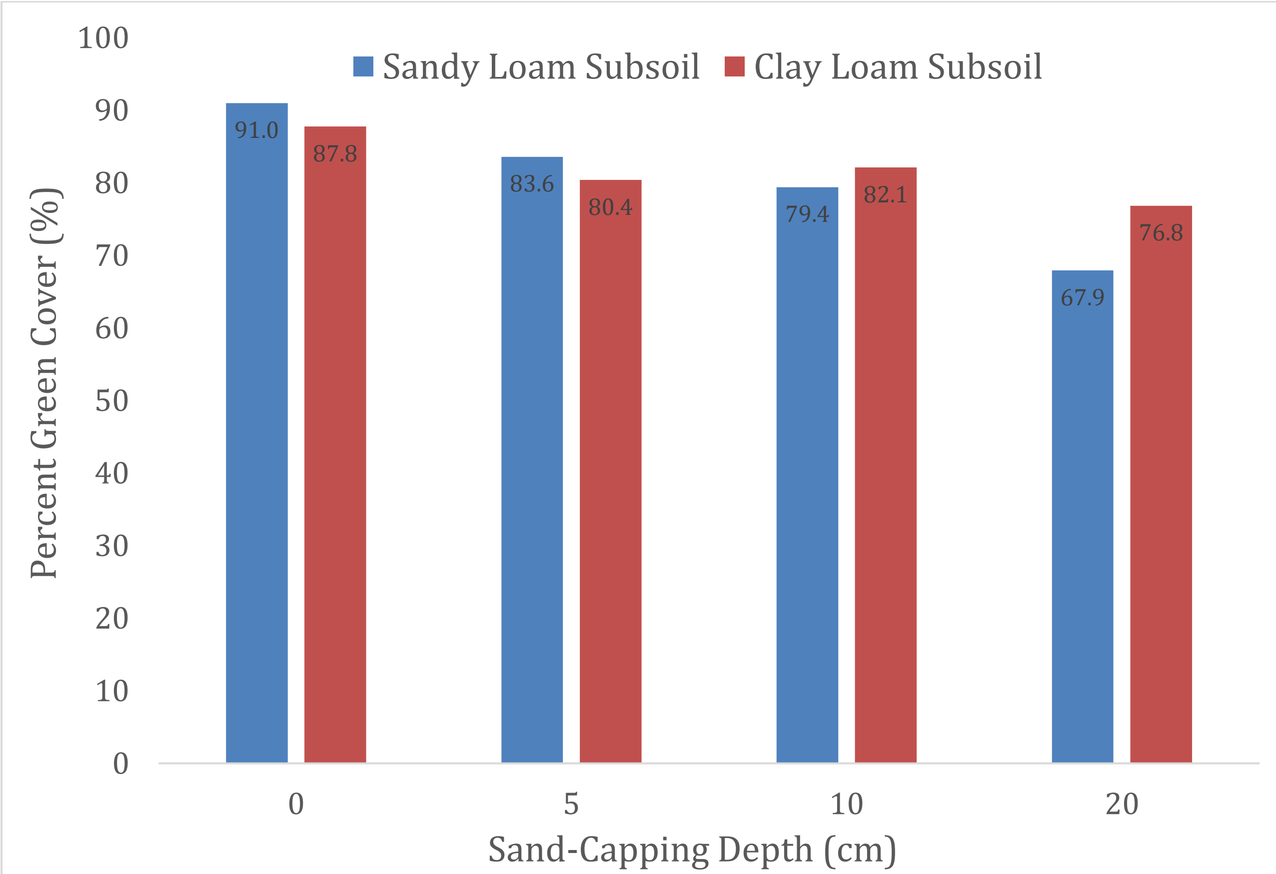

Figure 1. Two-year average Percent Green Cover of fairway plots as affected by Sand-Capping depth and subsoil texture. Measurements were obtained every two weeks during the study. Data are averaged across 1x and 2x per week irrigation frequency treatments for the 2015 and 2016 seasons.

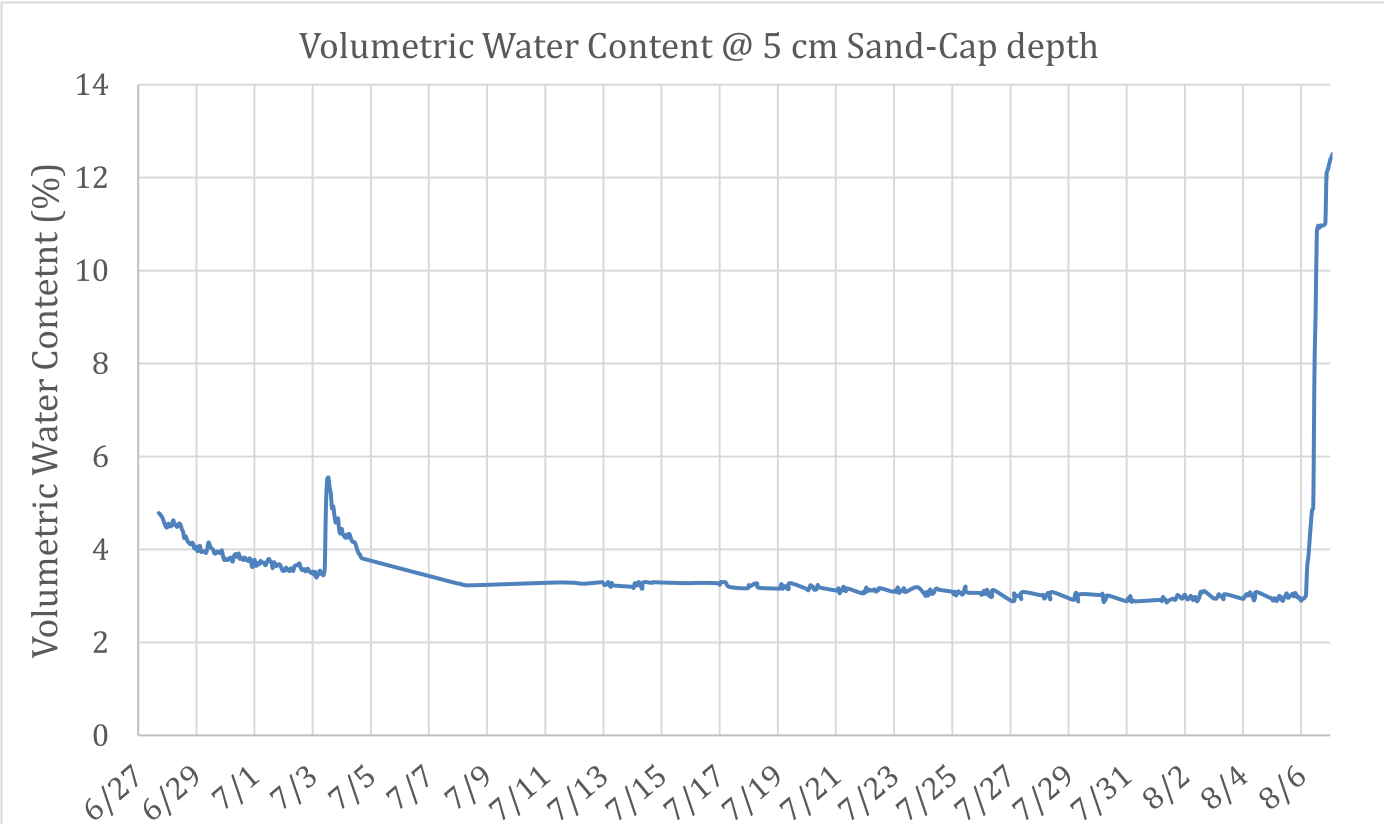

Figure 2. Soil Volumetric Water Content at the 5 cm depth within the 20 cm Sand-cap atop Clay Loam Subsoil during the 10 June- 8 Aug 2017 60-day dry-down period. Data shown are for 27-Jun through 8 Aug. No rainfall occurred from 10 June to 24 June. A 1.0" rainfall occurred 25 June. A 0.2" rainfall event occurred on 4 July. A 1.9" rainfall occurred on August 7.

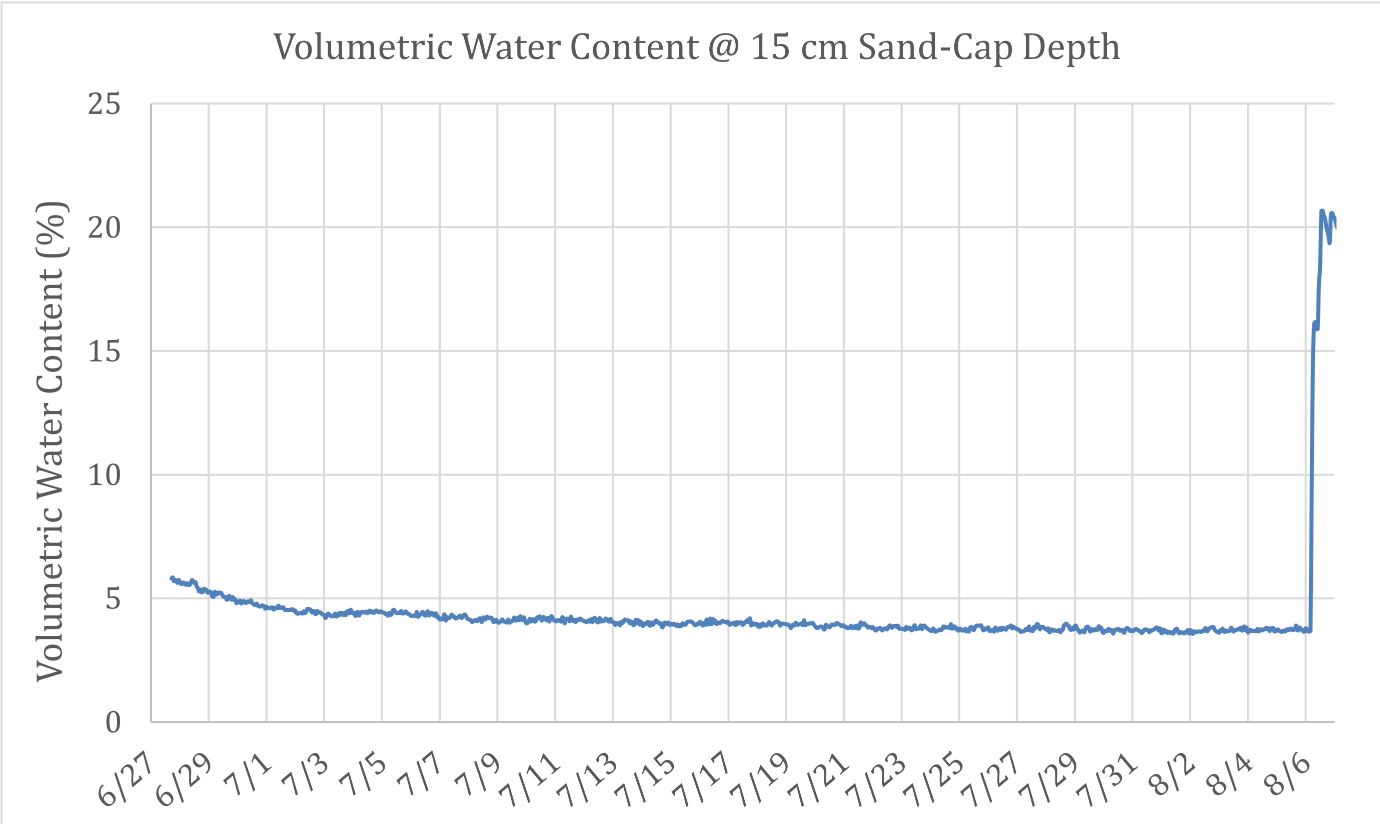

Figure 3. Soil Volumetric Water Content at the 15 cm depth within the 20 cm Sand-cap atop Clay Loam Subsoil during the 10 June- 8 Aug 2017 60-day dry-down period. Data shown are for 27-Jun through 8 Aug. No rainfall occurred from 10 June to 24 June. A 1.0" rainfall occurred 25 June. A 0.2" rainfall event occurred on 4 July. A 1.9" rainfall occurred on August 7.

Table 1. Mean Daily Reference Evapotranspiration (ET_o) and Cumulative Precipitation (inches) for the June, July, and August periods of the 2017 60-day dry-down phase. Data were obtained via an onsite weather station.

	ET_o (Inches day^{-1})	Precipitation (Inches)
June 10-30	0.25	1.1
July 1-31	0.26	0.4
August 1-8	0.20	1.99

Table 2. Percent Green Cover for 0 (topdressed), 5, 10, and 20 cm sand-capped fairway plots atop Clay Loam Sandy Loam subsoil during the 2017 60-day dry-down and recovery period. Dry-down period was imposed 10 June, with irrigation resumed to promote recovery on 8 August.

	Clay Loam Subsoil											
	Dry Down Phase								Recovery Phase			
	13-Jun	20-Jun	27-Jun	3-Jul	11-Jul	17-Jul	24-Jul	31-Jul	8-Aug	23-Aug	11-Sep	28-Sep
0 cm Topdressed	86.0	80.4	75.5	63.6	54.6	36.5	49.2	23.8	30.9	65.9	75.1	83.9
5 cm Sand-cap	85.4	71.6	69.6	58.2	50.7	28.1	45.4	19.8	24.4	60.0	67.6	81.8
10 cm Sand-cap	85.7	68.3	66.9	56.6	47.1	32.5	46.5	21.8	28.7	62.6	69.3	81.8
20 cm Sand-cap	84.9	65.9	63.1	47.1	28.0	23.7	31.6	16.8	20.6	46.7	62.6	80.0
LSD (0.05)	6.7	6.9	10.3	11.8	12.8	14.0	14.8	6.5	10.5	9.8	6.9	7.4

Table 3. Percent Green Cover for 0 (topdressed), 5, 10, and 20 cm sand-capped fairway plots atop Clay Loam Sandy Loam subsoil during the 2017 60-day dry-down and recovery period. Dry-down period was imposed 10 June, with irrigation resumed to promote recovery on 8 August.

	Sandy Loam Subsoil											
	Dry Down Phase								Recovery Phase			
	13-Jun	20-Jun	27-Jun	3-Jul	11-Jul	17-Jul	24-Jul	31-Jul	8-Aug	23-Aug	11-Sep	28-Sep
0 cm Topdressed	83.0	80.3	76.8	60.0	57.5	43.6	63.9	26.1	33.1	76.3	79.8	78.2
5 cm Sand-cap	78.8	74.1	72.5	59.3	54.9	41.1	57.5	26.9	36.3	74.0	75.3	78.1
10 cm Sand-cap	80.6	62.8	63.3	48.5	37.0	28.2	45.1	20.2	27.7	65.4	68.6	81.3
20 cm Sand-cap	82.5	58.2	44.5	27.2	19.0	20.1	31.7	17.3	22.1	51.8	59.0	79.2
LSD (0.05)	6.9	8.4	9.8	14.6	16.0	15.9	27.1	10.8	13.8	14.1	11.8	8.7

2016-06-556

Effects of Finer-Textured Topdressing Sand on Creeping Bentgrass Putting Green Turf

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Key Points:

- Topdressing improved the turf quality of the putting surface, reduced the OM concentration of the mat layer, and frequently produced a drier surface compared to non-topdressed plots.
- Medium-fine sand increased the fineness of sand within the mat layer, but this did not appear to influence volumetric water content compared to medium-coarse sand. Medium-coarse and medium-fine sand topdressing were similarly effective at reducing surface wetness.
- Fine-medium sand topdressing was not as effective at drying the surface due to the substantial increase in fine and very fine particles within the mat layer.
- Core cultivation and backfilling with medium-coarse sand was effective at reducing surface wetness and OM concentration as well as reducing the fineness of sand within the mat layer of medium-fine and fine-medium topdressed plots.

Sand topdressing of putting greens during the season is often avoided due to the potential of coarse sand particles interfering with play and dulling mower blades. This project is evaluating the effect of topdressing sand size on the playability and physical properties of putting green turf. Specific objectives include determining the effects that core cultivation and eliminating coarse particles from topdressing sand has on turf performance and the surface physical properties of a 'Shark' creeping bentgrass (*Agrostis stolonifera*) turf.

This trial was initiated in May 2016 on a 19-month-old 'Shark' creeping bentgrass maintained at 2.8-mm on a sand-based root zone. A 3 x 2 x 2 factorially arranged randomized complete block design with four replications included the factors of sand size (medium-coarse, medium-fine, fine-medium), quantity of mid-season (June to September) topdressing (50 and 100 lbs./ 1,000 sq. ft. every 10 to 14 days), and cultivation (non-cultivated or core cultivation plus backfill in May and October). Two non-topdressed controls (at both levels of cultivation) were included for comparisons resulting in 14 total treatments (Table 1). The medium-coarse sand met USGA recommendations for putting green construction; whereas the fine sand content of medium-fine and fine-medium topdressing sands exceeded USGA recommendations and contained little to no coarse particles (Table 2).

Turf color, density and quality was visually rated June through October. Volumetric water content (VWC) of the surface 0- to 38-mm and 0- to 76-mm depth zone was monitored routinely. Mower clippings from each plot were collected the day after topdressing three times during 2016 and 2017, to determine the quantity and particle size distribution of sand collected during mowing. Clipping samples collected in 2017 are being combusted to remove clippings and then sieved in the laboratory to determine particle size distribution. Core samples were collected before and one-year after treatment initiation to characterize the thickness of the thatch-mat layer and content of sand and organic matter (OM). Four 3-inch diameter undisturbed core samples were collected one-year after treatment in May 2017.

Sand Collected by Mower (Table 3)

Topdressing with medium-coarse sand increased the quantity and portion of sand collected during mowing compared to medium-fine and fine-medium sands during 2016. The portion of topdressing sand collected by the mower increased as the topdressing rate increased.

Mat Layer Depth and Organic Matter (OM) Concentration (Table 4)

Topdressing increased the depth of the mat layer and decreased the OM concentration compared to non-topdressed controls. Topdressing at 100 lbs./1,000 ft^2 developed a thicker mat layer depth and lower OM concentration compared to topdressing at 50 lbs./1,000 ft^2. Core cultivation reduced OM concentration but did not influence mat layer depth.

Sand Size Distribution in Mat Layer After One Year of Treatments (Table 5)

Core samples collected in 2017 are currently being measured in the lab; however, our initial assessment (1 of 4 subsamples) indicated that sand size of topdressing has affected the sand size distribution within the mat layer. Fine-medium and medium-fine sand topdressing increased the fineness of sand within the mat layer compared to topdressing with medium-coarse sand. Topdressing at 100 lbs./1,000 ft^2 with fine-medium sand intensified this response; whereas the fineness of sand in the mat layer was not strongly affected by the topdressing rate of medium-fine sand (data not shown).

Additionally, the resulting sand size distribution in the mat layer was dependent on topdressing rate and level of core cultivation (Figure 5a). Plots that were core cultivated and backfilled with medium-coarse sand offset the increased fineness of the mat layers formed by topdressing with fine-medium and medium-fine sand (Figure 5b).

Volumetric Water Content (VWC; Figures 1 to 3)

Core cultivation decreased VWC at the 0- to 38-mm surface depth zone throughout 2017 compared to non-cultivated plots (Figure 1). The effect of sand size on surface wetness depended on the cultivation factor. Without core cultivation, medium-coarse and medium-fine sand topdressing produced a drier surface compared to plots topdressed with fine-medium sand (Figure 2a). However, this sand size effect was either less prominent or not observed when plots were core cultivated (Figure 2b). Under core cultivation, the VWC of non-topdressed control plots was similar to topdressed plots (data not shown).

Table 1. Summary of the individual treatment combinations of topdressing (sand size and rate) and cultivation as well as two controls (no topdressing during the growing season) being evaluated on 'Shark' creeping bentgrass turf grown on a sand-based rootzone.

	Factors in the Experiment			
Treatment No.	Sand Size†	Topdressing Sand Rate during the Growing Season‡	Cultivation¶	Annual Quantity of Sand Applied
		lbs. / 1,000 sq. ft.		lbs. / 1,000 sq. ft.
1	Medium-coarse	50	Non-cored	1,300
2	Medium-coarse	50	Core + Backfill	1,700
3	Medium-coarse	100	Non-cored	1,800
4	Medium-coarse	100	Core + Backfill	2,200
5	Medium-fine	50	Non-cored	1,300
6	Medium-fine	50	Core + Backfill	1,700
7	Medium-fine	100	Non-cored	1,800
8	Medium-fine	100	Core + Backfill	2,200
9	Fine-medium	50	Non-cored	1,300
10	Fine-medium	50	Core + Backfill	1,700
11	Fine-medium	100	Non-cored	1,800
12	Fine-medium	100	Core + Backfill	2,200
13	None	0	Non-cored	0
14	None	0	Core + Backfill	1,200

†, First-mentioned size class represent the predominant size fraction in the sand.

‡, Topdressing applied every two weeks from 10 June through 12 October (10 applications) in 2016 and every 10-14 days from 12 June to 28 September (10 appliactions) in 2017. Topdressing at 50 lbs. per 1,000 sq. ft. represented a 'dusting' quantity (O'Brien and Hartwiger, 2003); whereas, topdressing at 100 lbs. filled the surface thatch and lower verdure layers.

¶, Core cultivation to the 1 ½-in depth was performed twice a year (10 May and 2 November in 2016; 15 may and 9 October in 2017) using ½-inch diameter hollow tines spaced to remove 10% of the plot surface area annually. Coring holes were backfilled with 600 lbs. per 1,000 sq. ft. of medium-coarse sand. Non-cored plots were topdressed with the respective sand size at 400 lbs. per 1,000 sq. ft. (300 lbs. per 1,000 sq. ft. in October 2016) to fill the surface thatch and verdure layers to the same extent as backfilled, cored plots.

Table 2. Particle size distribution of three sands used to topdress plots on a 'Shark' creeping bentgrass turf grown on a sand-based rootzone.

Sand	1000 µm Very Coarse	500 µm Coarse	250 µm Medium	150 µm Fine	53 µm Very Fine
	------------------------------- % (by weight) retained -------------------------------				
Medium-coarse	0	33.8	57.7	8.4	0.1
Medium-fine	0	0.1	76.7	22.7	0.5
Fine-medium	0	5.7	25.8	66.8	1.7

Table 3. Analysis of variance of sand picked-up with one pass of a mower (1.9 m^2) on the day after topdressing during 2016.

Sampling Date	7-Jul		17-Aug		28-Sep	
Mowing Height	0.110 inch		0.110 inch		0.125 inch	
Source of variation	Sand Picked-up‡	Portion of Sand Applied¶	Sand Picked-up	Portion of Sand Applied	Sand Picked-up	Portion of Sand Applied
	lbs./1,000-ft^2	%	lbs./1,000-ft^2	%	lbs./1,000-ft^2	%
Sand Size (SS)	***	***	***	***	***	***
Topdressing Rate (TR)	***	*	***	***	***	***
SS*TR	***	NS	***	NS	NS	NS
Core Cultivation (CC)	NS	NS	NS	NS	NS	NS
SS*CC	NS	NS	NS	NS	NS	NS
TR*CC	NS	NS	NS	NS	NS	NS
SS*TR*CC	NS	NS	NS	NS	NS	NS
Main Effect						
Sand Size						
Medium-coarse	4.0	0.5	5.4	0.8	1.3	0.2
Medium-fine	1.9	0.3	3.2	0.4	0.7	0.1
Fine-medium	1.9	0.3	1.8	0.2	0.6	0.1
LSD (5%)	0.4	0.1	0.5	0.1	0.1	0.0
Topdress Rate (lbs/1000 ft^2)						
50 lbs./1,000 ft^2	1.6	0.3	2.1	0.4	0.5	0.1
100 lbs./1,000 ft^2	3.6	0.4	4.8	0.5	1.2	0.1
LSD (5%)	0.3	0.0	0.4	0.1	0.1	NS
Core Cultivation						
None	2.4	0.3	3.3	0.5	0.8	0.1
Twice a year	2.8	0.4	3.7	0.5	0.9	0.1
LSD (5%)	NS	NS	NS	NS	NS	NS

* Significant at $p \leq 0.05$; ** significant at $p \leq 0.01$; *** significant at $p \leq 0.001$; NS: nonsignificant ‡ Sand and clippings combusted at 360 °C for 24 hours and weighed after removal of ash. ¶ Weight of sand collected by mower ÷ weight of topdressing applied to mowing area x 100

Table 4. Orthogonal contrasts and analysis of variance of the depth and organic matter concentration of the mat layer one-year after initiation of treatments in May 2017.

Orthogonal Contrasts	Depth¶	Organic Matter‡
	mm	%
Non-cultivated: Topdressed	17.4 ***	6.7 ***
vs. Non-topdressed	13.7	9.2
Cultivated: Topdressed	17.0 *	5.5 ***
vs. Non-topdressed	15.2	7.1
Source of Variation		
Sand Size (SS)	ns	ns
Topdress Rate (TR)	***	***
SS x TR	ns	ns
Core Cultivation (CC)	ns	***
SS x CC	ns	ns
TR x CC	ns	ns
SS x TR x CC	ns	ns
Main Effects		
Sand Size		
Medium-coarse	17.2	6.1
Medium-fine	17.4	6.1
Fine-medium	16.9	6.1
LSD (5%)	ns	ns
Topdressing Rate		
50 lbs./1,000-ft^2	16.4	6.4
100 lbs./1,000-ft^2	17.9	5.8
LSD (5%)	0.7	0.3
Core Cultivation		
Non-cultivated	17.4	6.7
Core Cultivated	17.0	5.5
LSD (5%)	ns	0.3

¶ The average mat layer depth was 6.3-mm at the initiation of treatments in May 2016.

‡ The average organic matter concentration was 6.7 % at the initiation of treatments in May 2016.

* Significant at p≤0.05; ** significant at p≤0.01; *** significant at p≤0.001; ns: not significant

Table 5a. Orthogonal contrasts and analysis of variance of sand particle sizes within the mat layer one-year after initiation of treatments in May 2017.

	Size Class/Particle Diam. (mm)				
	V. coarse 2.0-1.0	Coarse 1.0-0.5	Medium 0.5-0.25	Fine 0.25-0.15	V. Fine 0.15-0.05
	%	%	%	%	%
Orthogonal Contrasts					
Non-cultivated: Topdressed	2.9 ***	19.4 ***	47.7 ns	24.2 ***	5.8 ***
vs. Non-topdressed	4.6	25.4	46.4	19.7	3.8
Core Cultivated: Topdressed	2.8 *	19.7 ns	52.3 ns	20.9 *	4.3 ns
vs. Non-topdressed	3.5	21.7	51.9	19.2	3.7
Source of Variation					
Sand Size (SS)	**	***	***	***	***
Topdress Rate (TR)	*	ns	ns	ns	**
SS*TR	ns	ns	***	***	***
Core Cultivation (CC)	ns	ns	***	***	***
SS*CC	ns	**	***	***	***
TR*CC	ns	ns	ns	ns	ns
SS*TR*CC	*	*	ns	ns	ns

* Significant at p≤0.05; ** significant at p≤0.01; *** significant at p≤0.001; ns: not significant

Table 5b. The interaction effects of sand size and topdressing rate, and sand size and core cultivation on the proportion of sand sizes within the mat layer one-year after initiation of treatments in May 2017.

Interactions		V. coarse 2.0-1.0 mm	Coarse 1.0-0.5 mm	Medium 0.5-0.25 mm	Fine 0.25-0.15 mm	V. Fine 0.15-0.05 mm
		Size Class				
		%	%	%	%	%
Sand Size	Topdressing Rate					
Medium-coarse	50 lbs./1,000 ft^2	3.0	24.8	51.2 c	18.1 d	2.9 d
Medium-coarse	100 lbs./1,000 ft^2	2.8	25.2	52.6 bc	16.6 e	2.8 d
Medium-fine	50 lbs./1,000 ft^2	3.2	17.7	54.0 b	**21.5 c**	3.6 c
Medium-fine	100 lbs./1,000 ft^2	2.9	15.8	56.4 a	**21.4 c**	3.6 c
Fine-medium	50 lbs./1,000 ft^2	2.7	17.7	44.5 d	**27.3 b**	**7.8 b**
Fine-medium	100 lbs./1,000 ft^2	2.4	**16.2**	**41.4 e**	**30.4 a**	**9.5 a**
	LSD (5%)	ns	ns	1.4	0.9	0.5
Sand Size	Core Cultivation					
Medium-coarse	Non-cultivated	2.9	26.6 a	50.5 c	17.2 e	2.8 e
Medium-coarse	Cultivated	2.9	23.4 b	53.2 b	17.4 e	3.0 de
Medium-fine	Non-cultivated	3.1	15.6 d	54.5 ab	**23.0 c**	3.9 c
Medium-fine	Cultivated	3.0	17.9 c	55.9 a	19.9 d	3.3 d
Fine-medium	Non-cultivated	2.6	**16.1 d**	**38.0 e**	**32.4 a**	**10.9 a**
Fine-medium	Cultivated	2.5	17.8 c	47.9 d	**25.3 b**	**6.5 b**
	LSD (5%)	ns	1.1	1.4	0.8	0.4

¶ Different letter indicates statistically difference between treatments at α = 0.05

‡ Bold font indicates failure to meet USGA guidelines

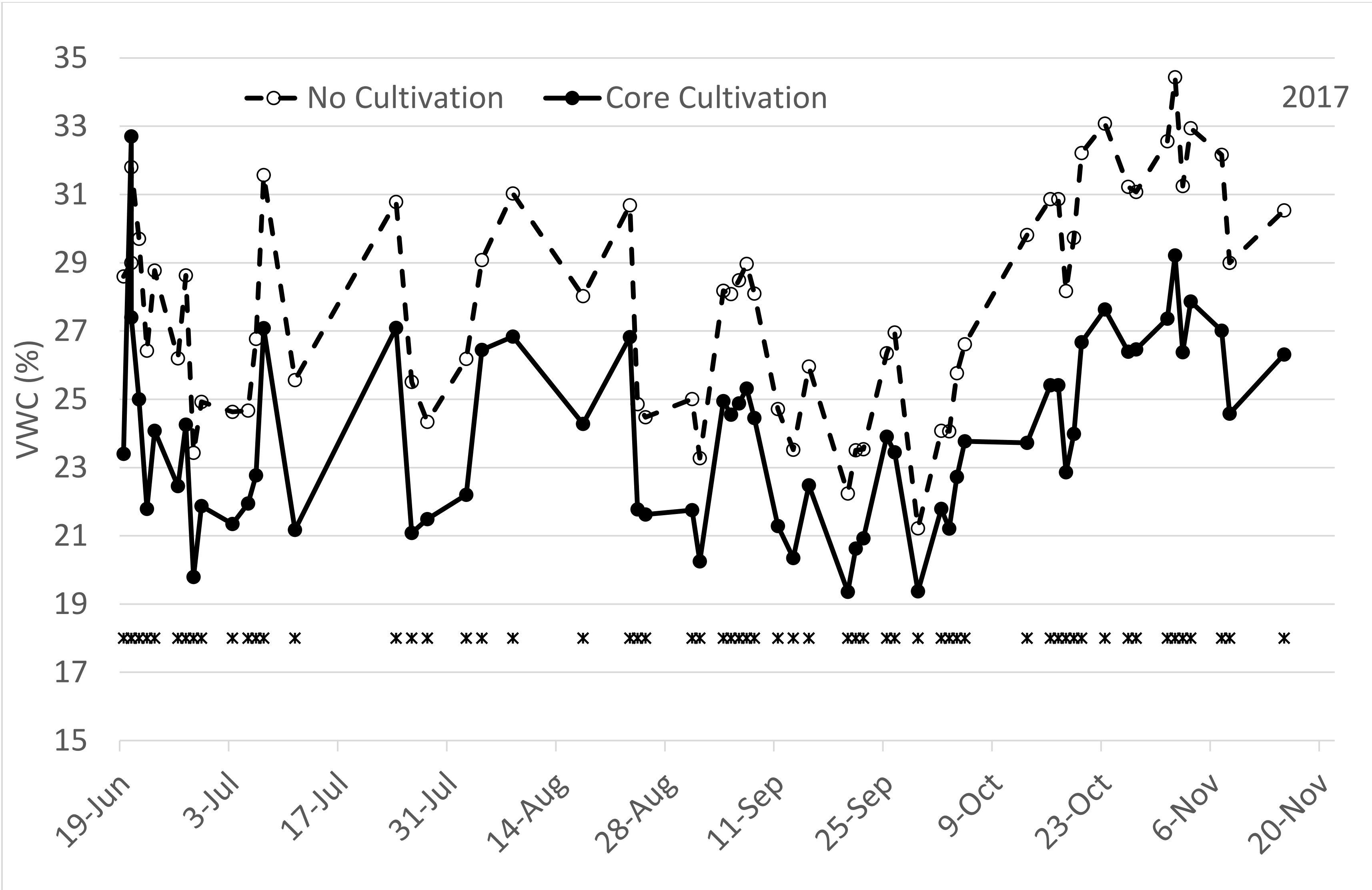

Figure 1. The core cultivation main effect on volumetric water content at the 0- to 38-mm surface depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2017.

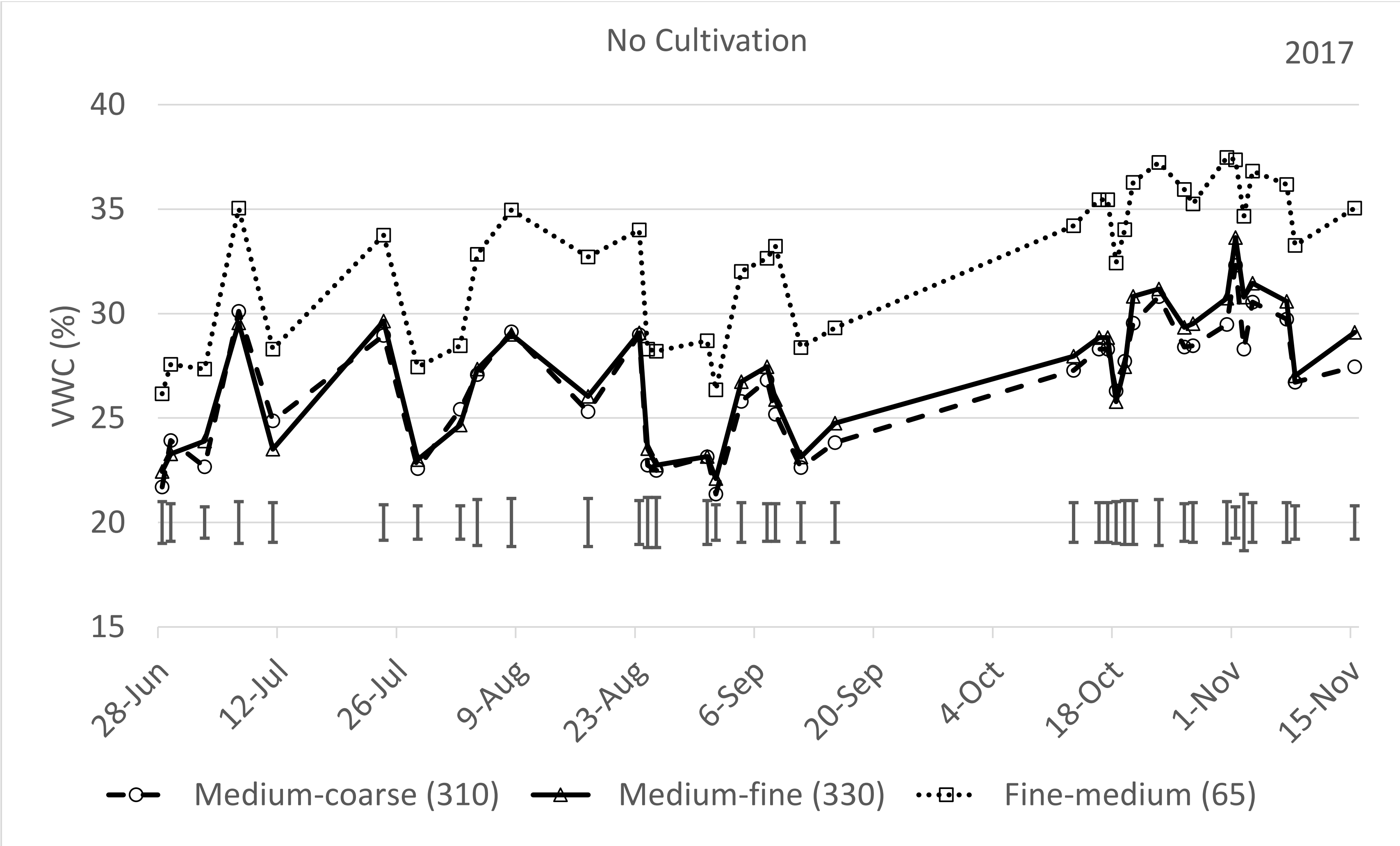

Figure 2a. The sand size effect under no cultivation on volumetric water content at the 0- to 38-mm surface depth zone of a ‘Shark’ creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2017.

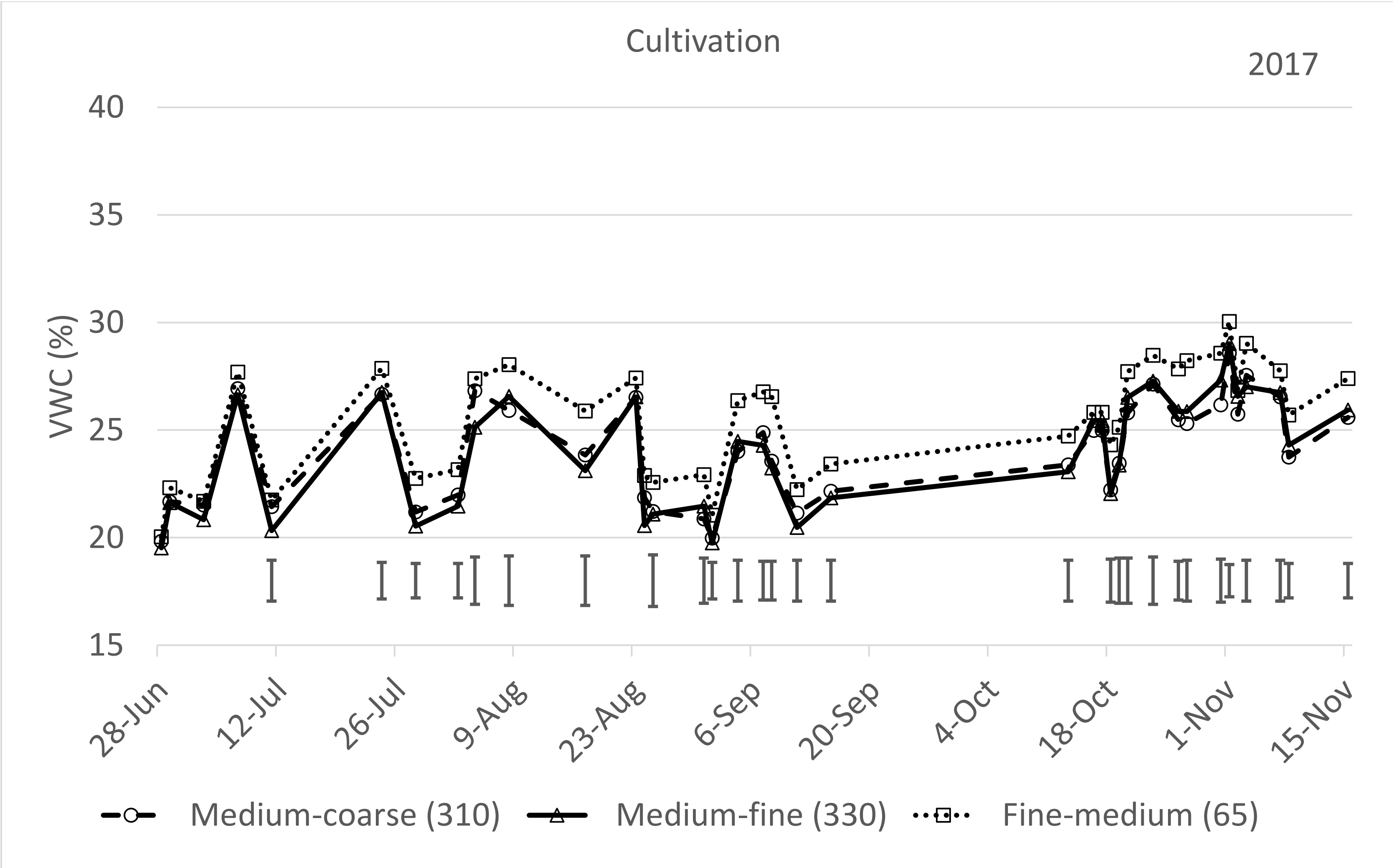

Figure 2b. The sand size effect under core cultivation on volumetric water content at the 0- to 38-mm surface depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2017.

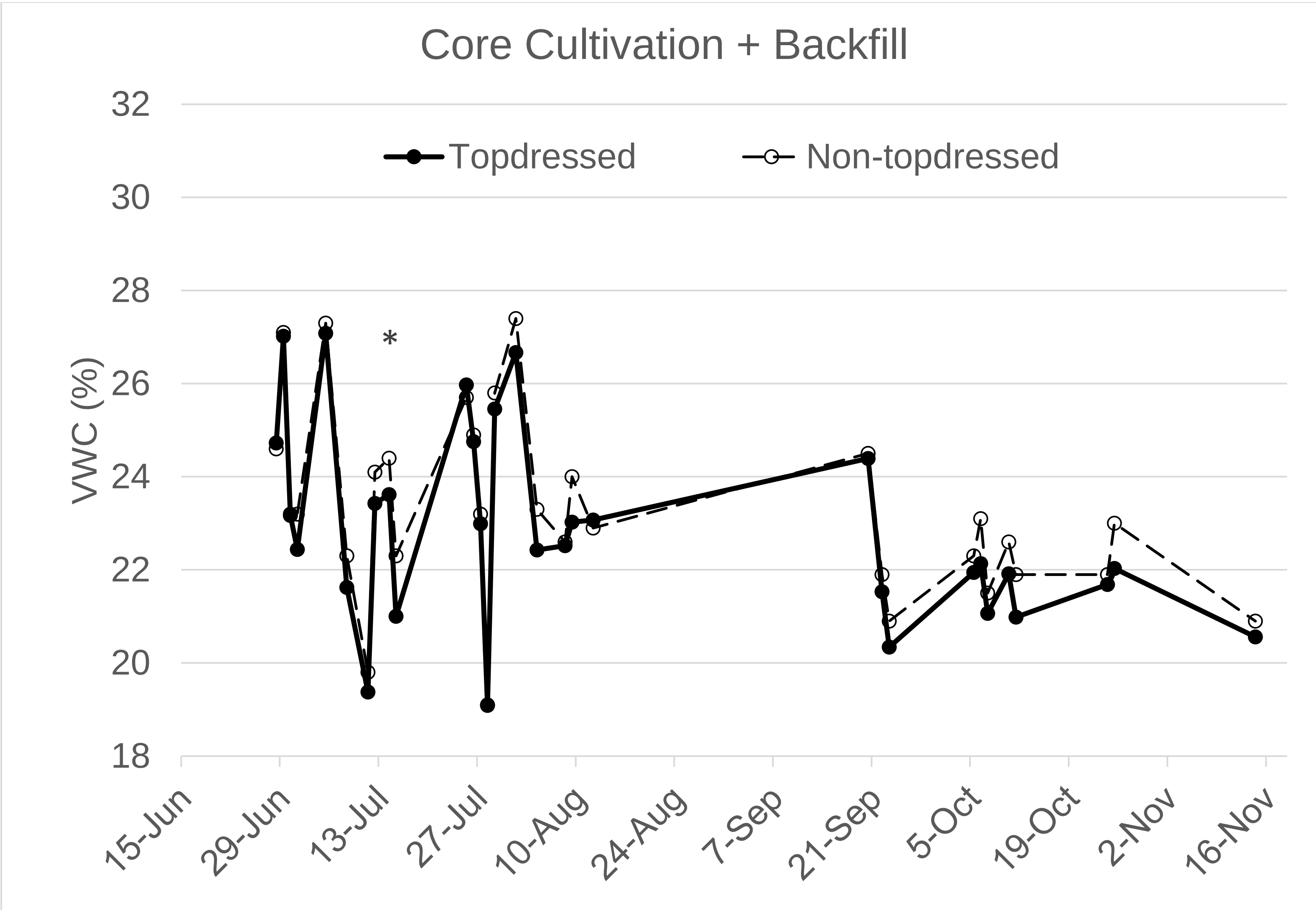

Figure 3a. The pooled effect of topdressing under core cultivation compared to non-topdressed plots on volumetric water content at the 0- to 38-mm surface depth zone of a ‘Shark’ creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2017.

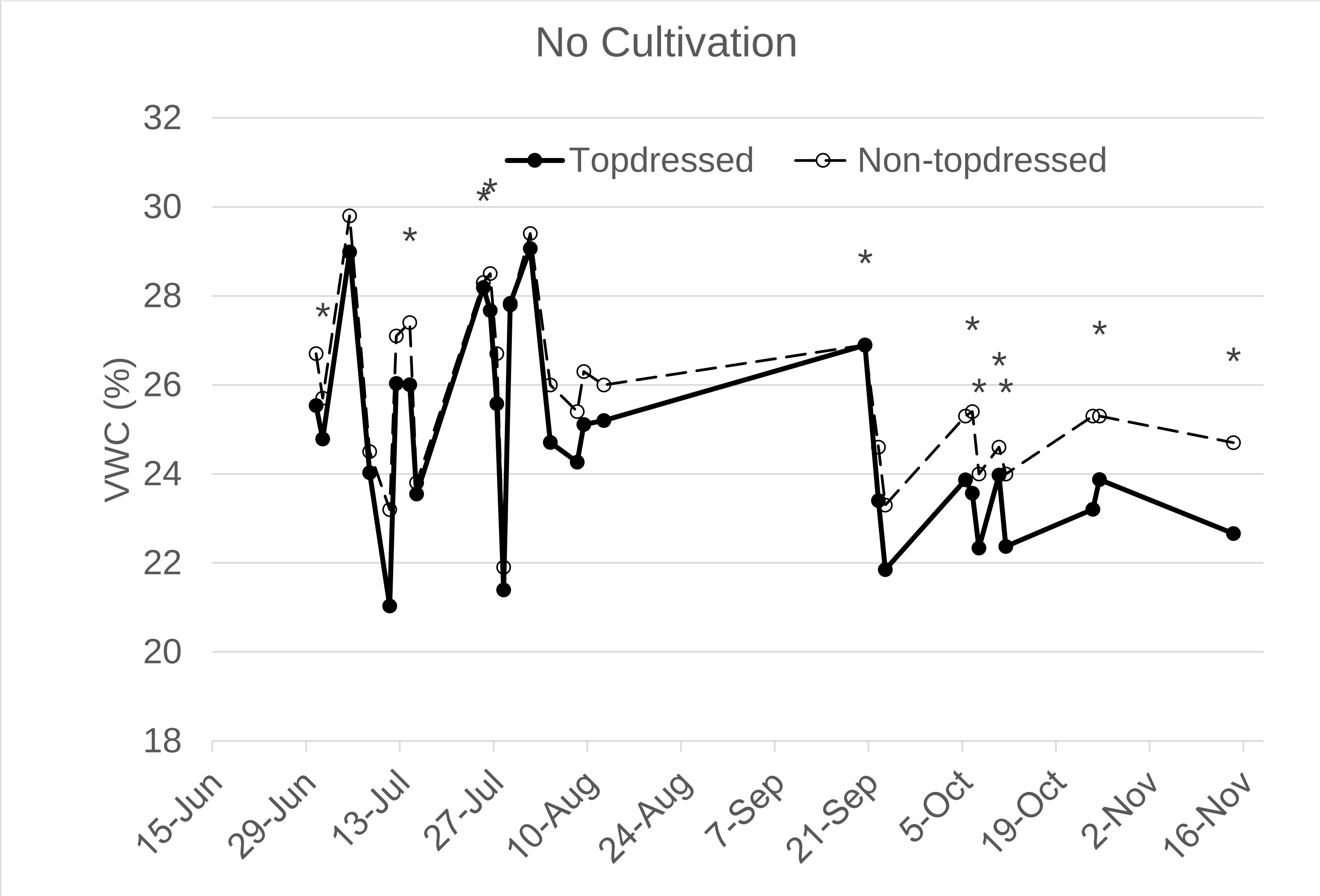

Figure 3b. The pooled effect of topdressing under no cultivation compared to non-topdressed plots on volumetric water content at the 0- to 38-mm surface depth zone of a ‘Shark’ creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2017.

2016-17-567

Assessment of Topdressing Sands and Associated Cultural Practices used to Manage Ultradwarf Bermudagrass Greens

K. McInnes, C. Reynolds, B. Wherley, and M. Sanchez - Texas A&M University

Ultradwarf bermudagrasses on golf greens produce a dense canopy that traps some topdressed sand particles. Larger sand grains appear to be more resistant to falling or being worked through the canopy than are finer grains. Sand trapped in the canopy can produce a less desirable playing surface and can be picked up by and damage mowers. Given such, it is becoming common practice to topdress ultradwarf bermudagrass greens with sand having finer particles (i.e., with less fraction of large particles) than those of the sand that the green was originally constructed. We are investigating the consequences of using finer sand. Co-Investigator Dr. Casey Reynolds left the project on taking the executive directorship of Turfgrass Producers International. Dr. Manuel Sanchez joined the program August 1, 2017 as a postdoctoral research associate.

Putting greens on four courses in southeast Texas have been sampled for particle size distributions of sands in putting greens, sands used for topdressing, and sands picked up with grass clippings on mowing after topdressing. Infiltration rates, apparent total porosity, and apparent capillary porosity of the putting greens also were measured.

Particle size distribution of sand in the surface of the putting greens have been found to be on finer side of the USGA recommendations for sand used to construct greens (Figure 1). This occurs from either use of a finer sand for topdressing or from removal of coarser sand with mower clippings (Figure 2), or a combination of the two. The course with the finest sand in the surface has been allowing the depth of sand (surface to the gravel drainage) to increase with time by not aggressively removing sand with cultural practices such as hollow-tine aerification (Figure 3). The course with the coarsest sand at the surface had the poorest performing greens.

A 15-cm diameter permeameter was used to test in situ infiltration rates and near-surface water retentions of the putting greens. The permeameter is 30 cm in total height and is inserted into a green so that half is below the surface. In operation, fifteen cm of water is added to the permeameter and allowed to infiltrate then second 15 cm of water is added and allowed to infiltrate. During the second run, infiltration rate is determined from the recorded change in depth of water in the permeameter with time (Figure 4). After this second aliquot has infiltrated, the surface water content is measured for one hour to estimate the effective capillary porosity (Figure 4).

The majority (71%) of the variability in infiltration rate on greens could be explained by a linear model with particle size (using the d50, particle diameter with 50% larger and 50% smaller) and organic matter content as variables. The majority (94%) of the variability in apparent total porosity in the top 2 inches of the greens (maximum observed surface water content) could be explained by a linear model with particle size (d50) as the sole variable. Greens with finer particles had greater maximum water contents.

Scheduled sampling of additional courses in the Houston area has been delayed as a consequence of flooding from Hurricane Harvey.

Summary Points

- Particle size distribution of sand in the surface of putting greens tested are on the finer side of USGA recommendations for sand used in construction of putting greens.

- Particle size distribution of sand removed with mower clippings is on the coarser side of USGA recommendations for sand used in construction of putting greens.

- Particle size distribution in putting green surface is consistent with finer sand being used for topdressing and with the coarser fraction of topdressing sand being removed with mower clippings.

- Seventy-one percent of the variability in infiltration rate on greens could be explained by a linear model with particle size and organic matter content as variables.

- Ninety-four percent of the variability in apparent total porosity (maximum observed surface water content) could be explained by a linear model with particle size as the sole variable.

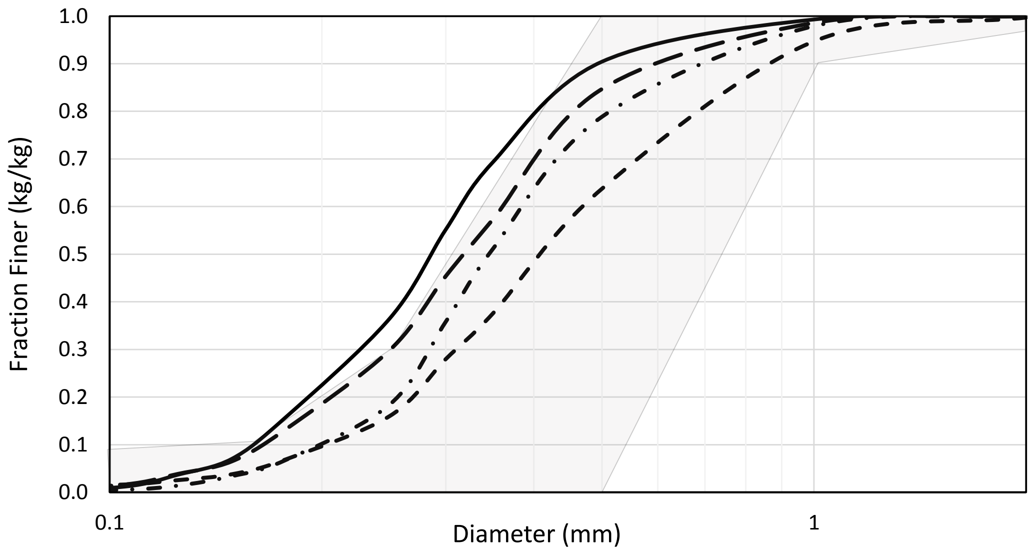

Figure 1. Particle size distributions of surface 1 inch of sand in putting greens sampled. Shaded area represents USGA recommendation for sand used to construct a putting green.

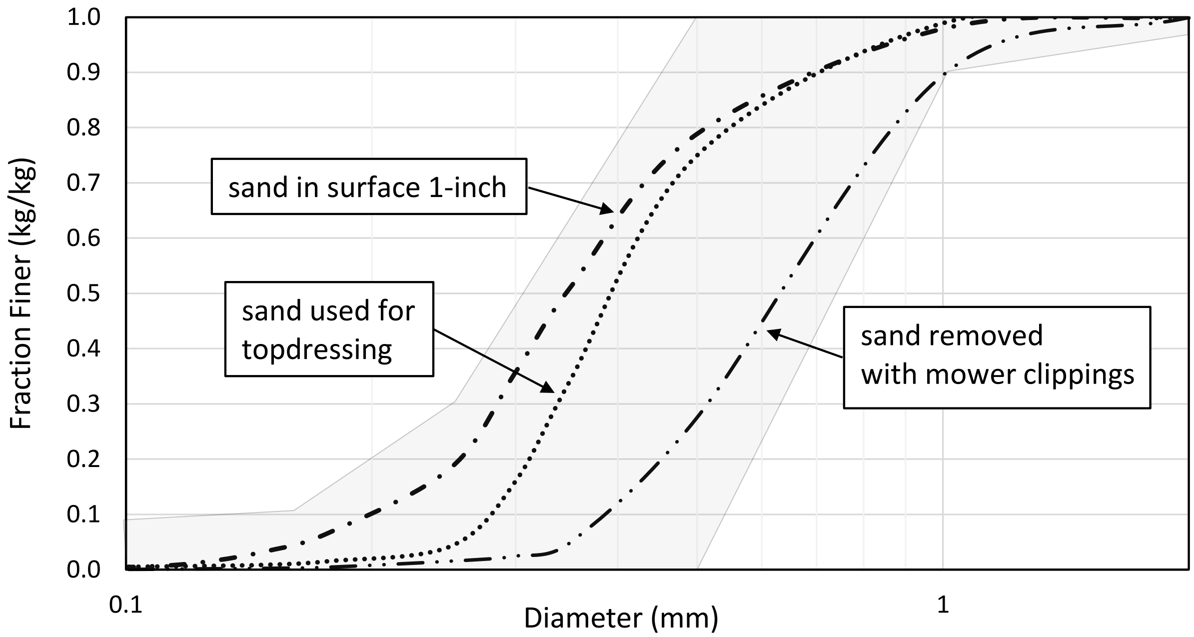

Figure 2. Particle size distributions of sand in a putting green surface along with that used for topdressing and that removed with mower clippings. Shaded area represents USGA recommendation for sand used to construct a putting green.

Figure 3. Increase in sand profile depth on a course using fine topdressing sand not removing sand with time via cultural practices.

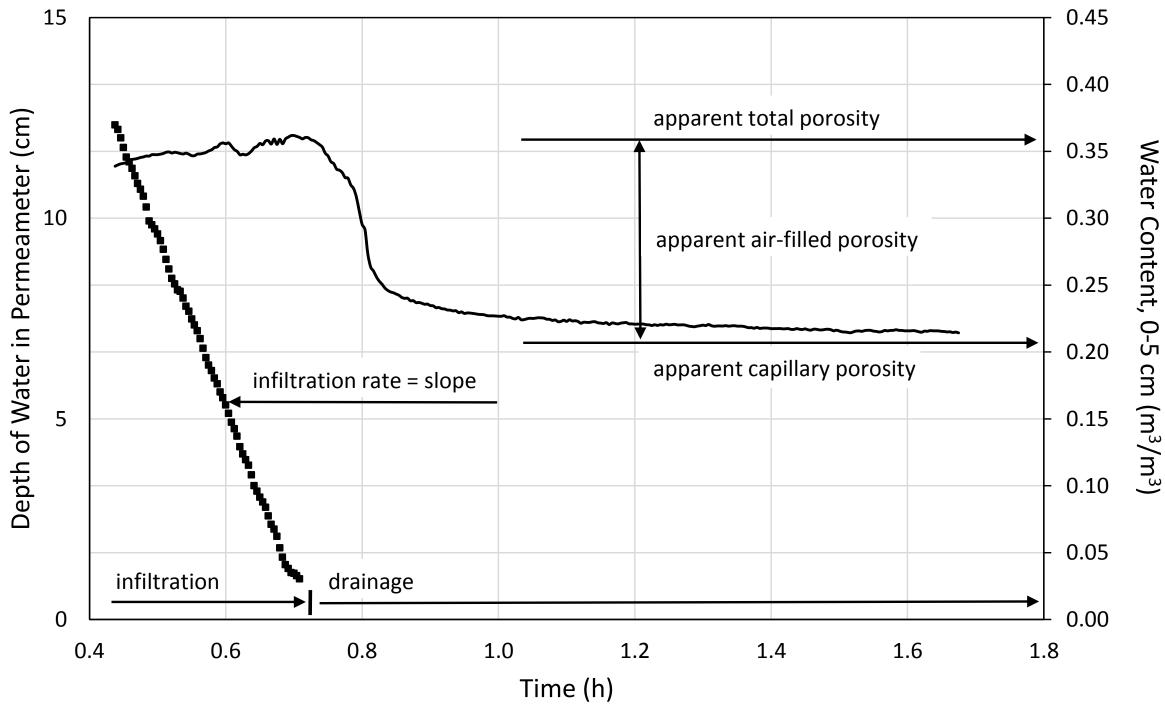

Figure 4. Data from permeameter used to measure infiltration rate and water holding capacity of a putting green.

2015-14-529

Genesis and prevention of iron-cemented layers in sand putting green soil profiles

Glen R. Obear and William C. Kreuser

- A column study will be conducted in 2018. The objectives of the study are to determine how root zone chemistry and Fe rate affect formation of potential layers in the soil.
- Preliminary data show that putting greens with high pH gravel layers may be more prone to formation of Fe-enriched layers when high rates of iron are applied. Root zones with high pH sand may be less likely to form layers at the sand/gravel interface due to immobilization of Fe near the surface.
- In 2018-2019, soil samples will be collected from at least 50 golf courses to determine the distribution of Fe-cemented layers, and to create and validate a model to explain their formation.

Iron-cemented layers form in putting greens, potentially leading to decreased water infiltration and anaerobic conditions in the soil. These layers have been documented, but the factors that lead to their formation have not been studied. The objectives of this study are to determine 1) how root zone chemistry affects iron accumulation at different application rates, and 2) the distribution of these layers across the US, which will provide a dataset against which a model can be created and validated.

A column study (Fig. 1) will be established as a 2x2x3 factorial design with three replications. The root zone will be comprised of a silica sand from Florida (pH 5.5) or a calcareous sand from Wisconsin (pH 8.2); both meet USGA particle size recommendations. The gravel layer will be comprised of either limestone (pH 8.8) or granite (pH 5.4). After establishment of creeping bentgrass, columns will receive weekly applications of ferrous sulfate at a rate of 10 or 50 kg ha^{-2}, and these are being compared to untreated columns. All columns are irrigated to replace 200% of water lost through evapotranspiration to produce downward movement of water through the profile. Air permeability will be measured every 14 to 28 days to track changes in pore space resulting from potential iron accumulation.

After each iron application, x-ray fluorescence (XRF) will be used to measure the concentration of Fe inside columns in 2.5 cm depth increments. To take these measurements, we constructed an autosampler stand to position the columns for automated XRF analysis (see this video for more details: https://www.youtube.com/watch?v=iJzYzuITz44). The stand allows for scanning while columns are rotating, producing an extremely accurate way to measure average soil Fe at different depth increments inside columns (Fig. 2). This stand is the first of its kind and offers a new way to study soil formation.

Data from a preliminary trial show that after eight applications at a rate of 200 kg $FeSO_4$ ha^{-2}, a marked accumulation was observable at the interface of sand and gravel in a column with low-pH sand and high-pH gravel (Fig. 3). Iron oxidized above the gravel layer in columns with low pH sand and high pH gravel. In columns with high pH sand, the Fe became immobilized near the surface and never reached the gravel layer. These findings suggest that iron-cemented layers are more likely to form in root zones with high pH gravel. However, these layers may be less likely to form in putting greens with high pH sand, since the iron is immobilized before it reaches the gravel. Despite the accumulation of iron, there was no observable difference in air permeability, suggesting that the iron that had accumulated was not enough to reduce porosity and air infiltration rate.

Figure 1. Columns were constructed to meet the recommendations of the USGA for putting green construction.

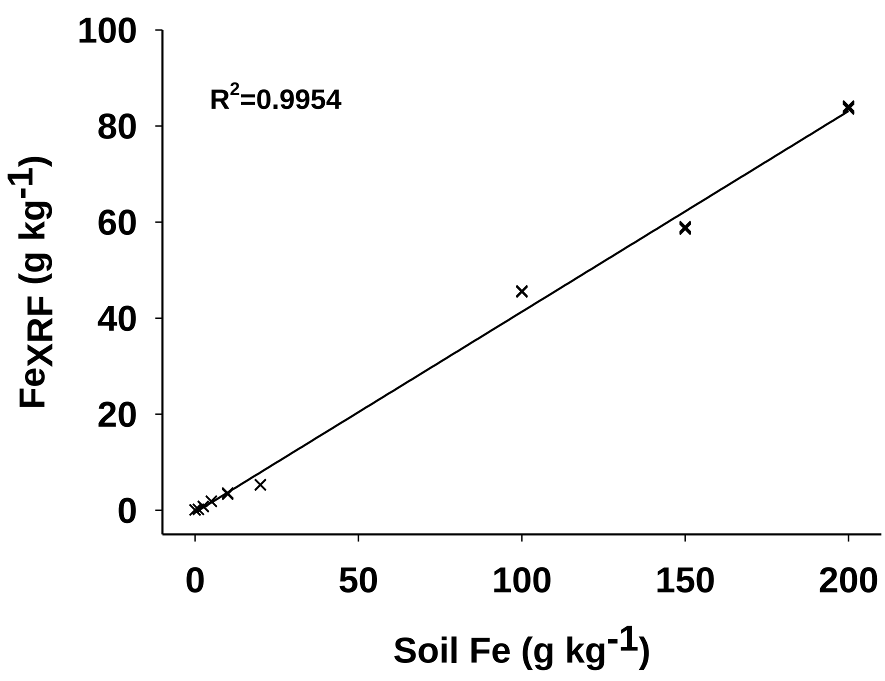

Figure 2. Calibration of an automated XRF stand with soil standards of known Fe concentration. Each sampling cluster on the graph above actually contains data points from 10 separate scans. This robust method will allow us to track Fe accumulation very accurately.

Figure 3. Iron-cemented layer at the sand/gravel interface of a root zone with a low-pH sand and a high-pH gravel. The column received eight total applications of Fe at a rate of 200 kg $FeSO_4$ ha^{-1}. Despite the visual observation of iron accumulation, there was no measured decrease in air infiltration rate after eight applications.

2016-16-566

How does clay move and accumulate in sand root zones?

Glen R. Obear and William C. Kreuser

- A column study will be conducted in 2018. The objectives of the study are to determine how water chemistry and construction practices influence clay movement in two-tiered sand putting greens.
- Columns are currently being constructed, and leaching events and measurements will begin in early 2018. A preliminary study helped inform column construction methods and hone XRF scanning methods.
- The results from this study will improve our understanding of how soil and water chemistry interact to influence performance of engineered turf soils.

In 2017, we documented thin layers of clay that had formed in 9-year old putting greens in a Mississippi golf course (paper available here: Catena- Clay Lamellae Paper). This observation led us to study how clay moves and accumulates in two-tiered sand putting greens. We will construct columns to the recommendations of the USGA (2004), and amended them to contain 0, 1, 3, or 5% clay by weight. These ranges were selected to be above and below the recommended cutoff of <3% clay-sized particles for new putting green construction. Columns will be leached with either 0.1 or 1 pore volume of water for a series of repeated leaching events. The entire study will be replicated using two different water sources (CaCl-based or NaCl-based) to study how water chemistry influences clay movement.

After each leaching event, x-ray fluorescence (XRF) is being used to measure the clay content (using Fe as a tracer) inside columns in 2.5 cm depth increments. To take these measurements, we constructed an autosampler stand to position the columns for automated XRF analysis (see this video for more details: https://www.youtube.com/watch?v=iJzYzuITz44). The stand allows for scanning while columns are rotating, producing an extremely accurate way to measure average clay content at different depth increments inside columns (Fig. 1). This stand is the first of its kind and offers a new way to study soil formation.

In addition to XRF measurements, air permeability will be measured to document changes in pore space resulting from clay movement. The columns will be photographed regularly to visually document clay accumulation, and at the end of the study, the columns will be split vertically and dissected to measure clay concentrations in 2.5 cm depth increments to further validate XRF clay measurements. A subset of columns with accumulations of clay will be analyzed using a micro-CT x-ray scanner, which produces 3-D models of soils and allows for calculation of pore space in 50 µm depth increments. Leachate will be collected from each column throughout the study period, and a mass balance of clay will be produced to document how clay responded to leaching treatments.

In a preliminary study, a column was constructed with 1% clay by weight and leaching events was conducted with 0.1 pore volumes of CaCl-enriched water. After seven leaching events, compared to the baseline clay distribution, leaching resulted in an accumulation at three inches, and a possible redistribution of clay from 4-10 inches down to 11 inches (Fig. 2). These preliminary data are proof-of-concept and show that XRF can accurately show clay movement in the columns.

The results of this research could help aid future construction recommendations for putting greens. The findings will also improve our understanding of how soil and water chemistry interact to influence performance of engineered turf soils.

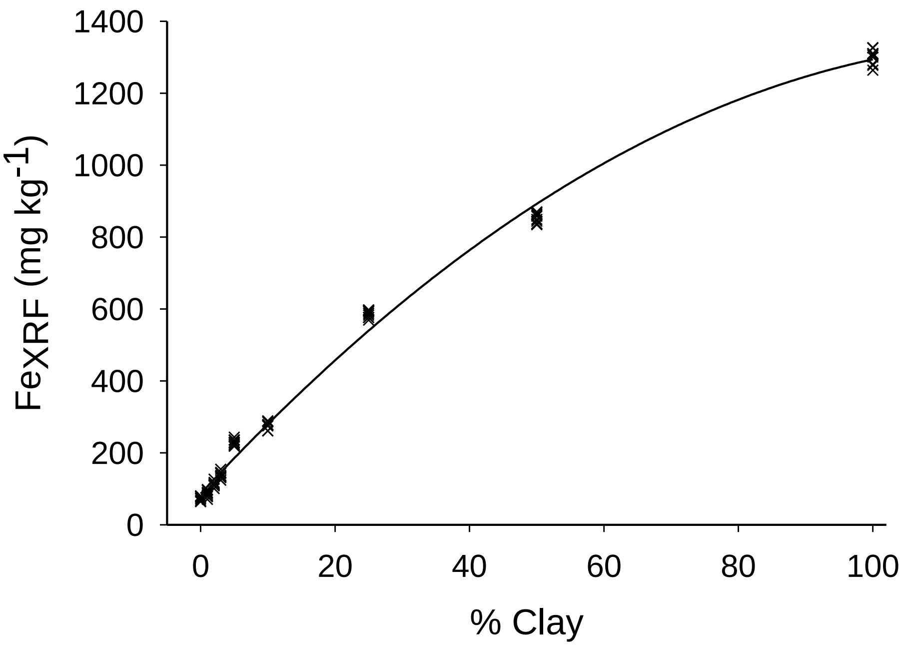

Figure 1. Calibration of an automated XRF stand with soil standards of known clay concentration. Iron is used as a tracer for clay. Each sampling cluster on the graph above actually contains data points from 10 separate scans. This robust method will allow us to track clay movement very accurately.

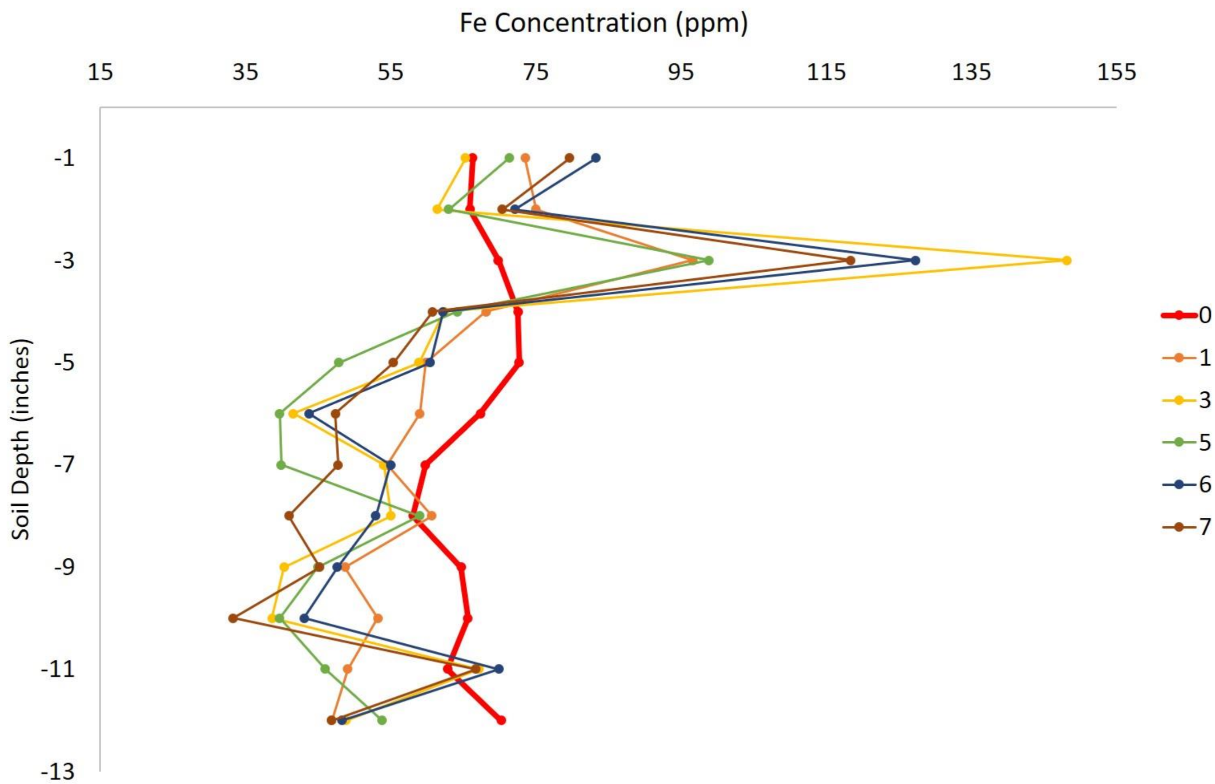

Figure 2. Clay distribution by depth as affected by seven consecutive leaching events. The column contained 1% clay by weight and each leaching event was done with 0.1 pore volumes of CaCl-enriched water. Compared to the baseline clay distribution, leaching resulted in an accumulation at three inches, and a possible redistribution of clay from 4-10 inches down to 11 inches. These preliminary data are proof-of-concept and show that XRF can accurately show clay movement in the columns.

2015-12-527

A New Sodicity Index for Improving Risk Assessment and Management of Saline and Sodic Soils

Doug Soldat, Ph.D. and William Bleam, Ph.D

University of Wisconsin-Madison

Objective: The objective of this project was to develop a new sodicity index that is superior to existing sodicity indices for managing turfgrass.

Start Date: 2014

Project Duration: 3 years

Total Funding: $65,399

Summary text:

The sodium adsorption ratio (SAR) is a commonly used irrigation sodicity risk index based on the initial amount of dissolved sodium, magnesium and calcium in the water. In reality, the sodicity risk of water is affected by evaporation, leading to calcite precipitation and increasing the percentage of sodium on soil cation exchange sites. Existing methods to estimate the evaporation-adjusted SAR to account for calcite precipitation are unreliable or unnecessarily complex for routine sodicity risk assessment. Water sources differ substantially in their sodicity potential and their latent sodicity risk only becomes apparent at moderate and high salinity. This paper proposes a new sodicity risk index, which utilizes two limits, the Limiting Sodium Adsorption Ratio (LSAR), which computes an upper limit toward which the SAR converges as calcium carbonates precipitates as a result of evaporation; and the evaporation-adjusted SAR (ESAR) which computes a lower limit where no calcite precipitation occurs as salinity increases. We analyzed seven different river waters and set the upper and lower boundaries based on the most diluted condition of the river (where sodicity risk is not usually apparent). The upper boundary, LSAR, represents the worst-case scenario, where nearly all the calcium is removed by calcite precipitation; the lower boundary, ESAR, is the best-case scenario where evaporation concentrates the water but assumes no calcite precipitation. The SAR of waters solely influenced by evaporation were bounded by the LSAR and ESAR boundaries. Water where SAR fell outside of the boundaries were influenced by subsurface or surface discharge from saline sources and these waters could be readily identified by the trend in bicarbonate and calcium ratio. The new sodicity risk method represent here is a simple, accurate way to identify the potential sodicity risk of an irrigation water as it concentrates in the soil.

The LSAR and ESAR boundaries are relatively easy to calculate, and only require the initial EC of the irrigation water, the threshold EC for the particular turf species (in this work we used a threshold of 4 ds/m), and the sodium, calcium, and magnesium

concentration in the irrigation water. The Fc term is EC threshold concentration divided by the EC of the irrigation water. The equations are shown below:

$$\mathrm{LSAR} = \frac{\mathrm{F_c} \cdot \mathrm{Na_{iw}}}{\sqrt{\mathrm{F_c} \cdot \mathrm{Mg_{iw}}}} \qquad \mathrm{ESAR} = \frac{\mathrm{F_c} \cdot \mathrm{Na_{iw}}}{\sqrt{\mathrm{F_c} \cdot (\mathrm{Mg_{iw}} + \mathrm{Ca_{iw}})}}$$

The boundaries can then be plotted on a graph, and the user (golf course superintendent etc.) can see how the SAR is expected to change as the soil EC increases. If the EC threshold is crossed before the SAR reaches 15, then simply managing the EC below the threshold will be sufficient – no sodicity management would be required (i.e. applying gypsum, acid injecting, etc.). The method is conservative, and data points falling outside of the LSAR and ESAR boundaries were extremely rare.

Summary Points:

- Proper assessment of irrigation water quality is critical for the golf industry
- Current sodicity indices are flawed and likely produce inaccurate estimates of sodicity hazard
- After irrigation is applied, the solution concentrates which changes the SAR of the soil water solution. We developed equations for two boundaries (a best case and a worst case scenario) that describe how the SAR is expected to change as the EC of the soil water solution increases.
- We studied the SAR/EC relationships of several rivers and found that the majority were bounded by the LSAR and ESAR boundaries as the water concentrated. Waters high in alkalinity tended toward the LSAR boundary, while waters low in alkalinity tended toward the ESAR.
- The LSAR is a simple, accurate, conservative estimate of sodicity hazard and should be favored over all existing sodicity indices in turfgrass management and agricultural production. We developed a spreadsheet that irrigation water laboratories or end users could use to follow our method.

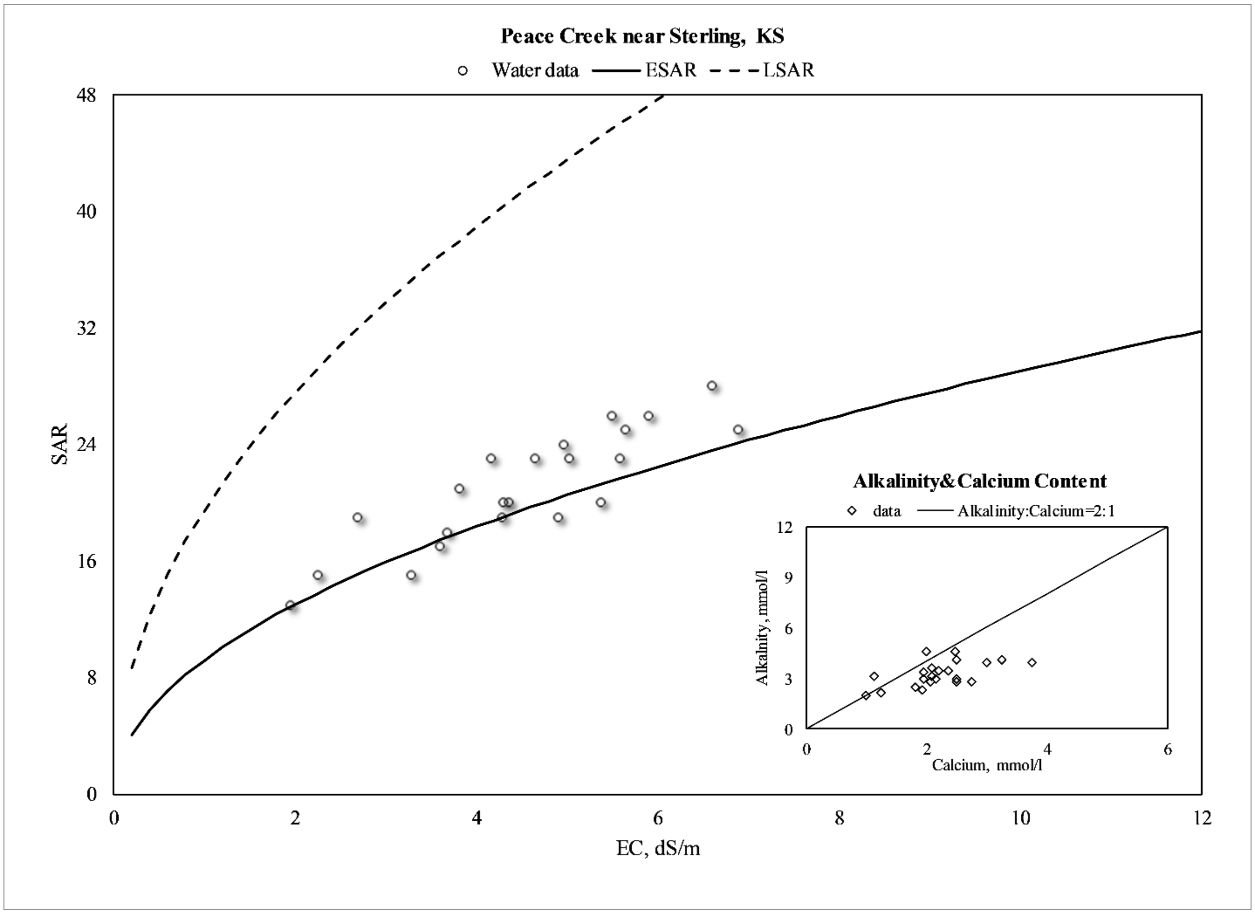

Figure 1. The SAR and EC relationship for the water in Peace Creek, near Sterling, KS. This water is low in alkalinity (alkalinity: Ca ratio <2) and therefore the water tends toward the ESAR boundary as the water concentrates from evaporation.

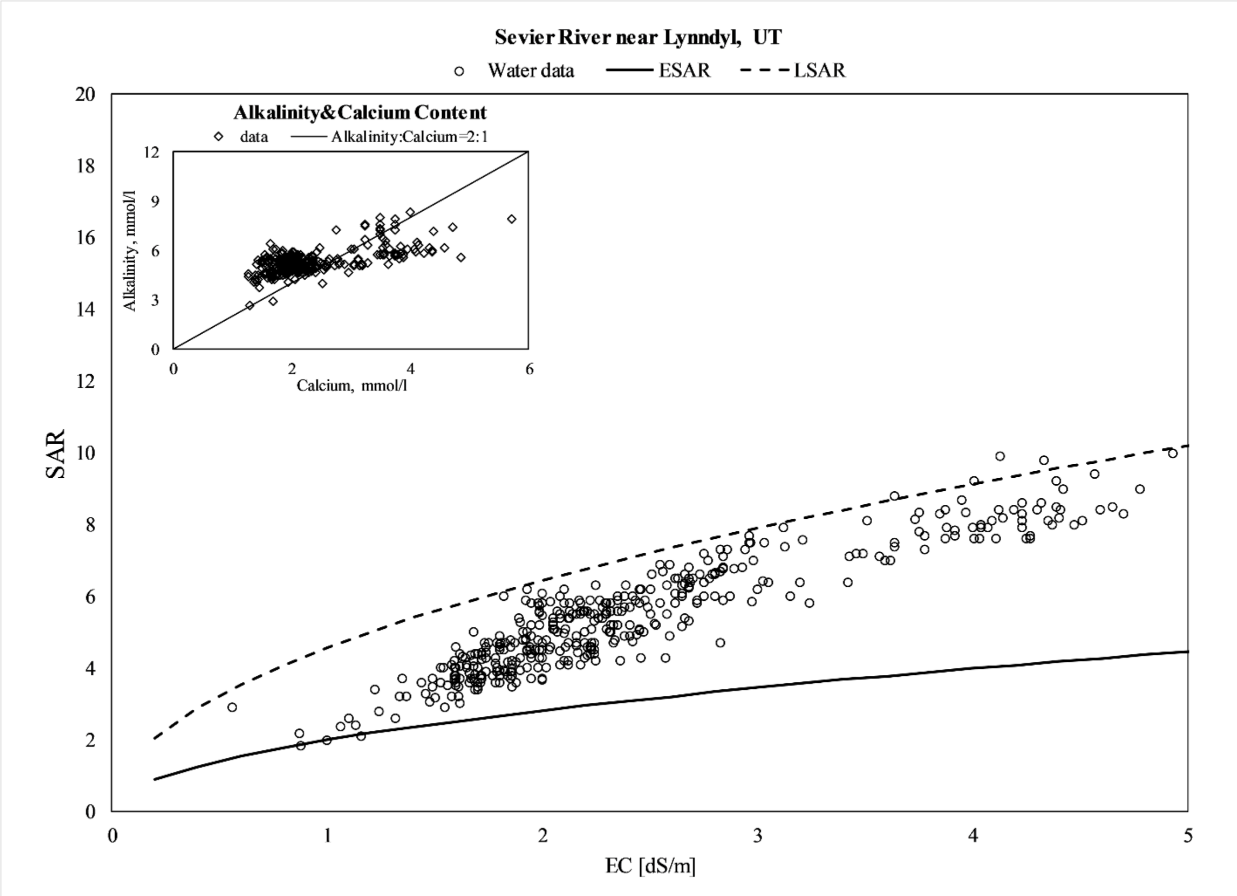

Figure 2. The SAR and EC relationship for the water in the Sevier River, near Lynndyl, UT. This water is high in alkalinity (alkalinity: Ca ratio often >2) and therefore the water tends toward the LSAR boundary as the water concentrates from evaporation.

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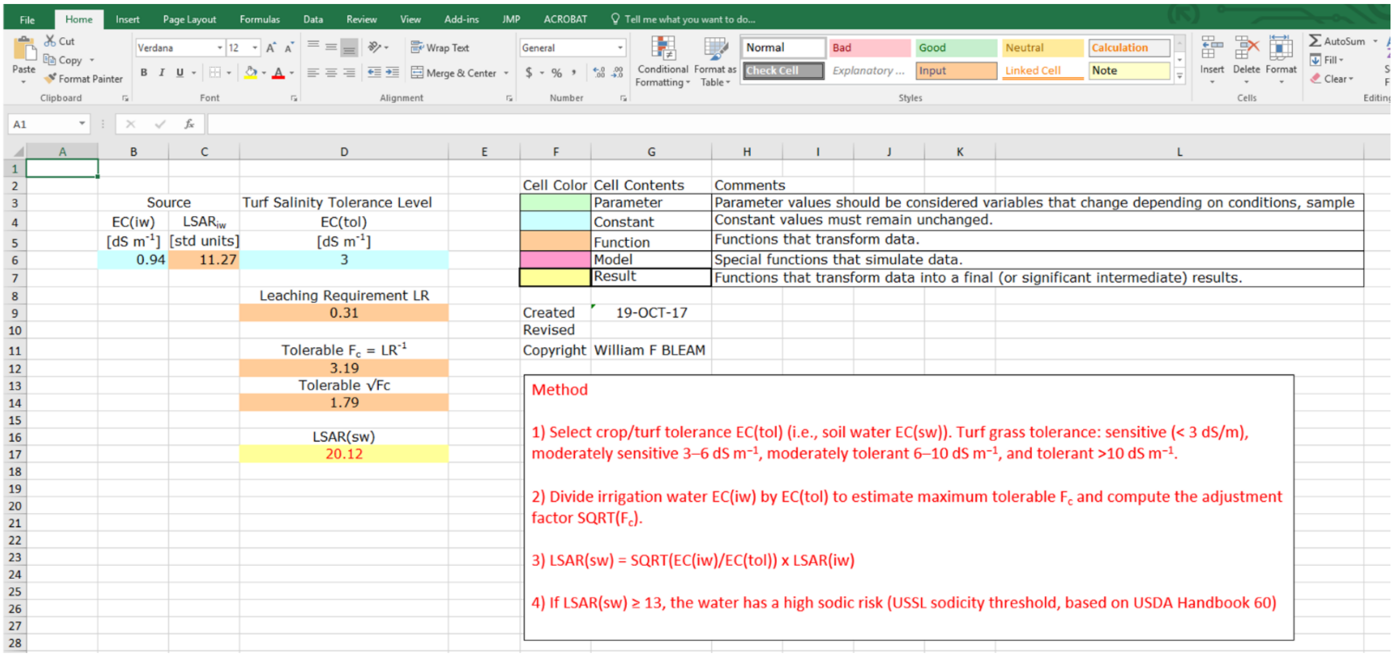

Figure 3. Screenshot of spreadsheet that predicts LSAR and ESAR for laboratories of end users.

2017-05-615

Title: Solvita® Soil Test Kits to Categorize Golf Course Fairway Responsiveness to Nitrogen Fertilization

Project Leader: Karl Guillard

Affiliation: University of Connecticut

Objectives of the Project:

Objective 1: Determine if Solvita® Soil CO_2-Burst and Soil Labile Amino N tests are correlated to bentgrass fairway turf quality, color, density, thatch accumulation, divot recovery, and traffic tolerance.

Objective 2: If test results are correlated to bentgrass fairway turf responses in Objective 1, then categorize the responsiveness to N fertilization as a function of Solvita® soil test results.

Start Date: 2017

Project Duration: 3 years

Total Funding: $90,000

Summary

Need for the Study:
The ability to predict the N mineralization potential of any turfgrass site and its expected response to N fertilization would be a valuable tool in nutrient management. Turfgrass soils often accumulate organic matter over time, and this increases their mineralization potential. However, assessing this mineralization potential is not routine due to the lack of mineralization tests offered with many labs, cost of the tests, and the long-term requirements (a week to months) of these tests for reliable results. Solvita & Woods End Laboratories offers two test kits that have been developed to rapidly measure the biologically-active C and N fractions in soil organic matter: the Soil CO_2-Burst (SCB) and Soil Labile Amino Nitrogen (SLAN) test kits. These labile C and N fractions are correlated to soil microbial activity, and therefore, the Solvita® soil tests should be able to estimate the mineralization potential of turfgrass soils.

Methods:
The study site is located in Storrs, CT with creeping bentgrass as the fairway species, and was initiated in August, 2017. The experiment was set out as a split-block design with traffic (with/without) as the horizontal factor and compost (10 rates, in 0.25-lb increments from 0 to 2.25 lbs available N per 1000ft^2) as the vertical factor with three replicates. Compost was incorporated throughout the 0 to 4-inch soil profile by rototilling. Beginning in 2018, an organic fertilizer will be applied to the compost plots at the same rates as the initial compost rates. In addition to the organic fertilizer treatments, a standard fertilizer regime treatment with 0.2 lbs

N 1000ft^{-2} will be applied every 21 days as urea in spring and summer and greater amounts applied in September and October, for a seasonal total of 2.45 lbs N 1000ft^{-2}, will serve as the standard fertilization treatment. The fall of 2017 will be used as the establishment period. Full implementation of the proposal treatments and data collection will begin in 2018.

Beginning in the spring 2018, turf response measurements (Visual Quality, NDVI, green cover, DGCI, clippings yield, clippings N concentration) and soil samples will be collected monthly from April to November from each plot. Soil samples will be analyzed using the Solvita® SCB and SLAN tests. Fairway performance will be determined by measuring thatch accumulation, divot recovery, and traffic tolerance. Turf responses and fairway performance measurements across the season will be correlated to the Solvita® soil test results to determine if any relationship exists between the variables using regression analyses. If correlations are found, binary logistic regression will be applied to determine the probability of response to N fertilization in relation to a given soil test value, using the standard N fertilization practice response as the benchmark value.

Results to Date:
The field study was initiated in August 2017. As of late November 2017, the plots are establishing well (percent green cover 90 to 94%). To date, there is no significant ($P > 0.05$) difference between treatments for NDVI (0.6297 to 0.656), hue (76.9 to 78.6), and DGCI (0.356 to 0.369).

Future Expectations:
If our hypothesis that the Solvita® soil test kits results are correlated to bentgrass fairway turf responses is valid, then golf course superintendents would be able to easily and quickly assess the mineralization potential of any fairway on their course. These tests will be site specific, and will give the superintendent an objective guidance for N fertilization. Using a more site-specific, objective means to guide N fertilization will maintain optimum turf quality and function, while reducing fertilizer costs, reducing turf loss due to certain N-related diseases, reducing the risk of water pollution caused by N losses, and reducing the greenhouse gas emission footprint (especially with N_2O) of the golf course by not applying N when it has a low probability of response due to high mineralization potential, or not applying the full rate of N when mineralization potential is moderate. The value of using the Solvita® soil test kits also would be seen on fairway areas where mineralization potential is low, and where they could benefit from N fertilizer applications. An additional advantage of the Solvita® soil test kits is that these could be conducted on-site by the superintendent, if desired, without the need to send samples to a laboratory.

Summary Points

- Compost has been applied and bentgrass seeded into plots.
- Bentgrass grow-in and establishment continuing on schedule.
- No significant differences in percent green cover, NDVI, hue, or DGCI during the grow-in period.

Figure 1. Compost application on plots prior to incorporation.

Figure 2. Incorporation of compost into plots.

Figure 3. Establishment of plots, 10 Nov. 2017. Plots seeded on 17 Aug. 2017.

2015-35-550

PROJECT TITLE:

National Evaluation of Turfgrass Water Use and Drought Resistance

PROJECT LEADER:

Kevin Morris, Executive Director
National Turfgrass Evaluation Program (NTEP)
BARC-West, Bldg. 005, Rm. 307
Beltsville, MD 20705

START DATE:

2016

PROJECT DURATION:

Four years

TOTAL FUNDING:

$400,000

SUMMARY TEXT:

With water restrictions becoming more commonplace, and with turfgrass being scrutinized for its water use, there is great need to highlight those cool and warm-season turf cultivars that use less water and are appropriate for golf course fairways, tees, roughs and other turf areas. Therefore, this project addresses that need to identify turfgrass cultivars that deliver high quality turf while using significantly less water. This trial, established at multiple locations nationwide, does the following: 1) measures the actual amount of water required to maintain a prescribed level of quality or green cover, and 2) documents the performance of cultivars under varying levels of reduced evapotransporation (ET_o) levels.

Rain exclusion shelters are used to simulate 100-day drought periods in higher rainfall regions. Under the rain exclusion shelters we measure the amount of water needed to maintain 50% green cover, rate turfgrass quality as well as evaluate recovery from drought when irrigation is resumed.

The drier climate ET_o-based sites evaluate performance at three deficit irrigation levels for 100-120 day periods. Data recorded includes percent green cover over time, turfgrass quality and recovery rate after sufficient irrigation is applied. The ET_o-based locations allow us to determine the minimum level of deficit irrigation appropriate for, and thus the water savings from each entry.

In separate trials, we will collect three years of data on cool-season and warm-season turfgrass entries at 8-10 trial locations each. This data will be used to develop and apply U.S. EPA WaterSense (http://www3.epa.gov/watersense/) certification (or another certification organization) label to grasses that qualify.

The cool-season trial entries submitted include nineteen tall fescues, fifteen Kentucky bluegrasses and one perennial ryegrass. In fall 2016 and spring 2017, these entries were established at ten locations, with five sites in higher rainfall regions utilizing a rain exclusion shelter, and five sites in low rainfall regions where irrigation is applied based on varying degrees of deficit ET replacement. Difficulties and delays in obtaining rain exclusion shelters, as well as developing irrigation infrastructure resulted in delayed plantings at some locations.

Of the ten locations planted, six were able to collect at least some data on drought response and recovery in 2017 (we agreed that the remaining four locations did not have test plots that were fully mature, and therefore not ready to apply drought stress). The locations that did not simulate drought in 2017 (Logan, UT; St. Paul, MN; Ft. Collins, CO; Amherst, MA), will initiate drought treatments in 2018.

The six cool-season trial locations that did initiate drought treatments in 2017 include Fayetteville, AR, College Park, MD, Griffin, GA and West Lafayette, IN (rain exclusion shelter sites); and Riverside, CA and Las Cruces, NM (deficit ET_o replacement sites). We are still receiving data from of these sites and thus far, have not produced 2017 results. However, we can make some inferences from the data we have received to date.

The ET_o-based site at Riverside, CA saw >95% grass loss in the 40% ET_o replacement treatment. We will evaluate these plots over the winter and spring to gauge if sufficient recovery occurs to warrant continuing the 40% ET_o replacement at this location. The 60% ET_o replacement level also saw some significant grass loss, and it will be interesting to see plant recovery, as well as each entry's ability to withstand this level of deficit irrigation in 2018.

At the Las Cruces, NM site, significant differences in drought resistance were noted among entries, as well as differences in recovery from drought. The 2017 data collected from rain exclusion shelter sites has not yet been analyzed, but our research cooperators indicate significant differences were noted in water needed to maintain green and consistent growth.

The warm-season version of this trial is currently in the planning stages, with ten trial locations identified, testing parameters being decided upon and establishment scheduled for late spring/summer 2018. Rain exclusion shelters and deficit irrigation infrastructure will be installed in 2018 with drought treatments initiating in 2019.

SUMMARY POINTS:

- Thirty-five total entries in the Cool-Season Water Use and Drought Resistance trial were planted at ten locations in fall 2016/spring 2017.
- Five locations, located in high rainfall regions, induce drought via a rain exclusion shelter, while the other five locations, located in low rainfall regions, induce drought by restricting ET_o replacement.
- Delays in obtaining and/or installing the needed infrastructure (either rain exclusion shelters or irrigation systems) prohibited the initiation of drought treatments at four locations.
- Drought treatments were initiated at six of the ten locations in 2017, with significant drought responses being noted among entries.
- The 40% ET_o replacement level resulted in >95% grass kill at the Riverside, CA location.
- A warm-season water use/drought trial is now being developed, with planting in spring or summer 2018 at ten trial sites.

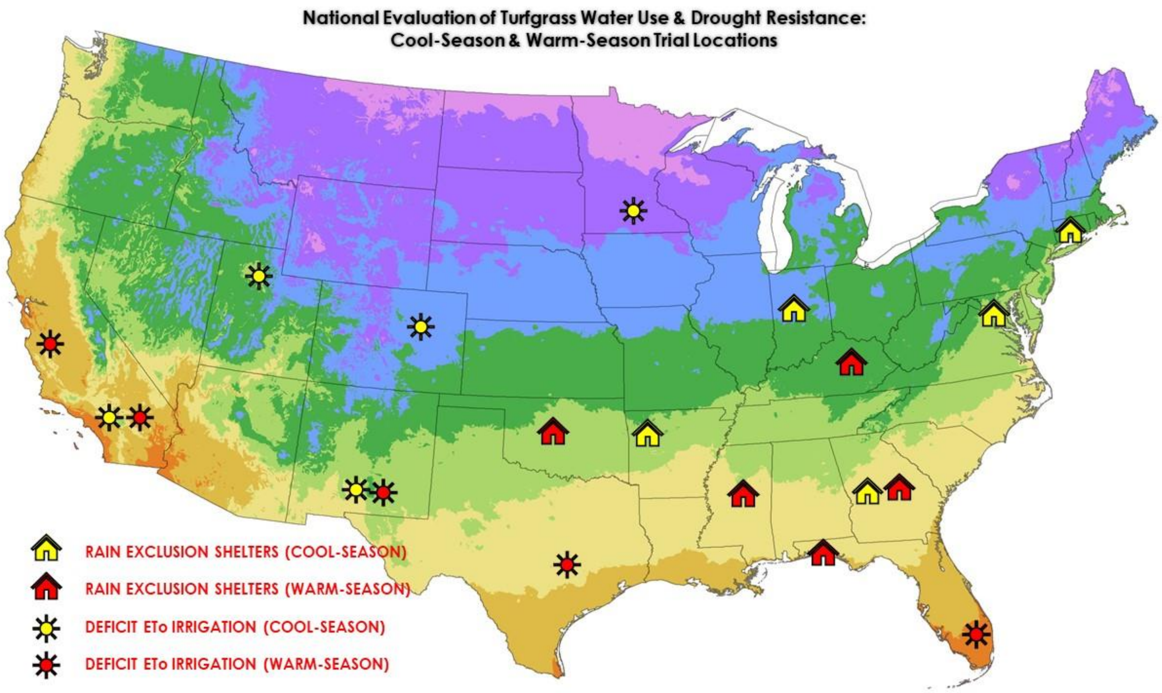

Figure 1. This trial is established at multiple locations nationwide to determine the actual amount of water required to maintain a prescribed level of turfgrass quality by documenting the performance of cultivars under various irrigation levels.

Figure 2. Rain-exclusion shelters are used to simulate 100-day drought periods in higher rainfall regions.

2016-08-558

Project Title: Assessing tree to grass water use ratios; Significance to the golf course industry

Project Leader: Dr. Dale Devitt

Affiliation: University of Nevada Las Vegas

Objectives of the project:

Research was undertaken to assess the water use rate of ten different mature landscape trees species relative to hybrid bermudagrass (C4 grass), bentgrass, perennial ryegrass and tall fescue (C3 grasses). The research was designed to address the following questions; 1)What are the water use rates of mature landscape trees growing in an arid environment? 2) What are the water use rates of these trees relative to morphological parameters that will allow such data to be scaled to other locations? 3)What are the water use trade-offs between tree species and turfgrass on an area basis?

Start Date: 2016

Project Duration: 3 years

Total Funding: $90,000

Summary Text

Water is a precious resource in the southwestern United States where population growth is placing greater demand on this finite resource. Water use in all sectors is being heavily scrutinized, with water users expected to maintain tight water budgets and implement as many water saving techniques as possible. It is estimated that 60 percent of all the water used in the Las Vegas valley is used in the residential sector, with 70% of that water used outdoors to irrigate urban landscapes. These landscapes are dominated by trees and turf grass and although much is known about the water use of turf grass species, little is known about the water use of landscape trees and therefore little is known about the tradeoffs between grasses and trees in urban landscapes. We are conducting a tree to grass water use ratio study focusing on ten common landscape tree species grown in the valley (mesquite, ash (Modesto and Arizona), desert willow, oak, Palo Verde, vitex, locust, elm and crepe myrtle) and four turf grass species (bermudagrass, bent grass, tall fescue and ryegrass). We are estimating water use by closing hydrologic balances on the trees (basins) and turf grass (lysimeters). We are also estimating transpiration of trees using Granier probes and estimating conductive tissue with a novel dye injection system. We will compare water use of all ten tree species with the four turf grass species and develop models that incorporate reference ET and morphological characteristics such as tree height, canopy volume, basal canopy area, LAI and leaf area. Observations are ongoing.

Hypotheses

1) In Southern Nevada, Mature landscape trees use more water than landscape grasses, based on tree basal canopy area. As such, tree to grass water use ratios will favor greater

removal of turfgrass to be equivalent to the water use of trees. Ratios will vary based on turfgrass species with cool season grasses such as tall fescue using significantly more water than warm season grasses such as bermudagrass.

2) Landscape tree morphological characteristics, such as height, basal canopy area, canopy volume, leaf area density and trunk diameter along with estimates of reference evapotranspiration (environmental demand) can be used to accurately estimate monthly and yearly actual evapotranspiration totals of tree species. However, the accuracy of these equations will be species dependent.

Results

Reference ET 12 month total = 156.6 cm
Tall Fescue ET 12 month total= 185.3 cm
Low fertility Bermuda grass ET 12 month total =106 cm (literature, Devitt et al.1992)
(Refer to Figure 1).

ET on a basal canopy area basis typically peaked during summer months and declined in fall and winter months with distinct separation on a species basis. (Refer to Figure 2).

When comparing tree and Bermuda grass ratios generated for Mesquite, Modesto Ash, and Crepe Myrtle ratios above one occurred for all species but the highest values were primarily confined to the fall and winter period. (Refer to Figure 3).

When similar ratios were generated for tall fescue fewer months had ratios above 1.0 with the highest ratio during January and February.

With the exception of Crepe Myrtle, tree grass water use ratios on a yearly basis always reflected lower water use for trees compared to grasses. This response indicated that smaller areas of turf grass would need to be removed to be equivalent to tree water use on a basal canopy area basis.

Research is ongoing including the analysis of the Thermal Dissipation Probe data and core dye analysis. Because of high mortality with bent grass and ryegrass during summer months, tree grass ratios will be confined to fall, winter, and spring periods for these grasses.

Summary Points

Water use of trees and grasses followed the basic bell shaped curve of reference ET for the Las Vegas area but variation occurred on a species basis.

On a basal canopy area basis all trees except Crepe Myrtle used less water than all 4 turfgrass species with greater differences occurring when the comparison was made with high water using tall fescue compared to low water using low fertility bermudagrass.

Variation in ET on a monthly basis could be described for some trees based on morphological parameters and reference ET but for some species the correlation was not significant.

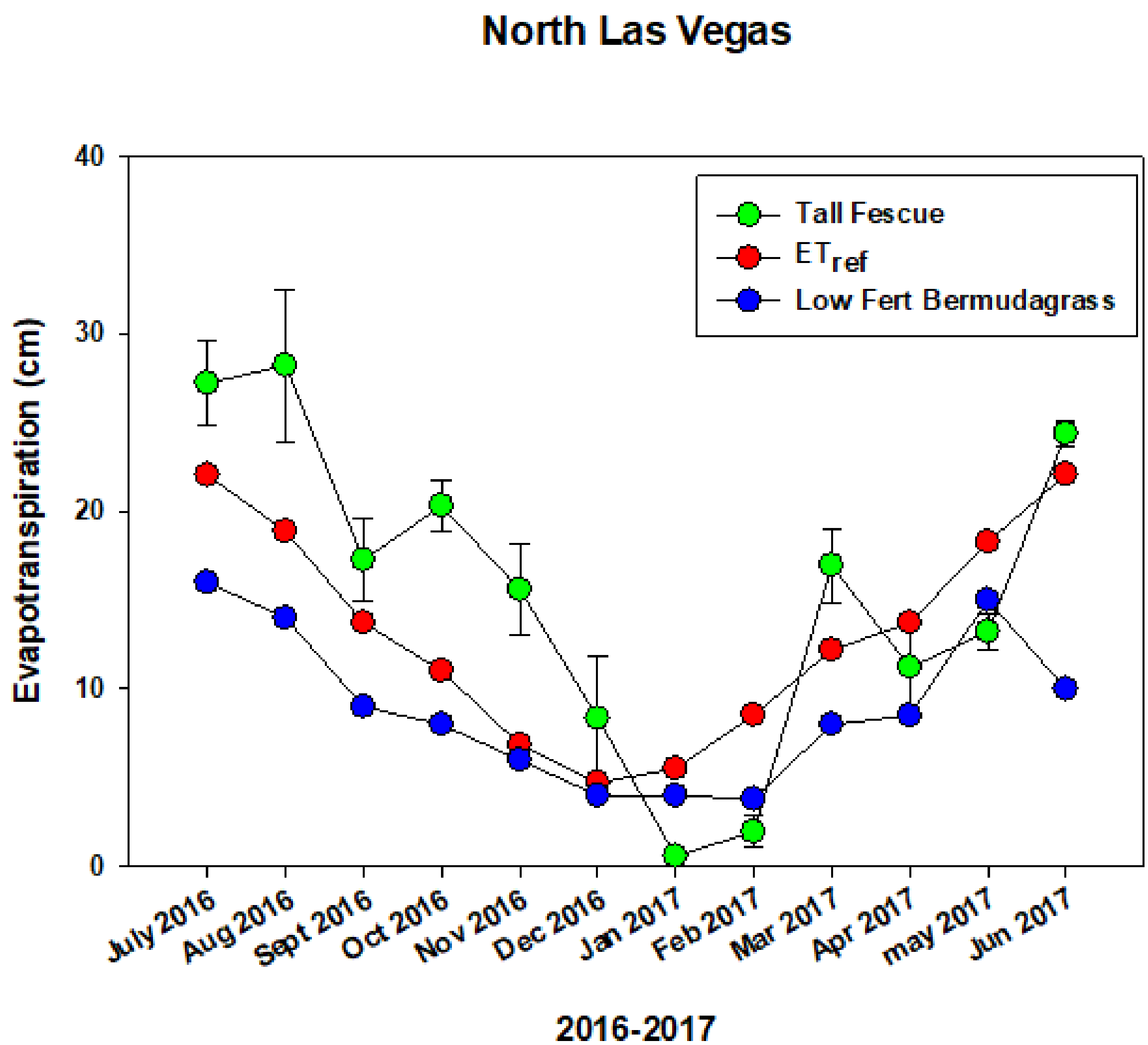

Figure 1. Evapotranspiration of tall fescue and bermudagrass, along with reference evapotranspiration over the 2016-2017 period.

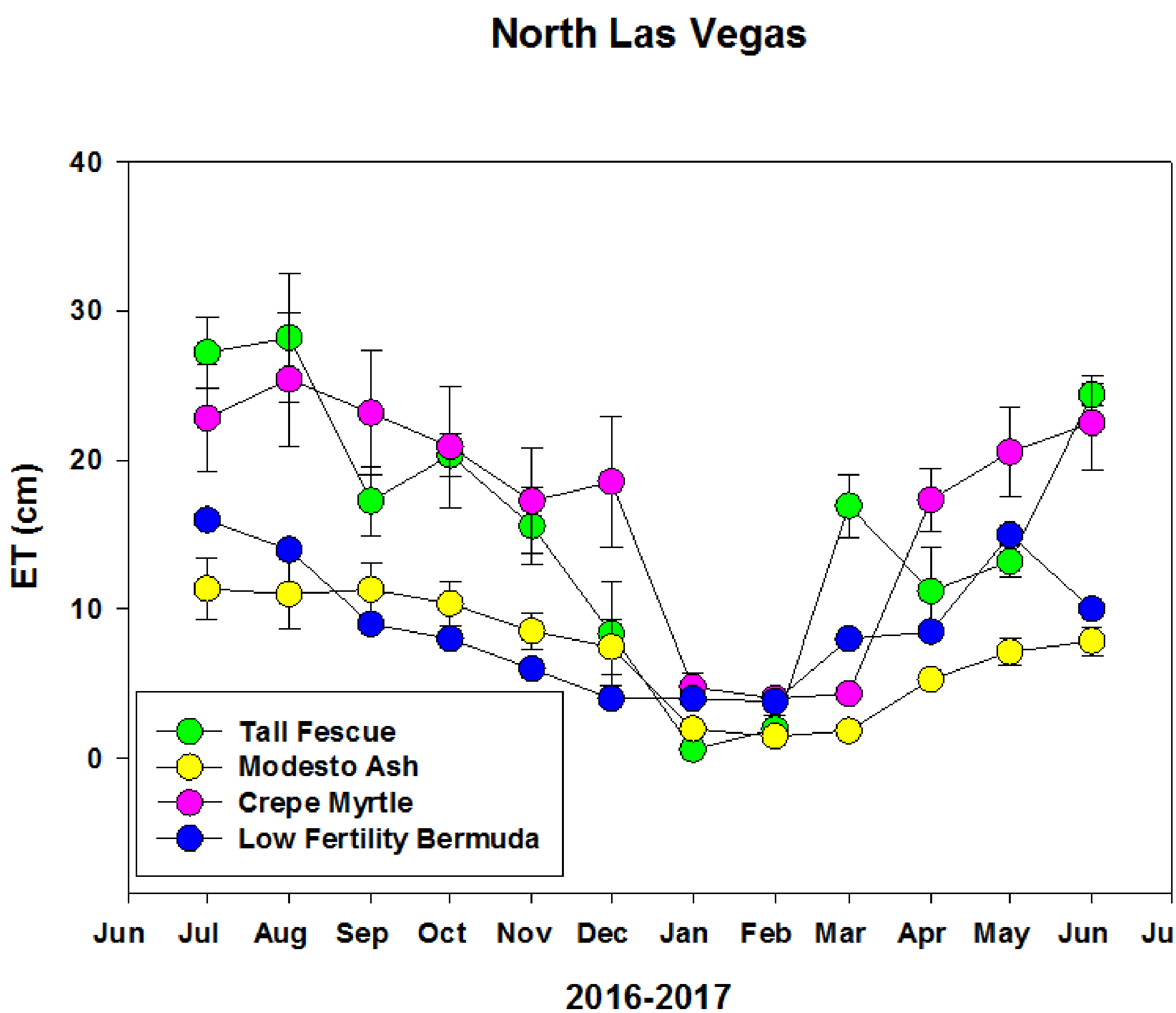

Figure 2. Evapotranspiration of tall fescue and bermudagrass with modesto ash and Crepe myrtle over the 2016-2017 period..

North Las Vegas

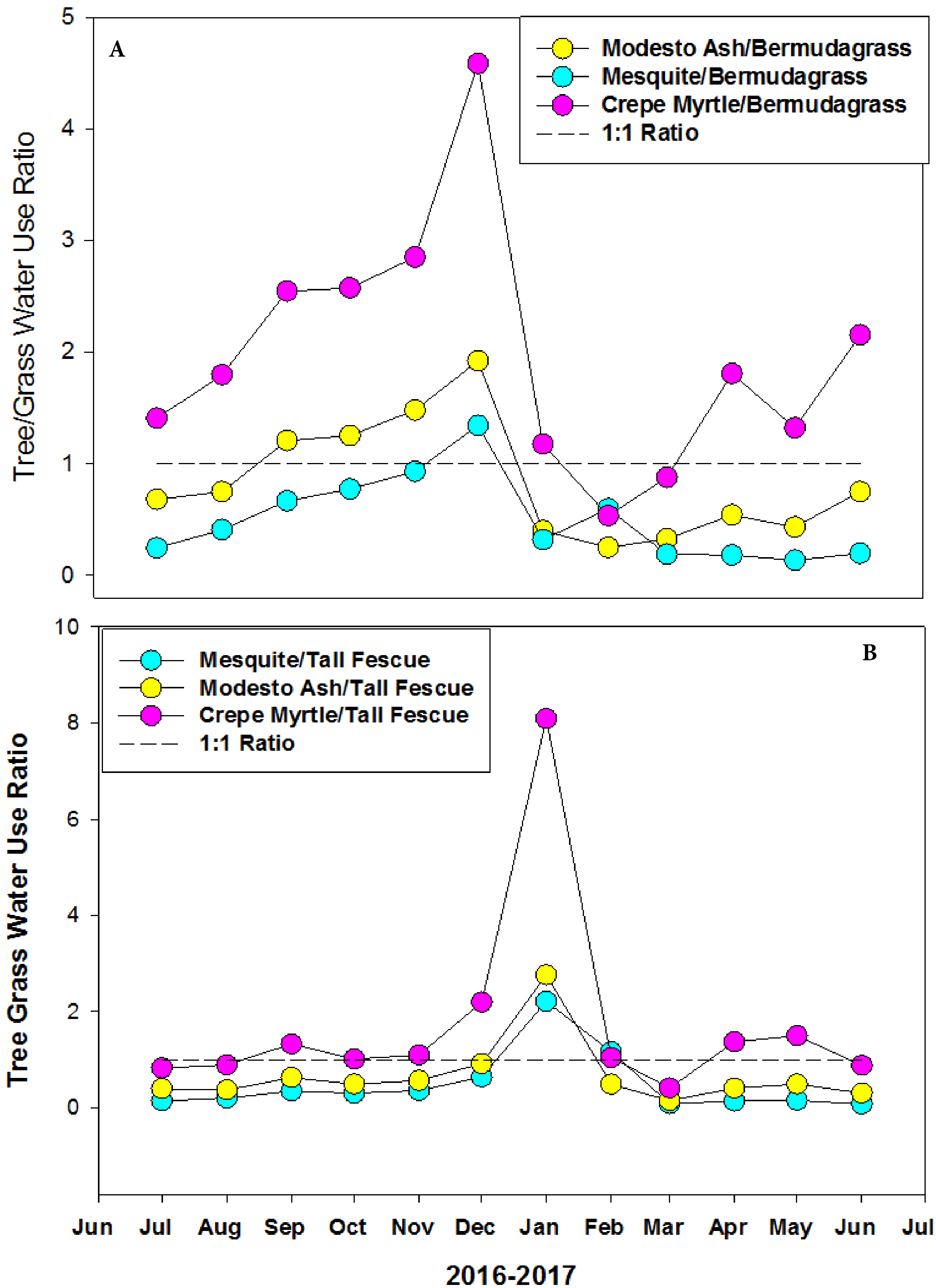

Figure 3. Tree/Turfgrass water use ratios comparing several tree species with bermudagrass (A) or tall fescue (B).

2017-01-611

Project Title: Effects of deficit irrigation and rootzone depth on water use and drought resistance of warm-season fairways.
Principal Investigators: Charles Fontanier and Justin Moss
Affiliation: Oklahoma State University

Objectives:

1. *Quantify water use of key turfgrasses as affected by deficit irrigation practices.*
2. *Evaluate the drought resistance of key turfgrasses as affected by rootzone depth.*
3. *Assess the effects of traffic on turfgrasses under drought stress caused by deficit irrigation programs.*

Start Date: 2017
Number of Years: 3
Total Funding: $90,000

<u>Background and Rationale</u>
Water used for turf irrigation has been considered the number one restriction to advancement of the game of golf in many regions of the United States. In some cases, reduction of total irrigated acreage can be utilized for immediate water savings. A more feasible approach for many superintendents is to reduce the quantity of water applied to the irrigated footprint. Fairways represent on average 38% of irrigated acreage on a golf course and are often irrigated in excess of turf minimum requirements (Lyman, 2012). Research aimed at developing targeted water conservation programs for fairway irrigation could create meaningful water savings in some regions of the country.
In mesic climates, irrigation should be applied as a supplement to rainfall and not in place of rainfall.

Modern irrigation practices typically rely on reference ET as calculated from meteorological data to estimate evaporative demand of the atmosphere. Warm-season turfgrass water use is then estimated as the product of reference ET and a crop coefficient of 0.6 to 0.7. Irrigation can then be scheduled to replace soil water lost through ET. Applying irrigation at volumes less than ETc is a common water conservation practice which attempts to maintain a target turf quality while reducing irrigation volumes. Many turfgrasses will demonstrate acceptable turf quality under deficit irrigation, although the severity of the program that sustains acceptable turf performance varies with species, cultivar, and soil/rooting properties (Feldhake et al., 1984; Poudel, 2010; Wherley et al., 2014). Research aimed at measuring the interactions of turf performance, plant water use rates, soil moisture content, rootzone depth, and traffic is warranted.

<u>Methods</u>
Completed: A field experiment is being conducted at the Turfgrass Research Center in Stillwater, OK, to measure turf water use rates as affected by cultivar and deficit irrigation program. Eight fairway-type grasses (U-3, Celebration, Tifway, Latitude 36, TifTuf, Meyer, PremierePro, and OSU 1403) were established from plugs in small plots

as a randomized complete block design with three replications. Grasses were planted in June 2017 and allowed to fully establish under non-limiting irrigation in Year 1.

To Be Completed: During winter 2017-18, access tubes will be installed for measurement of soil moisture using a soil profile sensor (PR2, Delta-T Devices). During year 2, cultivar main plots will be split by irrigation level (25, 40, 55, and 70% reference ET). Irrigation will be hand-applied once or twice per week using a nearby weather station to estimate reference ET. Turfgrass water use will then be calculated as the difference in soil moisture content between measurement dates. To assess how cultivar performance varies under the presence of restrictive rootzones, lysimeters (6-in and 12-in) will be installed within the same plots. Measurements of turf performance will be performed biweekly using turf quality ratings (NTEP methods) and NDVI.

A second experiment is being conducted at the OAES Research Station in Bixby, OK, to study the effects of traffic on irrigation water requirements of common fairway turfgrasses. Small plots will be established from plugs (TifTuf, U-3, Latitude 36, Celebration, Tifway, Meyer, OKC 1403, and OKC 1221) as a randomized complete block design having three replications. During the establishment period, a small–scale center pivot irrigation system will be designed and installed such that it creates an irrigation gradient moving from near the center (wet) to the outer edge (dry). An additional pivoting arm will be installed with golf cart wheels such that traffic can be simulated in a turning manner. NDVI sensors and infrared thermometers (Decagon Devices, Inc.) will be installed on the irrigation arm, while buried soil moisture sensors (Turf Guard, The Toro Co.) will monitor volumetric water content at a 3 to 4-inch depth.

<u>Early Results</u>

No data have been collected related to this project. Field plots at the Stillwater station were established as part of this first year. The Bixby project was delayed for one year due to issues with construction on the station. A preliminary design for the trafficker has been completed.

<u>Future Expectations</u>

Lysimeters and sensor access tubes will continue to be installed at the Stillwater station through winter. Construction of the center pivot / trafficker will begin in March 2018 with planting of plots to occur in April.

Summary Points:

- Field plots for a warm-season fairway deficit irrigation study have been established using seven commonly used cultivars and an OSU experimental bermudagrass.
- Research plots are being instrumented for soil moisture sensors and lysimeters during winter with irrigation treatments scheduled to be initiated in summer 2018.
- A preliminary design for an automated golf cart trafficker has been developed and initial construction is scheduled to begin in February 2018.

Fig. 1. An overview of the established fairway deficit irrigation plots in Nov 2017.

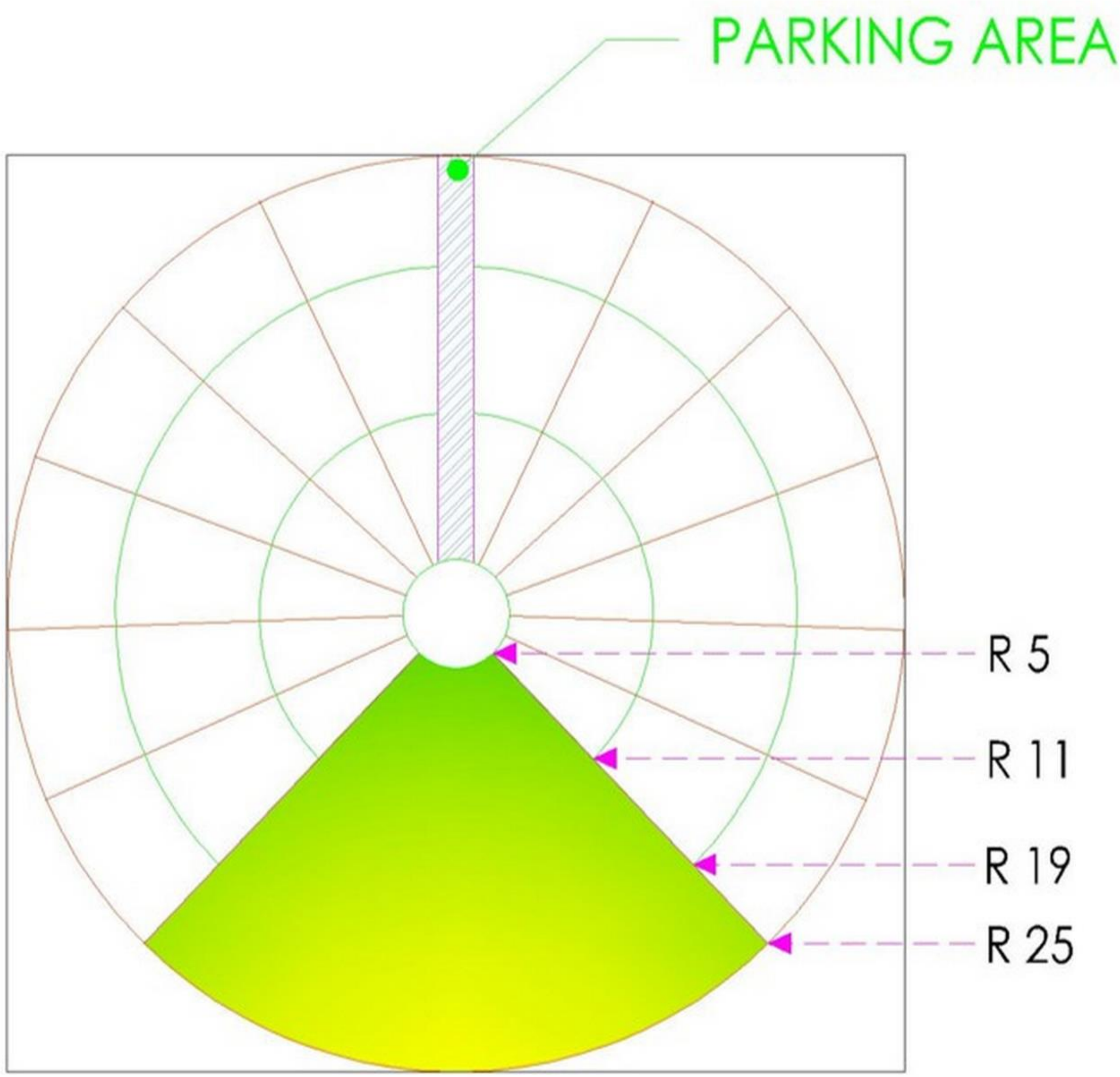

Fig. 2. Schematic of the proposed radial gradient irrigation system and trafficker.

2017-02-612

Project Title: Development of a remote sensing tool for golf course irrigation management: proof of concept.
Principal Leader: Charles Fontanier and Justin Moss
Affiliation: Oklahoma State University
Objectives:

The objective of this one-year project is to develop preliminary datasets which demonstrate the viability of thermal sensors for use in conjunction with unmanned aircraft systems (UAS) to monitor soil moisture stress of golf course fairways.

Start Date: 2017
Number of Years: 1
Total Funding: $10,000

Background and Rationale

Water used for turf irrigation is widely considered the number one restriction to advancement of the game of golf in many regions of the U.S. During periods of low rainfall, inefficiencies in irrigation systems and topography can result in significant soil moisture variability. Currently, visual cues and, to a lesser degree, soil moisture sensors are being used to trigger irrigation events. A rapid, whole-course assessment of plant water stress would be advantageous to superintendents who seek to maintain consistency from hole to hole. Further, quantitative estimates of plant water stress have the advantage of bypassing any potential variability associated with soil or rooting depth. Several technologies have become available which allow for plant stress to be remotely sensed. Among the more commonly used are RGB-visible cameras, multi-spectral reflectance sensors, and thermal cameras. To date, these technologies remain cost-prohibitive for many situations. Furthermore, how to incorporate remote sensing into current BMP's is not well understood.

Soil moisture sensors have become increasingly popular among golf course superintendents as cost has declined and user-friendly interfaces have been developed. It is reasonable to predict that remote sensing with multi-spectral or thermal sensors will similarly become more feasible in the future. Availability of guidelines for proper site selection, installation, and use of new technologies will be critical to initial adoption and long-term success of these precision turfgrass management tools. In this project, we have developed a small-scale remote sensing system which utilizes an unmanned aerial system (UAS) and thermal camera to measure turfgrass water stress as predicted by surface temperature.

Methods

In the first phase (proof of concept), we have integrated a thermal camera (Zenmuse XTR) with a UAS (DJI Inspire 1 v.2.0) and gathered preliminary data from a Riviera bermudagrass research plots (Fig 1) mowed three times per week at 0.5-in. Plots were subjected to one of four irrigation levels (0, 33, 66, 100% ET_c) from Aug 1 through Sept 24, 2017. Irrigation was hand-applied using a calibrated hose-end nozzle onto 4-ft by 4-ft square plots randomly assigned across the field in order to mimic random soil drying that might occur on a golf course fairway. Surface temperature data from the UAS was compared to ground-based measurement of soil moisture (Pogo, Stevens Water Monitoring Systems), NDVI (Greenseeker, Trimble Ag), and turf quality (NTEP Scale). Ambient temperature and accumulated solar radiation were also measured by a nearby weather station.

Early Results

Due to delays in obtaining the UAS system and significant rainfall in August, we were unable to develop a complete dataset from an extended drought period. Preliminary data show reasonable correspondence between UAS canopy temperature and ground-based canopy temperature. Relationships between UAS canopy temperature and soil water content and NDVI are less strong, presumably because of lack of significant drought severity. Further analysis of ambient weather conditions and sensitivity of the measurements is still needed.

Future Expectations

In 2018, data will be collected from irrigation studies at the experiment station to reach a more severe drought stress. Measurements will also be taken at two golf courses in the area. These data will provide a more complete view of feasibility of the system and major pitfalls needing further research.

A secondary goal of this project is to provide valuable preliminary data and equipment to pursue federal, state, or private funding in the future. The PI has initiated discussions with research faculty in other departments and universities to advance these ideas for development of a multi-state collaborative effort.

Summary Points:

- A DJI Inspire 1 v2.0 UAS was purchased and implemented with a Zenmuse XTR thermal camera.
- The UAS plus thermal camera system was able to detect differences in canopy temperature that correlated with ground-based measurements.
- Heavy rainfall in August did not allow for further data collection on golf courses or other sites in 2017.
- A multi-disciplinary research team is being assembled to conduct a more intensive investigation of remote sensing for turf management.

Fig 1. Riviera bermudagrass field used for evaluation of UAS – thermal camera system.

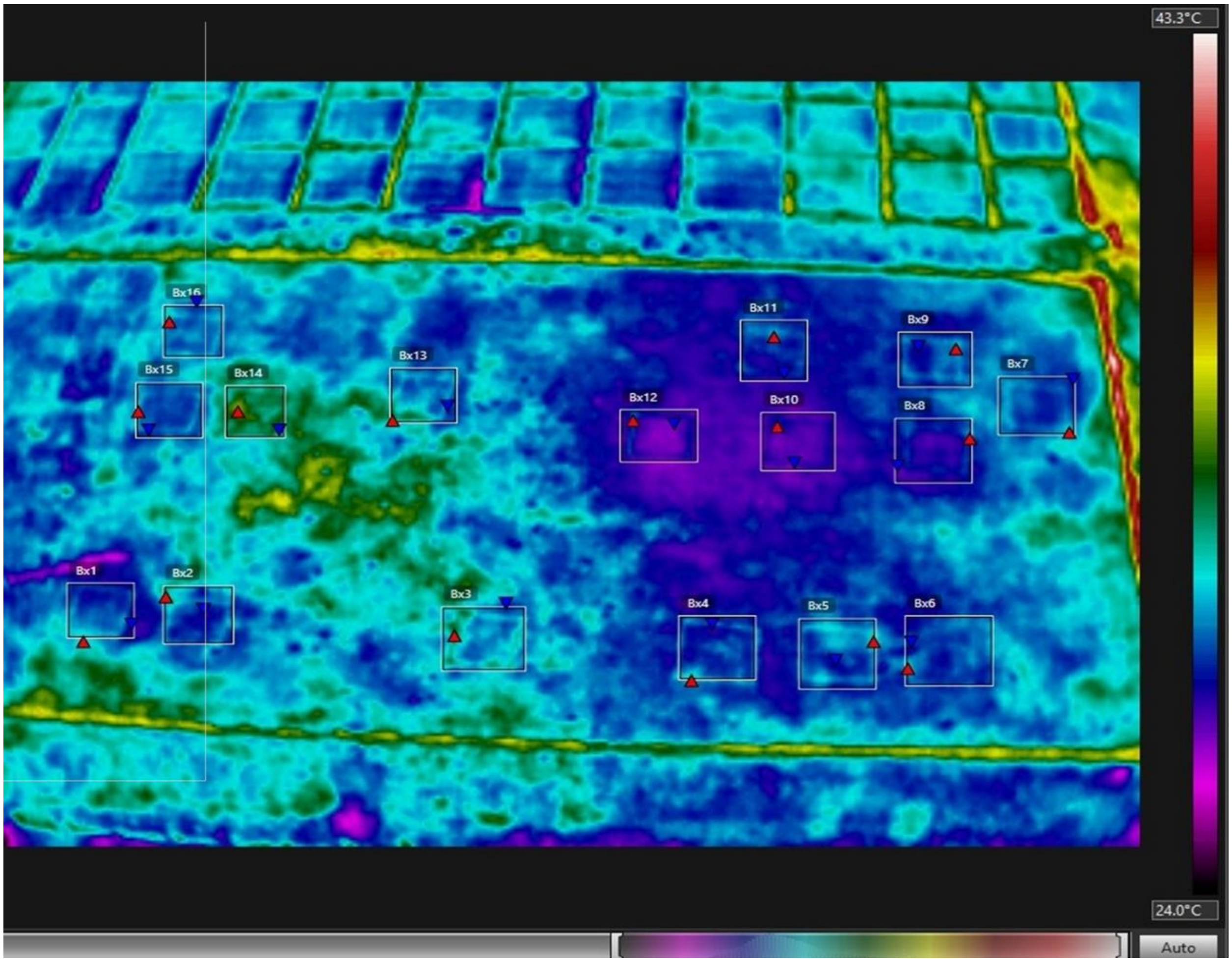

Fig 2. Thermal image collected from Riviera bermudagrass undergoing 4 irrigation treatments. Significant rainfall during August limited drought stress during data collection period.

2017-17-627

Title: Satellite-Based Estimation of Actual Evapotranspiration of Golf Course Cool-Season Turf

Project Leaders: Lawrence Hipps, Alfonso Torres, and Roger Kjelgren

Affiliation: Utah State University

Objectives: The general goal of this study is to acquire a high-quality data set for ET of turfgrass on a golf course, and use it to test several remote sensing based ET models, as well as improve understanding of how turf ET responds to changes in climate conditions. Specific objectives are:

1. Conduct eddy covariance measurements of the flux of water vapor and energy balance of a golf course over multiple years, to get hourly, daily and seasonal water use values. Use findings to test currently used simplistic ET approaches such as reference ET.
2. Apply several remote sensing approaches to estimate ET, and validate their performance against ground-based measurements. These include the Triangle Method and USDA-ARS Data Fusion approach. Examine their utility to estimate irrigation requirements.
3. Combine the surface energy balance measurements with theoretical knowledge to determine the relative importance of available radiation energy, atmospheric humidity and advection of heat from drier surrounding lands on the water use of turf.

Start Date: 2017
Projects Duration: Three years
Total Funding: $89,861.72

Summary Text:
Rationale
Turfgrass is the most widely irrigated managed plant system in the U.S. Irrigated turf landscape provides benefits such as sports surfaces, visual design, and mitigating urban heat islands. Golf courses in particular offer recreation, design aesthetics, and environmental cooling. Population growth and recent droughts amplified by climate change pose a critical need for more efficient irrigation in urban landscapes, particularly, but not exclusively, in the West. Golf courses have historically been proactive in addressing efficient irrigation in terms of amount and timing. But a robust and rigorously validated system for assessing actual turf water use and requirements has not been developed. The historical "black box" approach to estimate water use or evapotranspiration (ET) involves estimating a "reference ET" value (ET0), which is then multiplied by an empirical factor (kc). However, these empirical "black box" values are not extensively studied nor validated for turfgrass, so turf water use estimates from ETo ⍰ kc are not robust and rigorous. Limited water resources and more precise management of irrigation requires a more robust approach to quantifying actual water used by turf in golf courses as well as other turf surfaces.

Current State of Knowledge
Operational satellite imagery and recent advances in remote sensing-based ET models provide an opportunity to determine spatial distribution of daily ET for turf surfaces such as golf courses. Much of this began with the Triangle Method described in Carlson (2007), which uses data from several wavebands of radiation including thermal. This approach was tested in a preliminary study by USU for a region that included the Eagle Lake golf course near Layton, UT. ET estimates for the golf course were compared with measurements of actual ET made at the site by USU. Results were excellent, agreeing with ground-based values to within about 5%. Notice the 30 m elements display spatial variability on the

golf course. However, more evaluation is needed to assess the operational utility and accuracy of the method.

Recently, the USDA-ARS developed a suite of algorithms comprising a satellite “data fusion” ET model, described in for example, Semmens et al. (2015). Data sources include hourly data from the GOES satellite, daily data from the Modis platform, and Landsat overpasses at 8 or 16 day intervals. Physically based models simulate ET at the course scales. These are then downscaled to 30 m ET values. It has been tested and validated for a number of land surfaces, but not yet for urban landscapes nor turfgrass.

Methods

ET Measurements

The State of Utah funded USU to install an eddy covariance system on the Eagle Lake golf course in Layton, UT. The station has a sonic anemometer, an open path sensor for water vapor and CO2 densities, net radiometer, and soil heat flux sensors. The resulting ET flux estimates come from a footprint ~ 250 to 300 m of turf upwind of the sensors. Few trees are located upwind, and none near the station.

Eddy Covariance ET Measurements

This is the “gold standard” for determining the exchanges of mass and energy between surfaces and the atmosphere, and based on the definition that turbulence flux is the covariance of any property with the vertical wind. For example, the water vapor flux is the covariance of vertical wind and humidity.

$$E = Covariance(vertical\ wind, water\ vapor\ density) \qquad (1)$$

Similarly, heat flux is covariance of vertical wind and air temperature. Small turbulence structures require measurements at a high frequency (~20 times per second). Additional analyses are later required. Spikes, bad, and missing data must be identified, removed and gap filled. Other corrections are listed in Massman and Lee (2002). In addition, various time series analyses are used to find appropriate averaging periods, and verify measured turbulence conforms to known laws. Finally, the energy of heat and water vapor fluxes is compared to available energy (net radiation minus soil heat flux). When the ratio is too low (under ~85%) established scientific practice adds to fluxes to match available energy. This is an independent check of the reliability of the flux estimates. The above methodology will result in ET values for the golf course for the appropriate averaging periods, usually about one hour. These can be summed to yield daily, weekly and seasonal totals. The proposed graduate student for this project will conduct the eddy covariance measurements and perform the additional analyses under advisement of Dr. Hipps.

The final ET values will be used to check the reliability and quantify errors of the commonly used reference ET and empirical kc approach over a range of conditions. Also, analyses will determine the relative importance of radiation vs. atmospheric humidity and transport of heat from the surroundings on the ET of the turf. This will document how the turf ET responds to variations in weather and climate.

Remote Sensing

The Triangle Method shown above, will be further tested these studies. It can only yield high spatial resolution data every Landsat overpass, but uses nearly daily Modis data, but at 1 km resolution.

The other more substantial approach will be the suite of data fusion models by the USDA-ARS Hydrology and Remote Sensing Laboratory (Semmens et al., 2015). Starting with hourly data from the GOES satellite, the models use surface temperature changes and atmospheric thermodynamics to calculate ET at 4 km resolution. Higher spatial resolution is achieved combining Modis (daily, 1 km thermal) and Landsat (16 days, 100 m thermal) platforms. A downscaling algorithm increases the resolution of the Modis down to the Landsat value, later sharpened to 30 m. Then a two source model simulates transpiration and soil evaporation. The ET value is then integrated to a daily value using several well-known methods. The PI has a long relationship with the ARS developers, and they have already formally agreed to help USU utilize the models for this study.

Both the triangle method and data fusion approach will be tested during the irrigation seasons for the region shown earlier that includes the golf course. Models will be run for a set of days spanning the season. The ET values for days with no satellite data (2-4 overpass days of data per week), will be filled in using known physical relationships that are refined for the region. The results will then be compared to the eddy covariance measurements, and examined to observe any relationships between the fidelity of the model estimates and various environmental conditions. The graduate student will work with Dr. Torres-Rua to especially on the image processing, and with both PIs on the validation.

References

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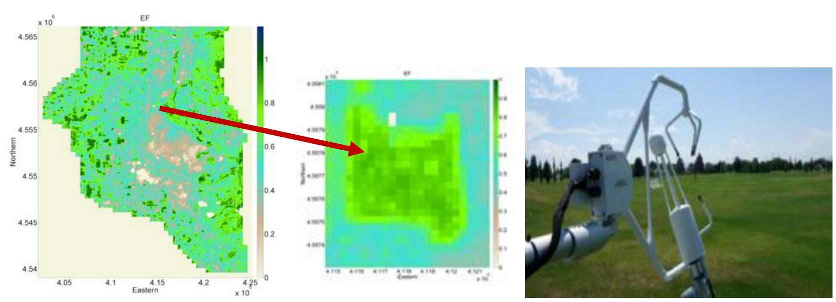

ET SLC Suburbs | Golf Course Daily ET = **0.16 in day^{-1}** | Measured ET = **0.17 in day^{-1}**

Figure 1. A preliminary study by USU for a region that included the Eagle Lake golf course near Layton, UT. ET estimates for the golf course were compared with measurements of actual ET made at the site by USU. Results were excellent, agreeing with ground-based values to within about 5%. Notice the 30 m elements display spatial variability on the golf course. However, more evaluation is needed to assess the operational utility and accuracy of the method.

2017-36-646

Title: Soil Moisture Sensor Irrigation Scheduling in Bermudagrass [*Cynodon dactylon* (L.)] Fairways

Project Leader: Priti Saxena

Affiliation: California State Polytechnic University, Pomona, CA

Objective:
The study is aimed to identify SMS systems that could reduce the number of irrigation cycles or amount of water applied while maintaining acceptable turfgrass quality, as compared to traditional time-based irrigation scheduling on fairways.

Start Date: 2017
Project Duration: Three years
Total Funding: $30,000

Summary text:
Twelve plots of 3 m x 3m hybrid bermudagrass GN-1 plots would be used. Treatments are three soil moisture sensors (SMS) and one control. The design of the study is a randomized complete block.
The study would be started with all plots at similar water content. Main Study Data Collection would be conducted during May – October 2018 and 2019. The parameters are Runtime for each plot and treatment average (by week, month, season), Irrigation applied for each plot and treatment average (by week, month, season), For SMS treatments, number of irrigation events that are bypassed or allowed (by week, month, season), For SMS treatments, amount of saved applied irrigation (actual amount and as a percentage of no SMS control treatment), Visual turfgrass quality and color ratings taken once every four weeks, Soil salinity (bulk electrical conductivity) measured on a continuous basis and summarized, and Soil water content measured on a continuous basis and summarized. ETo precipitation and other climatic data will be accessed from CIMIS station #78 based, about 0.25 miles from the test site.

The results would be expected to provide amount of irrigation applied for all the treatments, along with water savings for the SMS treatments. Water savings calculations will be based on the control treatment and SMS response compared to research grade soil moisture sensors will also be reported. The bermudagrass turfgrass quality rating also be collected and analyzed.

Soil Moisture Sensor Installation:
Toro Turfguard sensors were installed in Bermudagrass plots on Nov 20th, 2017. Sensors were installed in three randomly selected plots. Before the installation, sensors were activated and registered on Toro SMRT Logic Cloud. Toro SiteVision™ software was installed in the office computer to access the data from the cloud. The sensors were placed in the center of each plot using cup cutter. Turfguard sensors were placed at 3 inch depth, measured from the top of the turf surface to the top of the SMS unit housing. The probes of the sensors were pressed into the sidewall of the hole to ensure contact with undisturbed soil. After the installation, holes were filled and turf plugs were placed back. One of the two Toro Turf Guard® Wireless Repeaters was wired to a power source and installed on the exterior metal wall of the shed at 10 feet height on the field and other repeater was wired inside the office (approx. 100 ft. far from the plots) to facilitate the signals. Research grade golf course-oriented SMS from Rain Bird (wired) and Tucor (wireless) will be installed in the first week of January.

Turfgrass Management:

Bermudagrass plots were double cut in opposing directions using a Tru-Cut walk behind reel mower at a 1” height and clippings were removed from the plots. Glyphosate was spot-sprayed utilizing a Solo® 3-gallon backpack sprayer at a rate of 1 oz/ gallon to eradicate broadleaf weeds between rows. SpeedZone Southern® Boradleaf Herbicide was applied on the plots @ 1.5 oz /1000 sq. ft for the post emergent control of broadleaf weeds. Currently, Irrigation is applied at 80% ETo, one day per week.

2017-37-647

Title: Encouraging adoption of precision irrigation technology through on-course application and demonstration of water savings

Project Leaders: Josh Friell[1], Brian Horgan[2], Sam Bauer[2], and Chase Straw[2]

Affiliation: [1]The Toro Company, [2]University of Minnesota

Objectives:

1. Quantify response of turf and course conditions to changes in plant available water.
2. Quantify changes in water consumption, relative to typical practices, due to implementation of ET-based and soil moisture sensor-based irrigation scheduling.

Start Date: 2018
Projects Duration: Three years
Total Funding: $204,876

Introduction

The golf industry is under increasing pressure to improve environmental impacts and operate with smaller budgets and fewer resources. As such, it seems natural that turf managers should find benefit in adopting precision management practices and tools. Indeed, precision management, sometimes referred to as site-specific management, has become increasingly studied for turfgrass applications and has been adapted from concepts in precision agriculture (Krum et al., 2010). A wide variety of tools exist to implement precision irrigation including soil moisture sensors (SMS), optical sensors, spectrometers, electrical conductivity sensors, electromagnetic sensors, multi-sensor platforms, and many others. Use of in-ground soil moisture sensors to schedule irrigation has been shown to reduce water use by up to 74 percent (McCready et al., 2009) and, despite common misconceptions, greater benefits are typically found in wetter climates (Dukes, 2012). Evapotranspiration (ET)-based irrigation scheduling has also been identified as a potential means of reducing water use; however, changes in water consumption have been more variable ranging from 62 percent decrease (McCready et al., 2009) to 68 percent increase (Devitt et al., 2008).Increases in water consumption are often due to the use of off-site reference ET values, which may overestimate ET relative to actual on-site values and lead to overapplication of water (Vasanth, 2008).

Although the majority of work in this area has been conducted on home lawns with residential-type sensors and control systems, irrigated fairways occupy an average of 28 acres on golf courses in the United States and represent significant potential for water savings. Still, our experience and data to date suggests that adoption rates of precision management technologies by the golf industry has been slow with just 33 percent and 4 percent of courses using hand-held and in-ground soil moisture sensors, respectively, and 18 percent using on-site weather stations to inform irrigation scheduling (Golf Course Superintendents Association of America, 2015). The lack of adoption of precision management technologies on golf courses is likely due to a combination of factors, including perceived technical barriers and difficulty of use, up-front equipment costs, and logistical issues such as uncertainty around sensors. As a result, precision management has not, in practice, achieved the level of results that theory would indicate are possible. Therefore, the long-term goals of this research are to encourage increased adoption, acceptance, and regular application of precision management tools and practices for golf course irrigation thereby reducing material, time, and labor inputs, and minimizing economic costs of management.

We propose to conduct applied research on precision management technologies and practices for golf course irrigation. Our intent is conduct an on-course case study to demonstrate that adoption of currently available technologies can provide golf course superintendents with appropriate, actionable information and can result in significant water and cost savings as compared to traditional irrigation scheduling methods. We will show that, given the diversity of technology currently available, golf courses of varying sizes, types, and budgets have multiple options to adopt data-driven irrigation practices and create meaningful change. We propose to study this by comparing frequency-, ET-, and soil moisture sensor-based irrigation scheduling methods for golf course fairways. We hypothesize that ET-based irrigation scheduling can provide a low-cost means of implementing site-specific irrigation practices and generate positive water and cost savings on a golf course. Further, we hypothesize that by implementing mobile sensor and geographic information system (GIS) technology to properly place in-ground soil moisture sensors, golf courses can realize even greater savings.

Research Methods

Experimental Setup

This research will be conducted at Brackets Crossing Country Club in Lakeville, MN (20 miles south of the Twin Cities). Initial surveys using the Precision Sense™ 6000 will be conducted in fall 2017 to gain a fundamental understanding of spatial variability at the research site and aid in experimental design. In spring 2018, georeferenced data including soil moisture and salinity, penetration resistance, and NDVI will be collected across the entire golf course using the Toro Precision Sense 6000 mobile sensor platform. Data will be collected and analyzed under a variety of conditions including immediately following a saturating rainfall, 1 to 2 d after that rainfall, and after an irrigation cycle. Remotely sensed multispectral imagery will also be collected using a UAS-mounted camera at the same time as each Precision Sense survey. Precision Sense data will be spatially analyzed using ordinary kriging as implemented in a combination of existing scripts for ArcGIS and R. The results of each analysis will be a spatially interpolated map of each response variable.

Using the data collected following a saturating rain, nine fairways will be selected that have similar mean and spatial variability of soil moisture. Those nine will be placed into groups of three that will be used as replications for treatments in Objective 3. One fairway from each replicate block will be assigned a SMS-based irrigation scheduling treatment. Georeferenced data from the Precision Sense survey will be used to create irrigation management zones around each sprinkler head and each management zone will be assigned to one of three or four soil moisture classes based on mean soil moisture value (Fig. 1). We will ensure that each fairway chosen contains zones representing each of the defined moisture classes. Results of the zoning process will be used to direct soil moisture sensor positioning. We will select representative location for each moisture class on each fairway at which Toro TurfGuard in-ground soil moisture sensors will be installed with the top tines at a depth of 2.5 inches. The sensors will be set to collect data every 5-10 min and monitored over time. At least one and no more than three sensors for each moisture class will be installed on each of the three fairways receiving the SMS-based treatment. Although only one sensor per moisture class will be used for scheduling irrigation cycles, the additional sensors will be used to verify that other areas representing the same moisture class exhibit similar trends in volumetric water content over time.

Soil core samples will be collected from the location of each sensor to be used in irrigation scheduling decisions for each moisture class on each fairway and fully characterized for particle size distribution, bulk density, organic matter, and soil water retention characteristics using standard lab methods. In addition, results of the initial mapping process will be used to direct soil sampling in order to fully characterize the contributions of soil physical properties, organic matter, and irrigation system distribution and performance to observed soil moisture distributions. Hourly precipitation and ET will be recorded using an on-site weather station and any changes in the relationship between ET, precipitation, and changes in VWC will be analyzed over time.

Objective 1: Quantify response of turf and course conditions to changes in plant available water.
Following a settling-in period of at least 30 d during which typical irrigation practices will be followed, fairways with soil moisture sensors installed will be irrigated to near saturation and a dry down will be initiated. Volumetric water content during the initial irrigation and dry down will be recorded using the installed soil moisture sensors. Aerial imagery (RGB and NDVI) and visual assessments of the turf canopy will be collected once per week. The Precision Sense mobile sensor platform will be used to collect georeferenced NDVI as well as soil moisture, salinity, and penetration resistance on those three fairways three times per week during the dry down. Hourly reference ET and precipitation will also be recorded during the dry down event using local weather station data. Using recorded VWC, aerial imagery, and NDVI data, VWC values corresponding to field capacity (FC) and permanent wilt point (PWP) will be determined for each installed soil moisture sensor. Field capacity will be determined as the stable VWC value following the initial saturating irrigation or precipitation event, but before significant ET-driven decline. Wilt point will be determined as the VWC value at which 50 percent of the irrigation management zones associated with a given sensor exhibit visible wilt, NDVI values begin to decline significantly, or the superintendent feels that we have reached the limit of his or her comfort. The difference between FC and PWP will determine the plant available water (PAW) value for each plot. This process will be repeated multiple times throughout the 2018 growing season to ensure representative values for FC, PWP, and PAW are achieved.

Objective 2: Quantify changes in water consumption, relative to typical practices, due to implementation of ET-based and SMS-based irrigation scheduling
Beginning in spring 2019, we will apply the knowledge gained from Objectives 1 to compare soil moisture sensor-based irrigation scheduling with ET-based and traditional approaches. First, we will conduct an irrigation audit of the nine fairways identified in Objective 1 and quantitatively define the relationship between the programmed water application and the true depth of irrigation applied. This information will be used when applying the prescribed irrigation treatment to adjust the command as necessary. Of the nine fairways identified in Objective 1, one fairway from each replicate block will be assigned a treatment corresponding to each of the irrigation scheduling techniques (Table 1).

For the soil moisture sensor-based treatment, we will make use of valve-in-head sprinkler control and schedule the head in each irrigation management zone to be run together with all other heads in the same corresponding soil moisture class. Irrigation will only be allowed once the PAW has been reduced by 50% as measured by the soil moisture sensor associated with that soil moisture class. When irrigation is allowed, the applied depth will be the lesser of: 1) the total forecasted ET before the next forecasted rain event or 2) the amount required to return the soil water content to 75% of total PAW. These upper and lower PAW limits will be adjusted as necessary. Forecasted reference ET (FRET) will be obtained from the national weather service's Forecasted Reference Evapotranspiration service (digital.weather.gov). For the ET-based scheduling treatment we will take a deficit irrigation approach and apply 70% of reference ET every three days. We will consult with local superintendents to ensure that our timing and percent deficit are representative of what would typically be used by a golf course in Minnesota and adjust as necessary. Finally, for the remaining treatment, we will ask the superintendent to irrigate the remaining three fairways as he or she typically would, taking into account any information that would typically be used. During the course of the growing season, total depth of irrigation applied will be recorded for each irrigation event and totals will be quantified on an area basis. We will also track and analyze relationships between precipitation, FRET, and actual on-site ET throughout the course of the study.

Expected Results

From this work we expect to gain a deeper understanding of the importance of spatial variability in golf course management. Further, methodologies developed for mapping, sensor placement, and monitoring via remote sensing can be of great value to the industry. Together, those technologies will help us develop a meaningful relationship between course conditions and soil water status as measured by the physiological response of the turf canopy. By doing so, we can demonstrate how information from these types of technologies can provide meaningful data for a superintendent to use in course management.

Most importantly, our on-course comparison of various irrigation scheduling technologies can provide easy to follow examples of how to effectively use information from available technologies to make meaningful changes in management practices. This will help superintendents understand which technologies can work for them and what the potential benefits are and it can help industry manufacturers understand how to provide data that is both meaningful and actionable.

Results of this work will be disseminated in peer-reviewed journal and trade articles and in presentations at conferences and seminars. Device manufacturers can also be industry advocates and help distribute information and results of this work at customer workshops, trainings, and on-course installations through training, sales, and service groups. This type of spatial data is also ideal for future addition to dashboard and management tools such as the USGA Resource Management Tool and irrigation controller interfaces.

Recent Activity

We have tentatively settled on performing the project at Brackett's Crossing Country Club in Lakeville, MN (Fig 3A). A full course Precision Sense survey was previously conducted in 2012 (Fig. 3B), which gives us some sense of the variability we can expect when we conduct an updated survey in spring 2018. The course currently has a TurfGuard wireless soil moisture sensor system installed. This eliminates the cost, time, and labor associated with installing a new system.

In January, the project team will meet to define a 2018 schedule. We will work on obtaining and interpreting the irrigation database records from Brackett's Crossing to evaluate current water use practices and begin preparation for the subsequent irrigation calibration and audit in spring 2018. The Precision Sense machine has been transported to the course and is ready to use as soon as the ground has thawed. A baseline survey will be conducted in spring 2018, which will be used to determine the fairways for our research.

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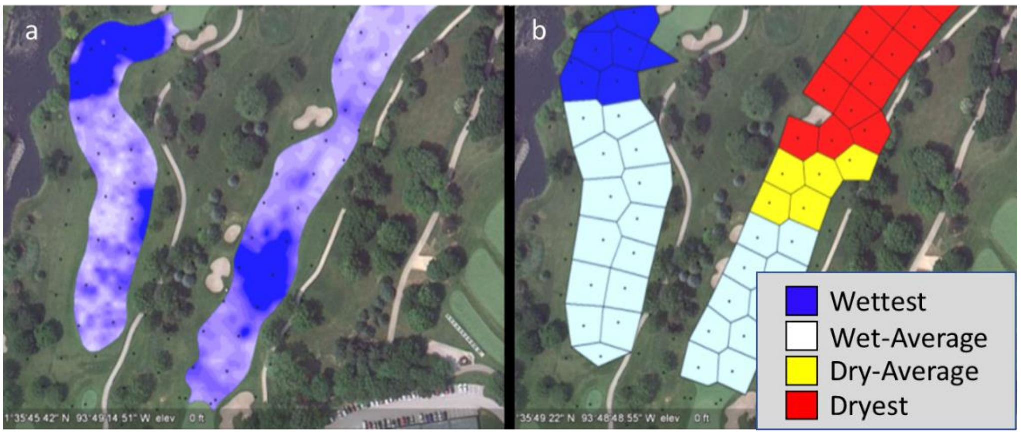

Figure 1. (a) Example of kriged soil moisture data and (b) corresponding irrigation management zone assignments for each sprinkler head.

	2018			**2019**			**2020**		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
Objective 1									
Sensor Install									
System Training									
Objective 2									
Irrigation Audit									
Data Collection									

Figure 2. Estimated schedule of work for major tasks in the irrigation scheduling comparison study.

Figure 3. (A) Location of Brackett's Crossing CC and (B) 2012 Precision Sense survey of Brackett's Crossing Country Club showing wet (dark blue) to dry (white) soil moisture on a stretched scale.

Table 1. Summary of treatments to be applied in the comparison of irrigation scheduling techniques

Treatment	Description
SMS-based	Irrigation allowed at ≥50% PAW reduction. Applied depth determined by FRET or sufficient to achieve 75% PAW level. PAW thresholds to be adjusted as necessary.
ET-based	70% ETo to be applied every three days. Percent deficit and frequency to be adjusted as necessary.
Traditional	As typically applied by course superintendent using any typically available information.

2017-38-648

Title: Development of Irrigation Scheduling Techniques that Conserve Water using Soil Moisture Sensors, Reference Evapotranspiration, and Turfgrass Quality Data

Project Leaders: Dale Bremer[1], Josh Friell[2], Jack Fry[1], and Andres Patrignani[1]

Affiliation: [1]Kansas State University; [2]The Toro Company

Objectives:
1. Determine quantitative turf canopy responses to plant available water from in-situ soil moisture sensors.
2. Compare SMS-based irrigation scheduling to traditional irrigation and ET-based irrigation scheduling.
3. Prototype a simple turfgrass irrigation forecasting tool.

Start Date: 2017
Project Duration: Four years
Total Funding: $129,733

Introduction

Turfgrass irrigation water management is critical to ensure turf playability, landscape aesthetics, and protect local water resources. Efficient application of water to match but not exceed requirements of high quality turfgrass is crucial. In the United States there are an estimated 1.5 million acres of maintained turfgrass in golf courses that used approximately 1.859 million acre- feet of water per year (EIFG, 2007, 2015). The use of soil moisture sensors to control irrigation has resulted in up to 70% water savings in lawn-or rough-height turfgrass, with greater savings in wet than dry climatic conditions (Chabon et al., 2017; Dukes, 2012).

Fairways represent about 30% of the turfgrass on a typical 18-hole golf course (EIFG, 2007). Although fairways are usually irrigated, to our knowledge there are no data available in the scientific literature regarding potential water savings on fairway height turfgrass of using soil moisture sensors to control irrigation. Sensors Magazine reported the Desert Mountain Golf Course had 15-20% water savings by using soil moisture sensors to control irrigation on their fairways and greens (Kevan, 2006). However, golf courses have not taken full advantage of soil moisture technology in fairways, possibly because of cost but also because of a lack of research into fundamental questions such as sensor placement, soil moisture thresholds for initiating irrigation, effects of soil type on irrigation thresholds, and unknown quantitative relationships between soil moisture and turfgrass quality.

We propose to conduct fundamental research on how to improve irrigation by using soil moisture sensors to control irrigation. This will involve addressing several questions. What are the plant available water thresholds for initiating irrigation based on turfgrass visual quality and the onset of stress symptoms, and how do different soil properties affect those thresholds? Can current and forecasted reference evapotranspiration (FRET) data be used to potentially delay irrigation in order to conserve water while not risking unacceptable damage to turfgrass? Can we use historical and FRET data to predict soil moisture deficits? How well does the increase or decrease in soil moisture correspond to ET and irrigation inputs? Essentially, we propose to use a controlled study to investigate the underlying factors governing irrigation scheduling using soil moisture sensors in golf turf. We will utilize research that has been conducted in other agricultural crops and in residential irrigation of turfgrass and leverage it into golf where there are little data available addressing these questions.

We also propose to use remote sensing to evaluate the turf canopy in the different areas. This will include using handheld as well as UAS-mounted NDVI and thermal cameras.

We hypothesize that when used properly, the integration of soil moisture, reference ET, and turfgrass quality data can be used to improve irrigation scheduling and reduce total water use in turfgrass. By extension, the goal is to encourage golf facility adoption of these new irrigation scheduling techniques for water and cost savings.

Research Methods

This research will be conducted on 12 plots (30 x 30 ft.), each representing a separate irrigation zone, of perennial ryegrass (Lolium perenne L.) at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas; perennial ryegrass will be established in fall 2017. Ryegrass plots will be maintained at 5/8 inch height and will be fertilized with 3 lbs N per 1000 ft2 annually.

Objective 1: Determine quantitative turf canopy responses to plant available water from in-situ soil moisture sensors (Phase I).

Recognizing the need for site-specific irrigation thresholds based on plant available water (PAW), the first objective of this proposed research will be to better understand turf canopy responses to soil moisture deficits. We will quantify canopy responses of perennial ryegrass using green canopy cover and NDVI during multiple soil drydown cycles during the first year of the project. Our approach will include both field and laboratory determination of soil physical properties.

First, we will fully characterize the existing soils on site for texture, organic matter content, pore size distribution, and soil water retention curves. This will ensure we have a full description of the site for which we are developing the threshold recommendations and will provide a point of reference for future work under different site conditions. Root depth will be measured and in- ground SMS will be installed with the sensing element at the mean root depth. Following a settling-in period of at least 30 days during which typical irrigation practices will be followed, the plots will be irrigated to near saturation and a drydown will be initiated. This cycle will be repeated multiple times during the summer in order to acquire sufficient information relating turfgrass quality and soil moisture. Volumetric water content and soil matric potential during the drydown events will be recorded using the SMS system, visual ratings for turf quality will be collected every 1 to 2 d, and handheld NDVI imagery and surface hardness will be measured every 2 d. Measurements with UAS-mounted NDVI and thermal cameras will be conducted every 4-7 d; the frequency of UAS measurements will be influenced by the pace of change in turf quality and weather conditions conducive for flying and obtaining viable data. Hourly reference ET will be recorded during the drydown events using local data from the Kansas Mesonet environmental monitoring network. Using recorded VWC, turfgrass quality ratings, and NDVI values, field capacity (FC) and permanent wilt point (PWP) VWC values from each sensor will be determined. Field capacity will be determined as the stable VWC value following the initial saturating irrigation event, but before significant ET-driven decline. Wilt point will be determined as the VWC value at which visible wilt becomes evident and/or NDVI values begin to decline significantly. The difference between FC and PWP will determine the PAW value for each plot.

Objective 2: Compare SMS-based irrigation scheduling to traditional irrigation and ET-based irrigation scheduling (Phase II).

In this objective we compare the SMS-based irrigation approach against a historical ET-based deficit irrigation treatment and a traditional calendar-based irrigation scheduling treatment (Table 1). For these treatments, we will consult with current and former superintendents on perennial ryegrass golf courses in Kansas to ensure our selections for percent deficit and timing are representative of typical practices in that area. Weather and current ET data will be obtained from an on-site weather station, which is an official station of Kansas Mesonet (mesonet.k- state.edu). The exact irrigation thresholds based on plant available water will be determined based on the results from phase I.

Treatments will be assigned to plots in a randomized complete block design. Irrigation decisions will be made periodically as determined by data collected from the in-situ SMS system and historical ET. Prior to initiation of treatment applications, irrigation application rates will be calibrated for each plot and distribution uniformity will be characterized using catch cans and handheld soil moisture sensor measurements. Where necessary, irrigation depths will be adjusted to account for differences in real application rates due to plot-to-plot inconsistencies.

Upon initiation of treatments, total irrigation applied and number of irrigation events will be recorded for each plot. For all plots, soil moisture will be measured continuously using Campbell Scientific CS655 sensors and Toro Wireless TurfGuard sensors. Soil matric potential will be recorded using Decagon MP6 sensors, which will be used in tandem with CS655 sensors to create in-situ soil moisture release curves. Multi-spectral cameras (e.g. visible, near-infrared, thermal) will be used to collect periodic digital images and monitor turfgrass canopy using standard indices such as NDVI and percent green turf cover. Multispectral data will be collected to assess spectral reflectance characteristics. Canopy NDVI and canopy thermal images will be collected biweekly to monthly with UAS (Bremer and van der Merwe, 2016) during phase III. Across each irrigation zone, NDVI images provide maps of the relative quality and stress level of the turfgrass (Bremer et al., 2011), while thermal images provide maps of canopy temperatures; the latter is also an indicator of relative ET rates. Both NDVI and thermal images indicate areas where the turfgrass may be stressed.

The results of phases I and II will produce a thorough understanding of the relationships between soil moisture, plant available water, and turf health.

Objective 3: Prototype a simple turfgrass irrigation forecasting tool (Phase III).
Our hypothesis for this phase of research is that turfgrass managers can successfully conserve water by incorporating multiple sources of information into a simple irrigation decision-support tool.

The tool will generate 7-day forecasts of plant available water (Figure 1) based on site-specific soil texture, information of plant available water obtained from the soil moisture sensors at the time of deciding a possible irrigation event, and short-term forecasts of reference ET and precipitation obtained from the National Weather Service (digital.weather.gov). The tool will generate an ensemble of possible scenarios with the aim of assisting golf course with irrigation decisions. The tool will provide the most probable number of days until stress and the required amount of irrigation to be applied. Because this tool will be based on stochastic forecasts, managers can test multiple alternatives and make decisions according to the risk that each golf course is willing to accept.

Finally, actual reference ET from the on-site weather station will be compared with FRET values from the NWS to evaluate the accuracy of FRET values by the NWS.

Expected Results
From this work, we expect to gain a more thorough understanding of how to best select PAW thresholds for implementing SMS-based irrigation scheduling. The information gained from this project will begin to provide turfgrass managers a more meaningful way of interpreting SMS data and enable them to make a

meaningful changes in their irrigation practices. In addition, a quantification of water savings generated through the use of data-directed irrigation scheduling will be achieved and can give increased motivation for turf managers to invest in new technology that allows them to be better water managers.

The knowledge gained through this research will be disseminated in peer-reviewed articles, extension activities, and presentations at conferences. New knowledge on how to use soil moisture sensors for turfgrass irrigation management can be provided to sales and support personnel of SMS manufacturers so that customers are able to better understand how to implement these technologies.

These results also have the potential to drive changes in other industries. Residential, commercial, and agricultural irrigation all have the potential to benefit from the methods and knowledge developed in this proposed work. The golf industry will likely be acknowledged for contributing valuable knowledge to the general field of data-driven landscape irrigation.

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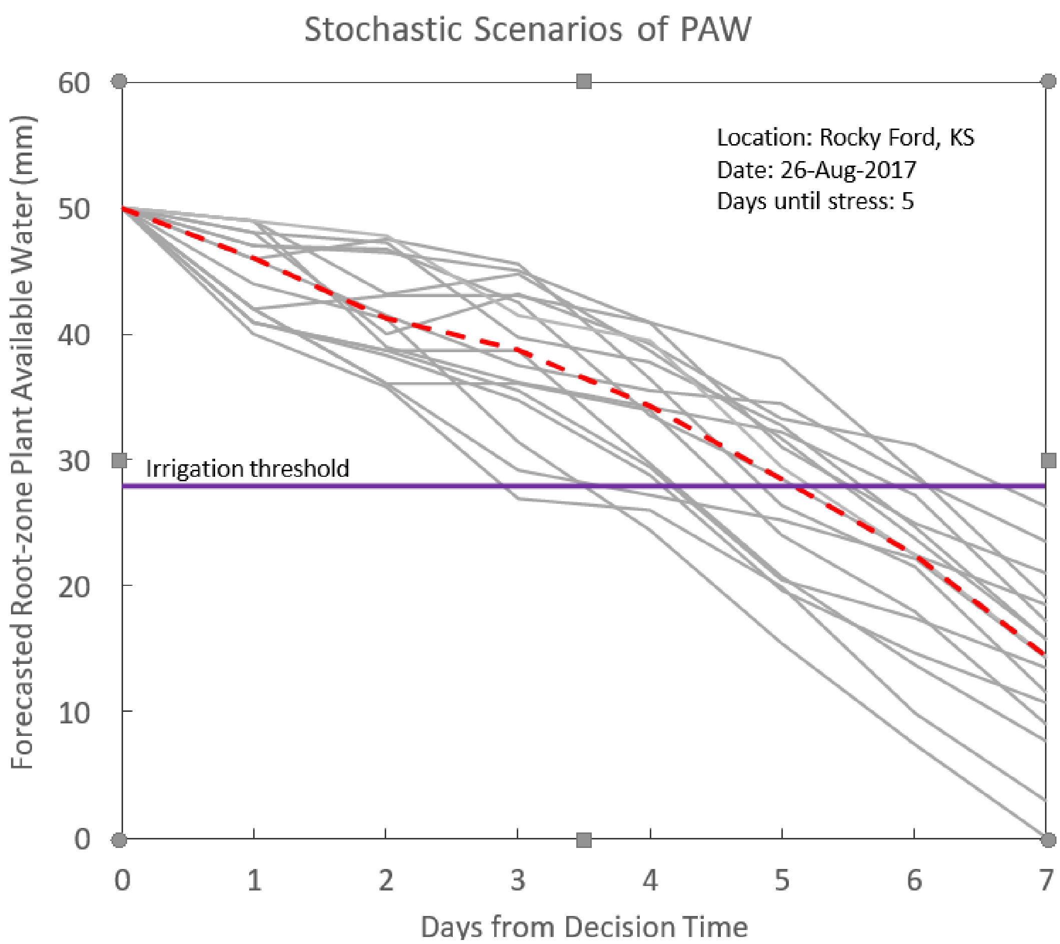

Figure 1. Example of stochastic forecasts of plant available water. Gray lines indicate each scenario using a 20-yr database of reference evapotranspiration. Dashed red line indicates the post probable scenario. The forecasts include a 25 mm (about 1 inch) of rainfall with 20% chance of occurrence 48 hours after decision time.

Table 1. Project treatments showing tentative treatment values.

Treatment ID	Description
1 (Traditional)	Traditional management based on a fixed irrigation schedule. No or little soil water stress. Usually leads to over-application irrigation. Three irrigation events per week totaling 1 inch per week.
2 (60% ETo)	Deficit irrigation. Irrigation represents a fixed portion of the reference ET. Arbitrary percentages are often hard to estimate accurately and vary across locations. We will start with 70% ET_O and adjust as necessary.
3 (SMS-based)	Irrigation based on plant available water. The concept of plant available water links the soil moisture condition with plant water stress, improving the timing and amount of the irrigation event. The irrigation threshold will be determined from phase 1 of the project.

2015-04-519

Detection and disruption of virulence factors associated with *Ophiosphaerella* spp., the causal agents of spring dead spot of bermudagrass

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Start date: 2015
Project duration: 4 years
Total funding: $61,496

Objectives:

1. To produce a genome sequence of *Ophiosphaerella korrae*.
2. To isolate and identify compound(s) secreted by fungi that elicit a necrotic host response.
3. Use a bioinformatics approach to identify the gene(s) that produce the secreted compounds and compare host responses to infection and colonization by wild-type and gene disrupted isolates.

Summary points:

- The genomes (DNA) of three *Ophiosphaerella herpotricha*, five *O. korrae*, and three *O. narmari* isolates were sequenced.
- The transcriptomes (RNA) of two isolates of each species were obtained.
- Protein coding genes of one *O. herpotricha* isolate was validated by mass spectrometry.
- These results include the identification of putative genes of *Ophiosphaerella* involved in pathogenicity and in root cell necrosis by using bioinformatics tools.
- Current efforts are ongoing to identify protein coding genes secreted by the fungi when infecting and colonizing resistant and susceptible hosts.

Summary text:

Bermudagrass is a perennial warm-season grass cultivated extensively in the southern United States. Spring dead spot (SDS) is considered the most devastating disease of bermudagrass where bermudagrass goes dormant in the winter. One of the long-term goals of the Oklahoma State University Bermudagrass Breeding Program is to develop bermudagrass cultivars with resistance to SDS. To achieve this goal the interaction of SDS pathogens and bermudagrass must be understood and much is still unknown. It was previously observed that the same isolate of *Ophiosphaerella* can switch from a disease-causing lifestyle (necrotrophic lifestyle) in susceptible cultivars to an endophytic/symbiotic lifestyle (non-disease) in a resistant cultivar. To continue these investigations, efforts in this research project are focused in identifying the genetics of how *Ophiosphaerella* causes disease and induces root cell necrosis in susceptible bermudagrass cultivars.

The genomes (DNA) of 11 isolates and the transcriptome (RNA) of 6 isolates of *Ophiosphaerella* were sequenced. The sequencing platforms used were Illumina and PacBio for the genome sequencing, and Illumina for transcriptome sequencing. By using bioinformatics tools, the genomes were assembled, assembly completeness was assessed, the transcriptomes were used as evidence for gene prediction, and then the genes were translated into proteins (protein coding genes, PCG) (Table 1). The function of the PCG of each isolate was predicted by using several bioinformatics tools and/or database searches that have been used in other scientific studies because they provide tailored functions related to pathogenicity and plant-pathogen interactions (Table 2).

In average, less than 30% of the eleven PCG sets had relevant plant-pathogen interaction database matches. The majority of the matches were in categories for a potential role in pathogenicity and virulence. Some of these results were duplicated due to disagreement in the literature/databases for the function of a particular gene. It was also found that approximately 40 genes in *Ophiosphaerella* spp. are potentially involved in developing plant avirulence (stopping infection due to cell death).

The PCG obtained by bioinformatics tools were validated by mass spectrometry. An isolate of *O. herpotricha* was cultivated in liquid media for 15 days in the laboratory. The proteins of the fungal mycelium were extracted and four samples were submitted for mass spectrometry analysis at the OSU Biochemistry and Molecular Biology Core Facility. Each sample was treated with Trypsin (digestion of proteins into peptides) prior to scanning in Orbitrap and Fusion mass spectrometers (Figure 1). The peptides obtained by those machines were compared to the predicted PCG of *O. herpotricha* using MaxQuant software and custom Python scripts. The PCGs that had at least two peptides identified by mass spectrometry were considered validated.

A total of 594 PCG were identified in the Orbitrap, whereas 2,884 PCG were identified by the Fusion spectrometer. The PCGs validated by the Fusion included all PCG validated by the Orbitrap. All PCG validated by the Fusion, were searched against the proteins in the PHI database for determining hypothetical function. There were 1,974 PCG that did not match to any proteins relevant to plant-pathogen interactions, and 431 yielded mixed hypothetical functions (literature disagrees on the ultimate function). There were 472 genes with hypothetical role in disease and seven genes with hypothetical role in plant avirulence.

Concluding remarks:
Potential genes present in the pathogen's genome that are involved in developing plant avirulence have been identified. One potential gene involved in symbiosis/endophytic lifestyle was also found. These will be investigated further as the tools and databases used are not suited for endophytic interactions. Also, to validate these findings current efforts are ongoing to identify protein coding genes secreted by the fungi when infecting and colonizing resistant and susceptible hosts. Another piece of this puzzle is to study the PCG of the plant. Recently the genomes and transcriptomes of a susceptible cultivar and of a resistant common bermudagrass biotype were sequenced. Bioinformatics pipelines will be used to analyze the genetic information of the plant hosts that will provide answers about the role of plant genes in pathogenicity and symbiosis. Therefore, the current efforts are moving the bermudagrass breeding program at Oklahoma State University closer to the identification of genes responsible for SDS resistance.

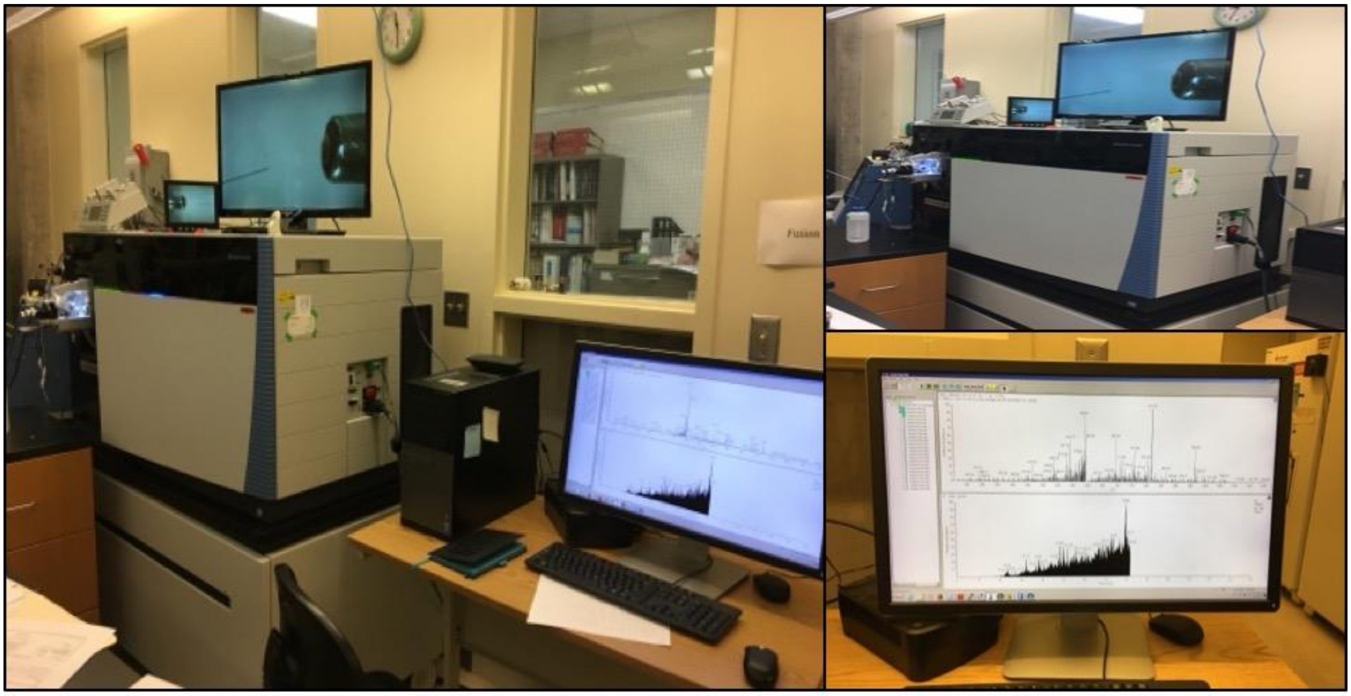

Figure 1. Fusion mass spectrometer at the OSU Biochemistry and Molecular Biology Core Facility (left). A close-up of the ion-source sprayer screen where the samples enter the mass spectrometer (upper right). The computer screen in which the results of the analysis can be followed in real-time (lower right).

Table 1. Genome statistics for three isolates of *Ophiosphaerella herpotricha*, five isolates of *O. korrae*, and three isolates of *O. narmari*.

Species	Isolate	Assembly size	N50 (bp)	Number of contigs	GC-content (%)	Gene count	Gene density (genes/Mbp)	Intergenic bases (Mbp)	Complete & single-copy genes (%)
Ophiosphaerella herpotricha	KS28	66.1	61,683	27,846	41.4	13,901	210.30	45.2	96.6
Ophiosphaerella herpotricha	TX2.5A	67.2	54,308	29,099	41.1	14,001	208.35	45.6	96.9
Ophiosphaerella herpotricha	16FISCC	63.8	50,289	20,526	40.1	13,285	208.23	42.8	97.6
Ophiosphaerella korrae	14BISCC	68.1	37,869	26,403	39.2	13,460	197.65	46.2	96.4
Ophiosphaerella korrae	OW11	67.3	40,856	14,402	38.1	12,576	186.86	47.0	97.0
Ophiosphaerella korrae	TX1.4	72.1	31,766	34,418	41.5	13,880	192.51	50.5	96.5
Ophiosphaerella korrae	KY162	71.4	51,429	13,696	39.2	12,602	176.50	50.8	96.8
Ophiosphaerella korrae	HCW2	71.1	47,026	12,155	38.6	12,615	177.43	50.7	96.6
Ophiosphaerella narmari	BCGCC2	47.0	213,028	7,233	46.5	12,006	255.45	26.7	97.3
Ophiosphaerella narmari	AUS58	47.0	221,777	7,094	46.4	14,091	299.81	25.8	97.6
Ophiosphaerella narmari	ATCC202719	47.7	1,524,584	5,309	45.8	13,384	280.59	26.6	97.3

Table 2. Number of protein coding genes of *Ophiosphaerella* spp. predicted to have a potential role in vitality, pathogenicity, virulence, and plant avirulence.

	O. korrae	O. korrae	O. korrae	O. korrae	O. korrae	O. herpotricha	O. herpotricha	O. herpotricha	O. narmari	O. narmari	O. narmari
Isolate identification	ISCC14B	TX14	OW11	HCW2	KY162	ISCC16F	KS28	TX25A	ATCC201719	AUS58	BCGC-C2
Role in lethal	197	159	146	140	138	148	171	155	151	147	155
Role in pathogenicity	462	434	391	381	391	372	414	415	369	371	379
Role in virulence	1640	1602	1465	1458	1471	1440	1565	1571	1480	1497	1471
Role in plant avirulence	37	44	36	36	37	31	31	32	36	34	33

2016-18-568

Title: Management Strategies of a *Sclerotinia homoeocarpa* Population with Multiple Fungicide Resistance and Multidrug Resistance

Project leader: Geunhwa Jung

Affiliation: University of Massachusetts

Objectives of the project:

1. To assess field efficacy of dicarboximide, DMI and SDHI fungicides in a dicarboximide-resistant *S. homoeocarpa* population.
2. To develop the best fungicide options for controlling a *S. homoeocarpa* population with multiple fungicide resistance.
3. To understand how many applications of non-dicarboximides are required in order to revert a dicarboximide-resistant population into sensitive by monitoring the population shift.
4. To determine how persistent the reverted dicarboximide-sensitive population will be after reversion.

Start Date: 2016
Project Duration: Two years
Total Funding: $20,000

Summary Text:

Dollar spot, caused by *Sclerotinia homoeocarpa* F.T. Bennett, is one of the most significant diseases of cool-season turfgrass on golf courses. Resistance to the benzimidazole and dicarboximide classes and reduced sensitivity to the sterol demethylation inhibitor (DMI) fungicide class in *S. homoeocarpa* populations has been reported, moreover, a select number of golf courses also contain *S. homoeocarpa* populations with resistance to dicarboximide (iprodione and vinclozolin) sensitivity. In order to better understand the dynamics of multiple fungicide resistance (MFR) population and to develop fungicide options for dollar spot control, we conducted a field trial in 2015 and 2016 on a golf course fairway with a multiple fungicides-resistant *S. homoeocarpa* population.

During the 2015 and 2016 field season, fungicide efficacy was tested on two different fairway locations at Wethersfield Country Club (WCC) in Connecticut and the population exhibited a combination of four different isolate genotypes with differing resistance profiles to the benzimidazole, dicarboximide and DMI fungicide classes. Field efficacy data in 2015 and 2016 showed a fairly similar trend. Reduced field efficacy was observed using the following fungicides: iprodione (Chipco 26GT), vinclozolin (Curalan), and low rate of propiconazole (Banner MAXX II). On the other hand, good control was observed with high rate of boscalid (Emerald), fluxapyroxad (Xzemplar), fluazinam (Secure), and Enclave (Fig. 1).

The 2014-Initial *S. homoeocarpa* population displayed a higher proportion of DMI-R/Ben-R and DMI-R/Dicar-R/Ben-R isolates than the proportion of DMI-R and DMI-R/Dicar-R isolates. The 2016-Initial sampling had a higher proportion of DMI-R isolates than DMI-R/Dicar-R isolates (except for boscalid at 0.28 kg a.i. ha^{-1} treated plots), and the DMI-R/Ben-R or DMI-R/Ben-R/Dicar-R isolate phenotypes were at the lowest proportion among all isolate phenotypes or absent. DMI-R/Ben-R/Dicar-R isolates disappeared over the growing season in 2014 and 2016 (Fig. 2).

The proportion of DMI-R/Ben-R isolates on the untreated plots decreased and the proportion of DMI-R isolates increased after 2014-2015 overwintering. The *S. homoeocarpa* population's phenotypic structure on the untreated plots in 2015 showed a similar proportion to the Initial population in 2016, despite these being different plot locations. Isolate phenotype proportion on the untreated plots did not significantly change during the 2016 growing season according to repeated measures MANOVA. This was the only treatment that did not significantly change from the Initial to Final sample times in either plot location (Fig. 2A).

After treatment of both boscalid rates, the proportion of DMI-R/Ben-R isolates increased in the 2014-7-DAT, 2015-Final, and 2016-7-DAT sample times. Boscalid provided excellent control of dollar spot in 2015 and dollar spot lesions with active mycelia were not observed on either rate of boscalid treated plots at the 2015-7-DAT sample time. The proportion of DMI-R/Ben-R isolates selected by boscalid decreased after overwintering in 2014-2015 or 2015-2016. The proportion of DMI-R isolates increased after overwintering in 2014-2015 at Loc 1. The proportion of DMI-R/Dicar-R isolates decreased or was not detected by the both rates of boscalid treatments at the both locations (Fig. 2B and C).

On propiconazole (both rates) or iprodione treated plots, the proportion of DMI-R/Dicar-R isolates increased in all sample times. On the other hand, the proportion of DMI-R/Ben-R and DMI-R decreased or was absent by propiconazole (both rates) or iprodione treatments. After overwintering, the proportion of DMI-R/Dicar-R isolates decreased but the proportion of DMI-R isolates increased in every sample time except for 2016-Initial sample time on the propiconazole (0.5 kg a.i. ha^{-1}) treated plots at Loc 1 (Fig. 2D, E and F).

Summary points:

- Fluxapyroxad (low and high rates, succinate dehydrogenase inhibitor, SDHI), boscalid (high rate, SDHI), fluazinam (an uncoupler of phosphorylation), and Enclave™ (a four-way mixture of chlorothalonil, tebuconazole, iprodione and thiophanate-methyl) provided better dollar spot control than the dicarboximides (iprodione and vinclozolin) or DMI (low rate of propiconazole).
- Propiconazole or iprodione application selected isolates with both DMI and dicarboximide resistance (DMI-R/Dicar-R), but controlled isolates with both DMI and benzimidazole resistance (DMI-R/Ben-R).
- Boscalid application selected DMI-R/Ben-R isolates but controlled DMI-R/Dicar-R isolates.
- Previously selected DMI-R/Dicar-R or DMI-R/Ben-R isolates decreased after overwintering, in the absence of selection pressure. In addition, the proportion of isolates with DMI, dicarboximide, and benzimidazole resistance (DMI-R/Dicar-R/Ben-R) decreased regardless of fungicide treatment.
- This is the first report of multiple fungicide resistant population dynamics in response to different fungicide classes and overwintering effects and will help develop effective strategies for managing multiple fungicide resistance and potentially delay the emergence of future resistant populations.

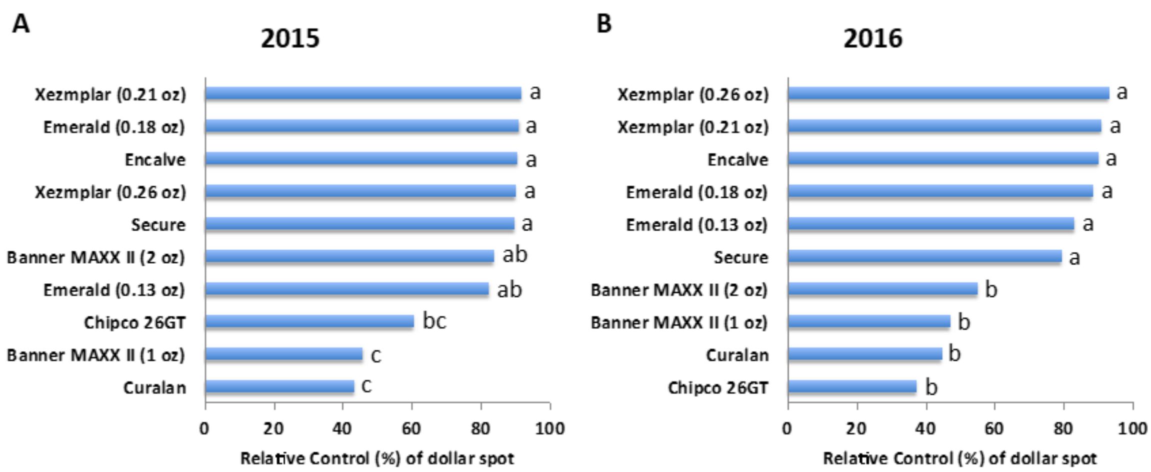

Fig. 1. Relative control percent (%) of dollar spot of fungicide treatments on two different fairway locations at Wethersfield Country Club, CT in 2015 (A) and 2016 (B). Relative control percentage (RC%) data were collected by counting number of individual infection centers and calculating area under (AUDPC) values for all rating dates among all treatments. Rating began on the first date of the first fungicide application and concluded 21 days after the final application. RC% was calculated with the following formula: [(untreated-fungicide treated)/untreated] × 100 = RC%. Different letters on top of bar indicated significantly different (p<0.05) according to Fisher's protected least significant difference.

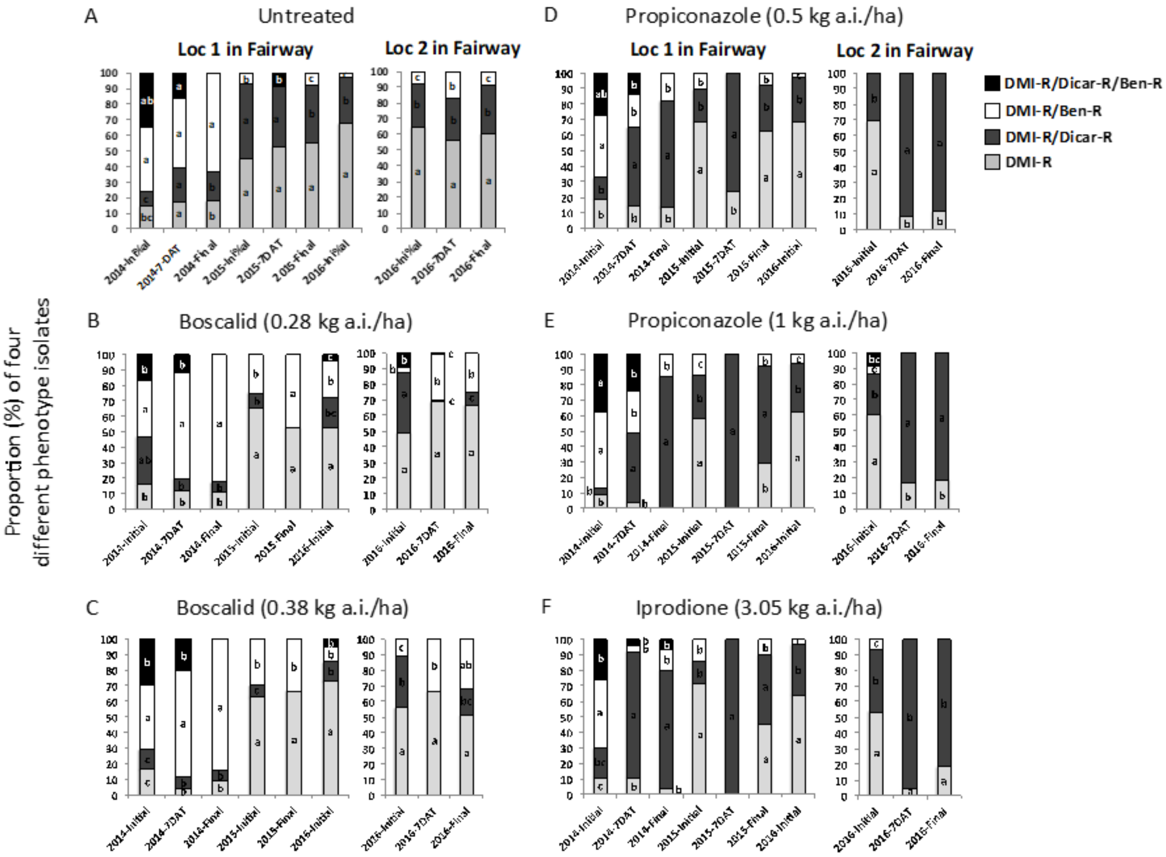

Fig. 2. Isolate phenotype proportions on untreated (A), boscalid (0.28 kg a.i. ha^{-1}) (B), boscalid (0.38 kg a.i. ha^{-1}) (C), propiconazole (0.5 kg a.i. ha^{-1}) (D), propiconazole (1.0 kg a.i. ha^{-1} (E), and iprodione (3.05 kg a.i. ha^{-1}) (F) treated plots on Loc 1 (location 1) of fairway in 2014 and 2015, 2016-Initial and on Loc 2 (location 2) of fairway in 2016. Initial, 7-DAT, and Final refer to initial sampling before fungicide application, 7 days after treatment of fungicide, and 21 days after final treatment of fungicide, respectively. Isolate phenotypes: DMI insensitive (DMI-R), DMI and dicarboximide resistance (DMI-R/Dicar-R), DMI and benzimidazole resistance (DMI-R/Ben-R), and DMI, dicarboximide, and benzimidazole resistance (DMI-R/Dicar-R/Ben-R).

Reference cited:

Hyunkyu Sang, James T. Popko Jr., and Geunhwa Jung. Evaluation of a *Sclerotinia homoeocarpa* population with multiple fungicide resistance phenotypes under differing selection pressures. (submitted to Plant Disease)

2016-21-571

Bentgrass Tolerance, Disease Predictive Models and Fungicide Timing to Control Dollar Spot on Fairway Turf

James A. Murphy, James Hempfling, Bruce B. Clarke
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Executive Summary Points**:**

- Dollar spot forecasting by a logistic regression model had good accuracy for highly susceptible cultivars during 2015, early-2016, and 2017.
- Moderate to excellent, season-long disease control was achieved when subsequent fungicide timing was based on a threshold program, but total fungicide inputs and the level of disease control depended on the cultivar and, to a lesser extent, the initial fungicide timing.
- Fungicide applications on ‘Declaration’ creeping bentgrass that were threshold-based produced excellent disease control and resulted in only three and four to five fungicide applications during 2015 and 2017, respectively, depending on the initial fungicide timing.
- In contrast, threshold-based fungicide applications on ‘Independence’ creeping bentgrass produced moderate disease control and resulted in a total of six or seven applications during 2015 and six to nine applications during 2017, depending on the initial fungicide timing.

This research project is organized into two field trials. The objectives of the first trial include evaluating dollar spot (caused by the fungus *Sclerotinia homoeocarpa* F.T. Bennett) incidence and disease progress on six bentgrasses that vary in tolerance to dollar spot disease; and assessing the reliability of two weather-based models for predicting dollar spot epidemics on those cultivars and species. Six bentgrass cultivars [‘Independence’, ‘Penncross’, ‘Shark’, ‘007’ and ‘Declaration’ creeping bentgrass (*Agrostis stolonifera*), and ‘Capri’ colonial bentgrass (*A. capillaris*) (Figure 1)] that vary in tolerance to dollar spot were evaluated for disease incidence every two to five days and compared to a growing degree day (GDD) model for predicting the onset of disease symptoms and a logistic regression model for predicting season-long disease activity.

Results from Trial 1:

The onset of disease symptoms in highly susceptible cultivars occurred at 73-, 27-, and 92-GDD during 2015, 2016, and 2017, respectively; whereas, disease onset occurred at 79-, 140-, and 112-GDD for moderate and low susceptibility cultivars. The logistic regression model reached a 20% risk index (the point at which the model was designed to predict visual symptom expression) at 7-, 7-, and 21-d before disease onset in highly susceptible cultivars during 2015, 2016, and 2017, respectively; whereas, a 20% risk index occurred at 11-, 29- and 28-d before symptoms developed on moderate and low susceptibility cultivars. The logistic regression model accurately forecasted disease progress in susceptible cultivars throughout 2015, early-

2016, and 2017 (Figure 2). Disease progress in moderate and low susceptibility cultivars was less responsive to the risk index; however, periods of disease incidence did occur during high risk. Interestingly, disease recovery often occurred when the risk index declined sharply, albeit greater than 20%.

The objectives of the second trial include evaluating the effect of pre-symptomatic (initial) timing of fungicide application on dollar spot incidence and disease progress on a susceptible and a more tolerant bentgrass cultivar; and determining the extent that pre-symptomatic fungicide application may affect total fungicide usage on each cultivar over a growing season when subsequent fungicide applications were based on either a disease-threshold or a predictive-model. Treatments in this trial were arranged as factorial combinations of bentgrass tolerance to dollar spot, initial fungicide application timing, and subsequent fungicide timing. Declaration (more tolerant) and Independence (susceptible) were the cultivars used for the bentgrass tolerance factor. Eight initial fungicide application timings were evaluated: at the first appearance of disease symptoms (threshold-based; (< 3 infection centers m^{-2}); on May 20 (calendar-based); when the logistic regression model reached a 20% risk index; or at a GDD ranges of 20-30, 30-40, 40-50, 50-60, or 60-70 (base temperature 15 °C [59 °F] starting April 1). Subsequent fungicide timings were based on the logistic regression model, or on a disease threshold, or were withheld completely to assess long-term effects of initial fungicide timings. All possible combinations of initial and subsequent fungicide timings were applied on both cultivars. Fungicide applications used Emerald 70WG (boscalid, BASF) at 0.18 ounce per 1,000 square feet from May 2015 to July 2017, or a tank mix of Curalan (vinclozolin, BASF) and Secure (fluazinam, Syngenta) at 1 ounce and 0.5 fluid ounce per 1,000 square feet, respectively, from Aug 2017 to Nov 2017. Threshold-based plots were monitored as often as daily for dollar spot incidence. The number of applications to threshold- and model-based plots were recorded each year.

Results from Trial 2:

Disease response to treatments was limited during 2016 due to unintended dollar spot suppression from the application of fludioxonil to control anthracnose. Cultivar and subsequent fungicide timing were the most important factors influencing disease progress during 2015 and 2017. Additionally, cultivar interacted with subsequent fungicide timing to influence the level of disease control and total annual fungicide inputs during 2015. Subsequent fungicide applications based on the logistic regression model and disease-threshold produced excellent disease control (< 3 infection centers m^{-2}) on Declaration; whereas, only the logistic-regression model based applications produced excellent disease control on Independence. Three and four to five threshold-based applications were made to Declaration plots during 2015 and 2017, respectively; whereas, six to seven and six to nine threshold-based applications were made to Independence over the same time period(Table 1). Moreover, disease incidence was occasionally unacceptable on Independence plots treated on a threshold-basis.

Figure 1. Bentgrass cultivars vary in their tolerance to dollar spot (clockwise from top left): 007, Declaration, Shark, Independence, Penncross and Capri. Photo: J. Hempfling

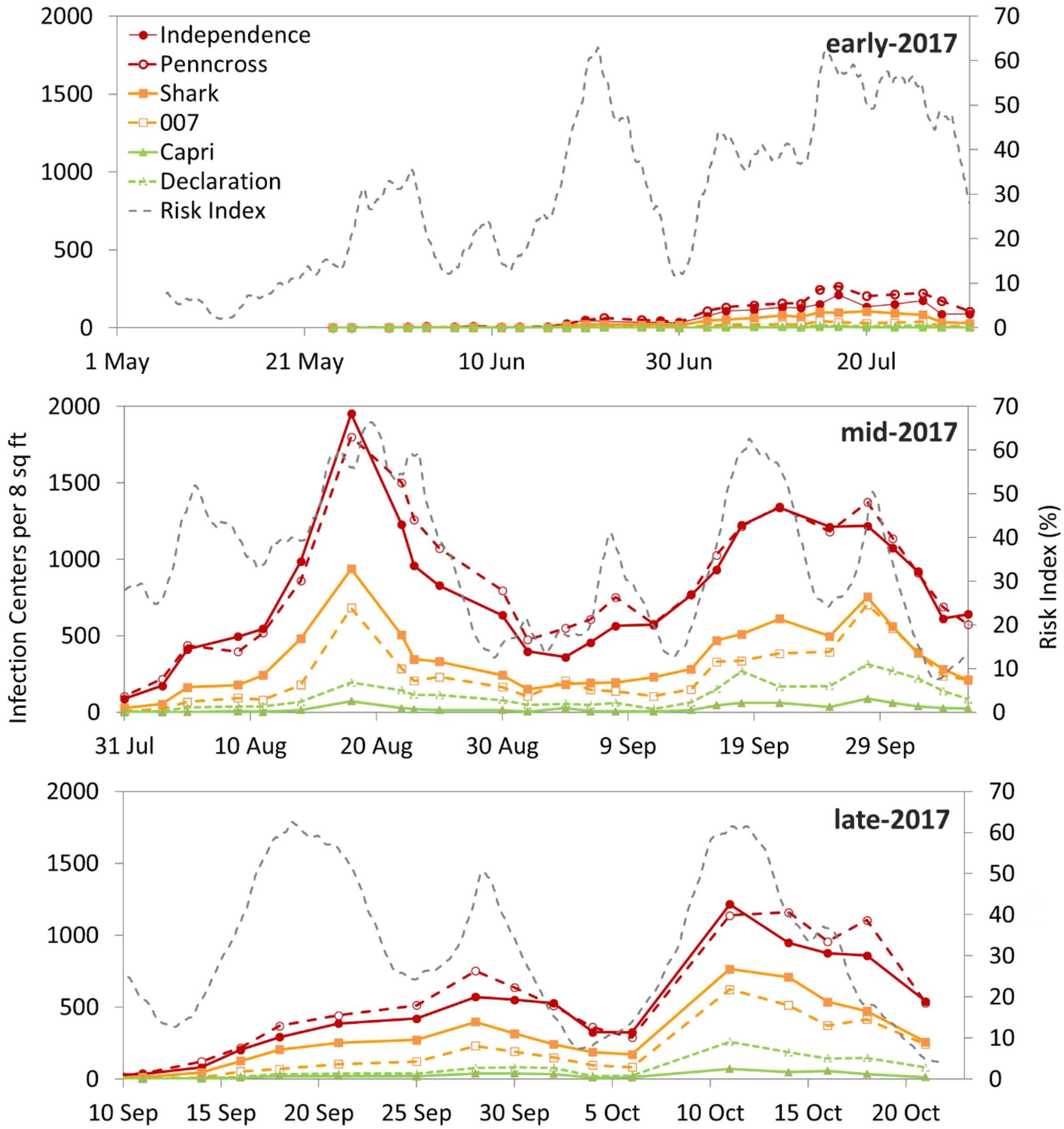

Figure 2. Number of dollar spot infection centers in high susceptibility (red lines), moderate susceptibility (orange lines), and low susceptibility (green lines) bentgrass cultivars and dollar spot risk index (gray dotted line) calculated using a logistic regression model during 2017.

Table 1. Total number of fungicide applications used to control dollar spot based on bentgrass cultivar and subsequent fungicide timings during 2015 and 2017.

	Declaration		**Independence**	
	2015	2017	2015	2017
	------------------------ Total Number of Fungicide Applications[†] ------------------------			
Calendar	9	9	9	9
Logistic	8 to 9	6 to 9	8 to 9	8 to 10
Threshold	3	4 to 5	6 to 7	6 to 9

[†] A range in the total number of fungicide applications indicates that the total number depended on the timing of the initial fungicide application.

2017-16-626

Fungicide Alternatives for the Management of Microdochium Patch

Clint Mattox, Brian McDonald, and Alec Kowalewski

Oregon State University

Introduction:

Previous field trials taking place from 2013 to 2016 have shown great promise in reducing the use of traditional fungicides to inhibit Microdochium patch on annual bluegrass putting greens. Products that have previously shown a potential for decreasing the dependency on traditional fungicides have included: the horticulture oil Civitas Defense, phosphorous acid products, sulfur, and iron sulfate. Data from previous work suggests that these products can inhibit Microdochium patch, but none of these products used alone have been shown to both inhibit disease and maintain turfgrass quality throughout the trial.

Two field trials are currently underway focusing on finding ways of both inhibiting Microdochium patch and maintaining acceptable turfgrass quality. The first trial incorporates the use of Civitas Defense and a phosphorous acid in a seasonal rotation with sulfur and a phosphorous acid. This first trial also includes a timing component that will quantify the effects of a two-week application interval compared to a three-week application interval. The second trial is exploring different rates of iron sulfate in combination with a phosphorous acid on a two-week application interval. Both trials are subjected to replicated golfer traffic (76 golf rounds a day) in order to mimic real-world conditions and to better assess the impact of the treatments on turfgrass recovery from traffic and overall turfgrass quality.

At the conclusion of these trials, an integrated pest management (IPM) program will be developed based on the results of these trials and made available to turfgrass managers.

Experiment 1:

Civitas Defense & phosphorous acid in rotation with sulfur and phosphorous acid

The field trial began on September 29, 2016 and final data collection for year one was taken on April 30th, 2017. The second-year trial replication began on September 28, 2017 on a new area of the same green and will conclude on April 30th, 2018.

Preliminary observations:

First year observations indicate that a 2-week application interval will provide a greater expectation of disease inhibition compared to a 3-week application interval (Image 1). There is also some indication that turfgrass quality is greater when Civitas Defense + phosphorous acid applications are avoided during the coldest part of the winter (Dec, Jan, and Feb).

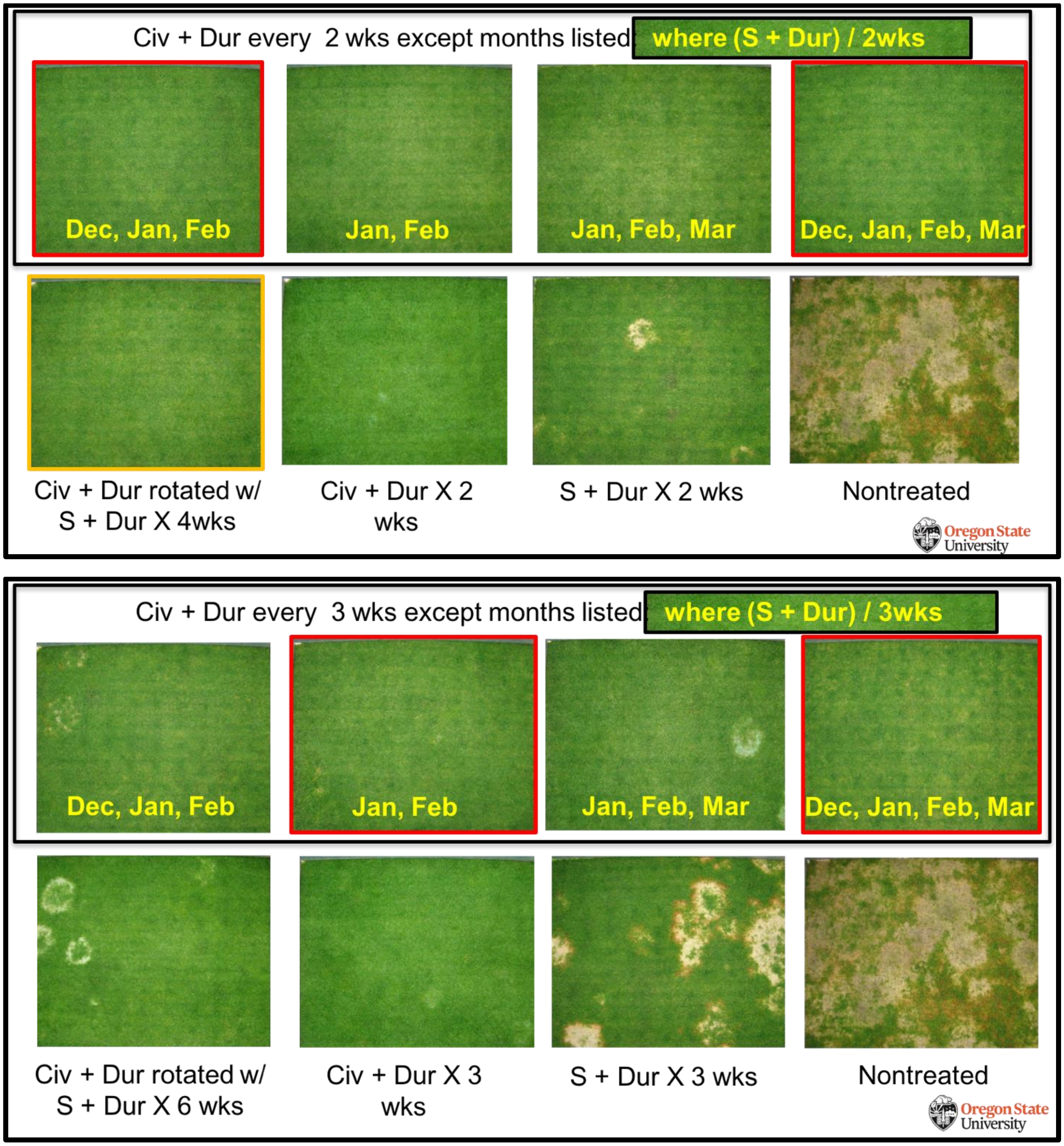

Image 1: Appearance of plots affected by treatments on a 2-week application interval (Top box) and a 3-week application interval (Lower box) on the incidence of Microdochium patch on an annual bluegrass putting green in Corvallis, OR. The field trial began on September 29, 2016 and final data collection for year one was taken on April 30th, 2017. Top row of each box received treatments of Civitas Defense (Civ) at a rate of 8.5 oz./M in combination with Duraphite 12 (Dur) at a rate of 3.2 oz./M except during the months listed in yellow. During the months listed, Sulfur DF (S) was applied a rate of 0.25#S/M in combination with Duraphite 12 at a rate of 3.2 oz./M. The bottom row includes treatments applied at the frequencies indicated of a Civitas Defense + Duraphite 12 rotated w/ Sulfur + Duraphite 12, a Civitas Defense + Duraphite 12 treatment, a Sulfur + Duraphite 12 application, and nontreated control plot.

Experiment 2:

Iron sulfate rates & phosphorous acid

The field trial began on September 29, 2016 and final data collection for year one was taken on April 30th, 2017. The second-year trial replication began on September 28, 2017 on a new area of the same green and will conclude on April 30th, 2018.

Preliminary observations:

First year observations indicate that as rates of iron sulfate increase, inhibition of Microdochium patch tends to increase (Image 2). Higher rates of iron sulfate also tend to lead to greater turfgrass thinning and lower turfgrass quality ratings. In addition, there is an indication that phosphorous acid applications tend to decrease the incidence of Microdochium patch and that there may be a benefit from applying phosphorous acid in combination with iron sulfate on disease inhibition and turfgrass quality.

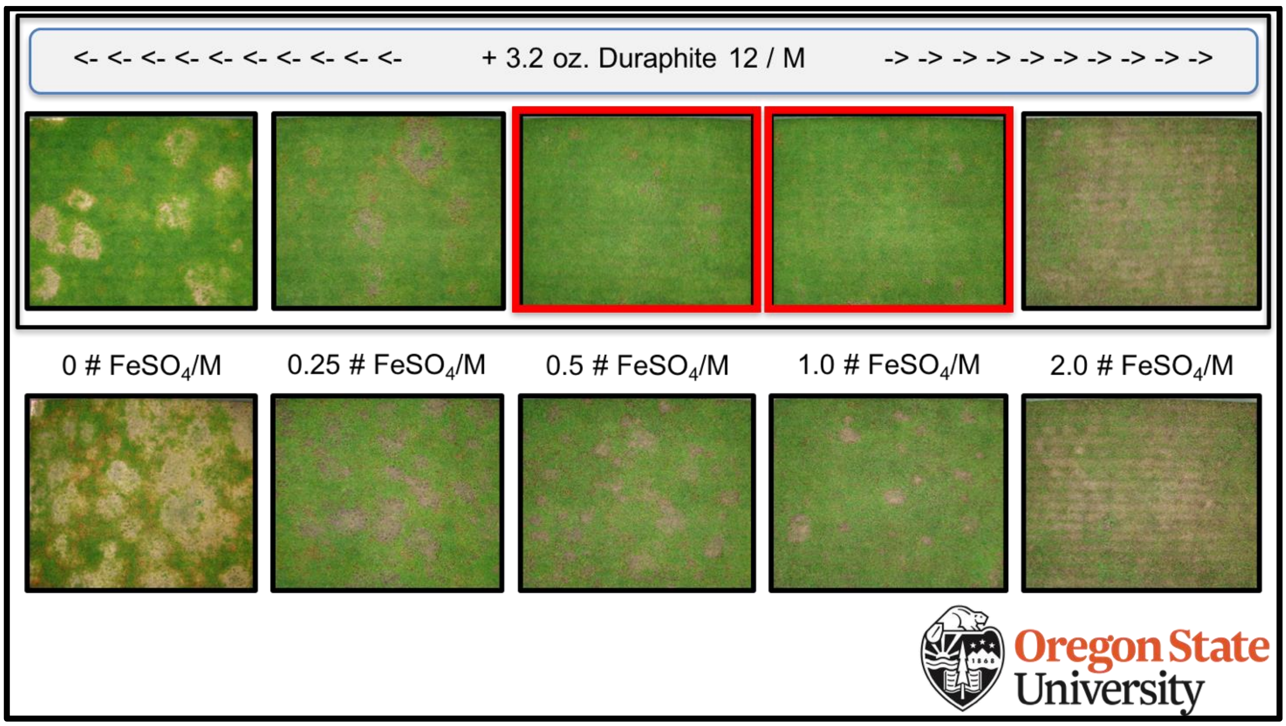

Image 2: Appearance of plots affected by treatments of different rates of iron sulfate ($FeSO_4$) applied either in combination with Duraphite 12 at a 3.2 oz./M rate (top row) or in absence of a Duraphite 12 application (bottom row) on the incidence of Microdochium patch on an annual bluegrass putting green in Corvallis, OR. The field trial began on September 29, 2016 and final data collection for year one was taken on April 30th, 2017. Treatments applied on a two-week application frequency.

Effects of winter applied nitrogen, phosphate and potassium rates on Microdochium patch

Brian McDonald and Alec Kowalewski

Oregon State University

Introduction:

Microdochium patch is particularly problematic on golf course putting greens from September through May in the Northwest. Historically, more money is spent on fungicides to combat this disease in the Northwest than any other turfgrass disease. Considering increasing concerns associated with pesticide use the turfgrass industry as a whole is in need of pesticide alternative control practices and strategies.

Research on primary nutrient (N, P and K) ratios have suggested that maintaining the proper balance of the nutrients is critical to disease mitigation. However, research on N, P, and K ratios relevant to annual bluegrass and Microdochium patch is not available. Contrary to traditional recommendations, recent research has also suggested that winter applications of N can improve annual bluegrass playing conditions and disease resistance.

Therefore, the objective of this research is to evaluate the effects of winter applied N, P and K rates on Microdochium patch development within an annual bluegrass putting green in the absence of traditional fungicides.

Materials and Methods:

This field trial began on September 29, 2017. Factors within this experiment included nitrogen rate, phosphorus rate, and potassium rate. Nitrogen (Urea - 46-0-0) rate include 0.10 lbs. N/1,000 ft^2 and 0.20 lbs. N/1,000 ft^2. Merchant Grade Phosphoric Acid (0-52-0) rates include an untreated control and 0.025 lbs. P/1,000 ft^2. Potassium Chloride (0-0-60) rates include an untreated control and 0.10 lbs. K/1,000 sq. ft^2. Nitrogen, phosphate and potassium rates were developed using N:P:K ratios that reflect tissue sampling data, and standard extension recommendations for putting greens.

Current Applications:

Nitrogen is being applied once per month at a rates of 0.1 or 0.2 lbs. N/1,000 ft^2 from October 2017 to April 2018 (totaling 0.7 and 1.4 lbs. N/1,000 ft^2 applied in the winter months). From October to April all treatments are receiving monthly applications of phosphite (Duraphite 12 applied at 3.14 oz/1,000 ft^2) and sulfur (Sulfur DF applied at 0.25 lbs. elemental S/1,000 ft^2), fungicide alternatives that have shown promising results for control of Microdochium patch. With these rates and intervals of phosphite and sulfur, we would not expect complete control but significant suppression to avoid disease levels from overwhelming plots. Anderson's 28-5-18 + micros fertilizer will be applied biweekly over the entire trial from May until September. Traditional fungicides are being applied to this experiment during the summer to control anthracnose for the duration of the study. All treatments will be repeated from October 2018 to April 2019, and again from October 2019 to April 2020.

Response Variables:

Turf quality and percent disease severity data is being collected every other week from October to April. Turf quality will be visually assed using the NTEP rating system; 9 being outstanding or ideal turf and 1 being poorest or dead. A rating of 6 or above is generally considered acceptable. To determine percent disease severity (0-100%) digital images will be collected using an enclosed light box and then analyzed using digital Sigma Scan Pro. Visual percent disease ratings will also be taken every other week.

Image 1: Reps 2 & 3 (November 28th): Annual bluegrass putting green in Corvallis, OR. The field trial began on September 29, 2017 and final data collection for the year will be taken in April 2018. Treatments are being applied monthly.

2016-20-570

Title: Comparative Control Methodology of *Belonalaimus longicaudatus* and *Meloidogyne* Species on Golf Course Putting Greens

Projects Leaders: Glenn Galle and Jim Kerns

Affiliation: North Carolina State University

Summary Text:

Trial one from the research project is progressing as anticipated, with the sampling for *Belonolaimus longicaudatus* entering its third year at Raleigh Golf Association ('L-93' creeping bentgrass) and Benvenue Country Club ('Champion' bermudagrass), and is about eighteen months along at Wilson Country Club ('A-1/A-4' creeping bentgrass). The data shows that sting nematode reaches its highest numbers in late summer on both bermudagrass and creeping bentgrass courses with numbers dropping significantly during the winter months. However, differences in start timing of nematode population growth has been observed with numbers increasing in March or April on creeping bentgrass putting greens whereas they increase in late April and May on bermudagrass putting greens. This is significant and indicates that earlier nematicide application is necessary depending upon the turfgrass species used.

An unanticipated result is the dramatic shift of nematode populations from the top ten centimeters of the soil column during the spring months to the middle ten centimeters during the summer months on creeping bentgrass in 2015 as seen in Figure 2. A similar trend was observed in creeping bentgrass in 2016, although sting nematode was more evenly distributed throughout the entire thirty-centimeter soil column during the summer. From Figure 1, the bermudagrass course also showed an even nematode population distribution throughout the entire thirty-centimeter soil column during the summer months of both years. This is beyond the rooting depth of both turfgrasses and we are further investigating why the nematodes are this deep in the soil column. In both turfgrass species, the winter months show a majority of the nematodes in the top ten centimeters of the soil column and at significantly high population levels, indicating that feeding may be occurring during the winter months when bermudagrass is dormant and creeping bentgrass is slow to produce new roots. This indicates the potential addition of a fall nematicide application to a current spray program may be necessary to protect turfgrass roots from nematode feeding when they are highly vulnerable.

The final year of sampling for sting nematode will help to provide stability to trends currently present, and potentially will clear up any differences observed between the two years of current data.

The *Meloidogyne spp.* sampling portion of the project at Sedgefield Country Club ('Champion' bermudagrass) has just finished its first year, and data is inconclusive and erratic. Unfortunately, we were asked to vacate the course for a year due to winter damage and therefore had to start sampling a year after we started the sting nematode portion. Sampling for three years is still planned.

Trial two from this project is currently in the planning phase. We are collecting nematodes and establishing populations in the greenhouse for use in the cultivar screen. Cultivar selection is also occurring at this time, and seed or sprig collection will begin in the winter. The planned start of the project is spring of 2017 and it is expected to take approximately one year.

Summary Points:

- Sting nematode has been observed deeper in the soil column during the summer months than expected.
- Sting nematode numbers increase earlier in the spring on creeping bentgrass putting greens than bermudagrass greens.
- Root-knot nematode sampling has been delayed, and results are unavailable.
- Cultivar screening is currently in the planning stage, and the project is expected to start in the spring of 2017.

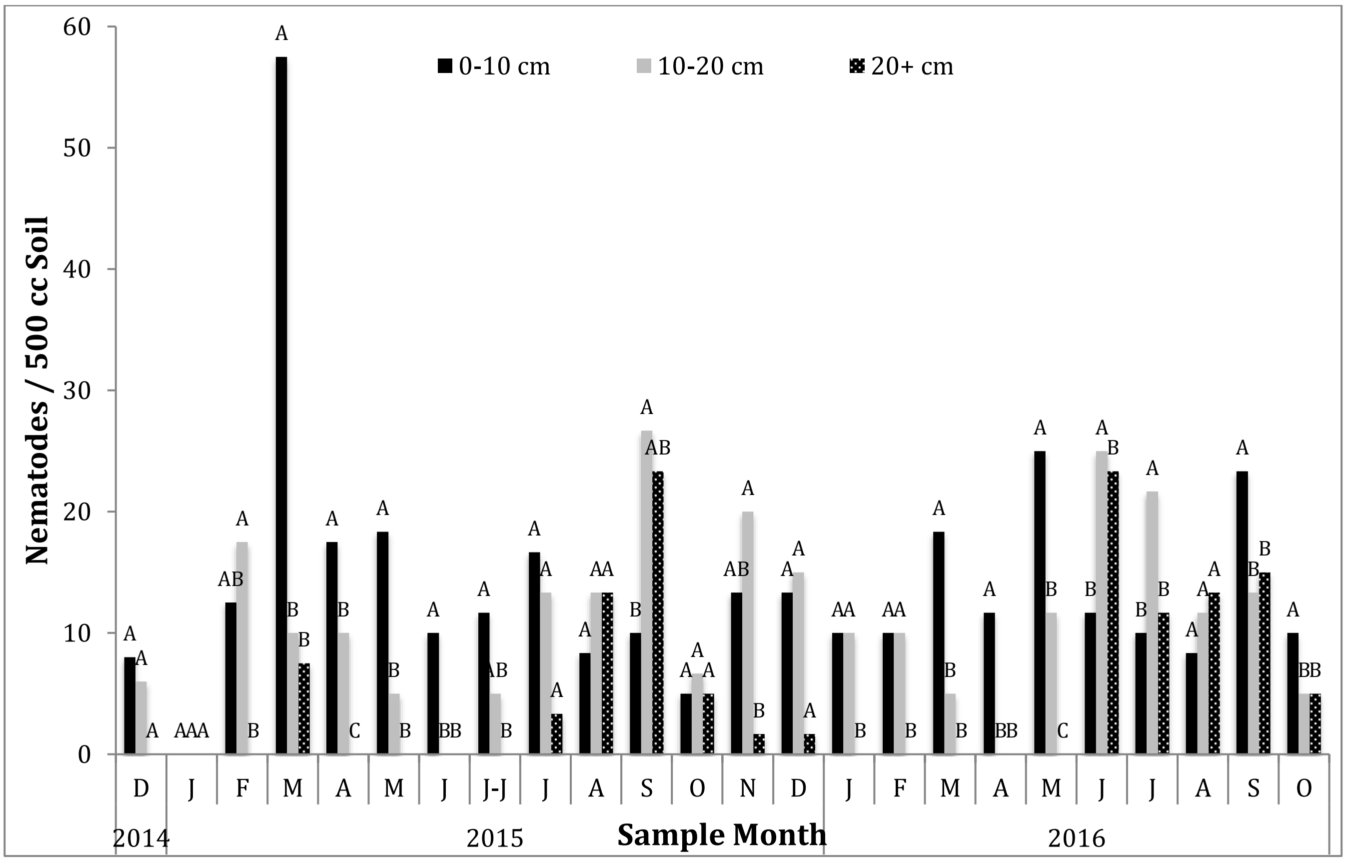

Figure 1. Sting nematode population sampling distribution on bermudagrass from Benvenue Country Club, Rocky Mount, NC.

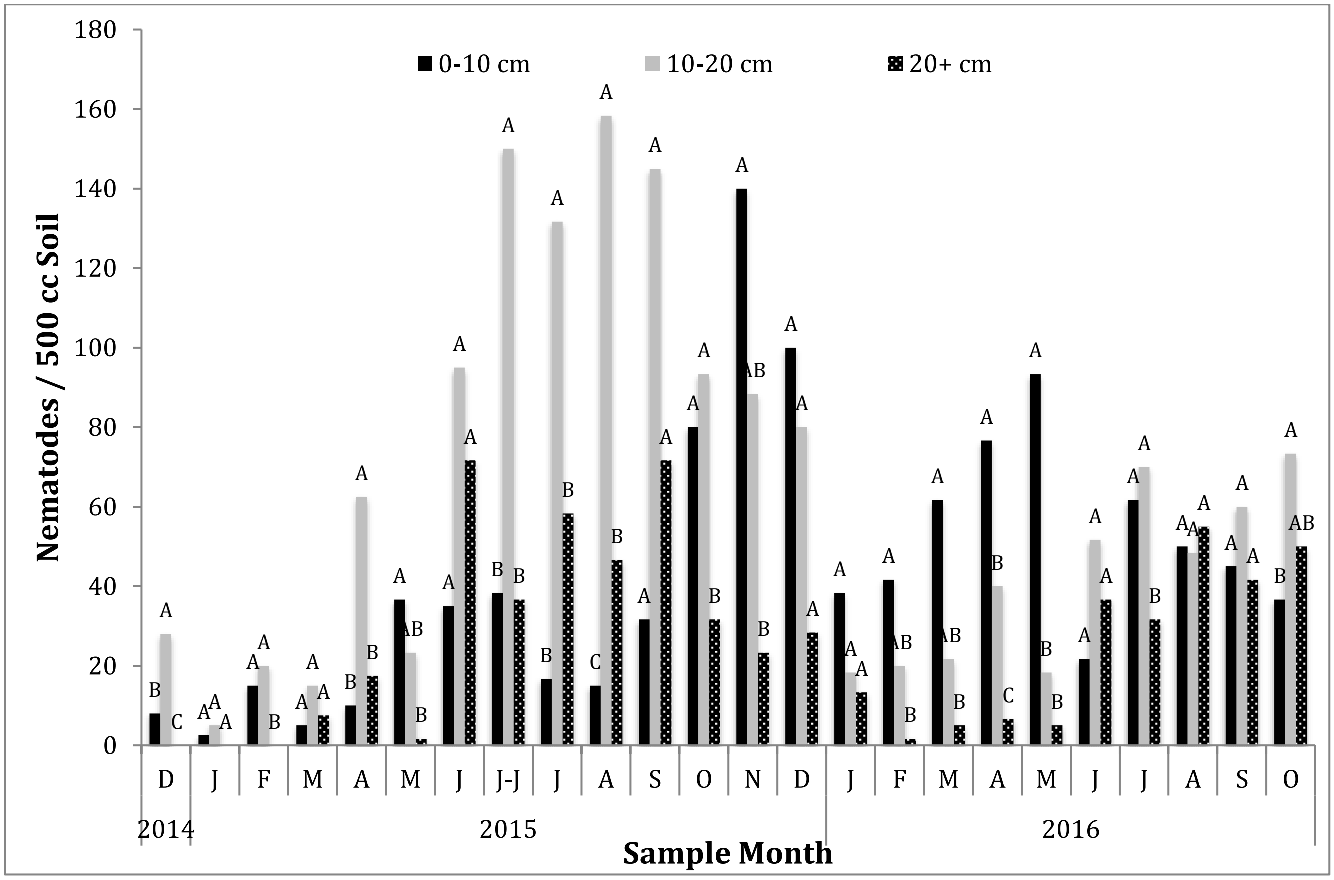

Figure 2. Sting nematode population sampling distribution on creeping bentgrass from Raleigh Golf Association, Raleigh, NC.

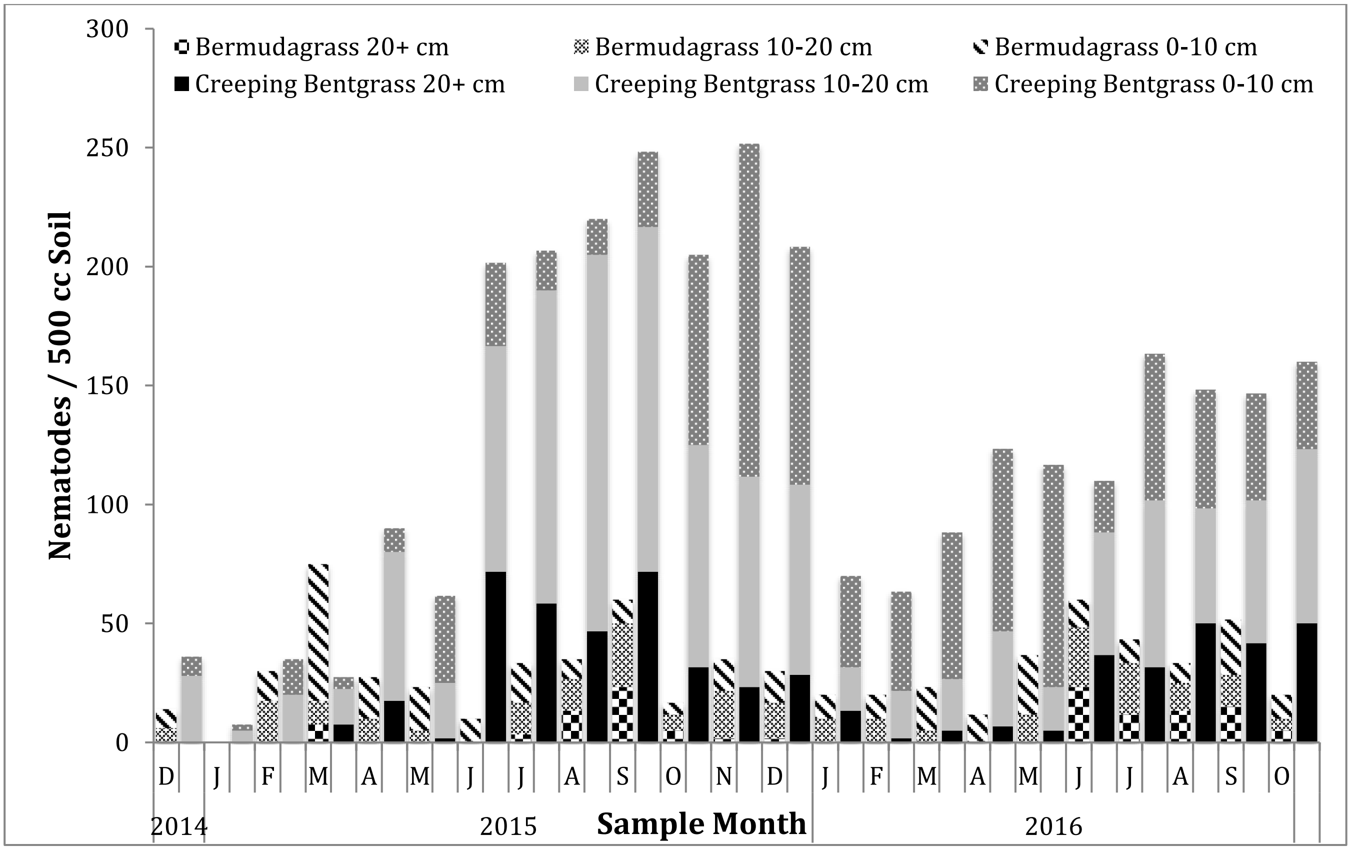

Figure 3. Comparison between creeping bentgrass and bermudagrass population dynamics.

2015-09-524

Title: Biological control of black cutworm in turf with baculovirus - 2017

Project Leader: Robert Behle (USDA-ARS-NCAUR, 1815 N. University Ave., Peoria, IL)

Co-Investigator: Doug Richmond (Purdue University, Department of Entomology, West Lafayette, IN)

Objectives:

1) Determine effective application rates and formulations of the virus required for control of larvae,
2) Compare baculovirus treatments with alternative control treatments when applied under field conditions,
3) Evaluate compatibility of virus applications with integrated management strategies for pest control within the golf-turf environment.

Start Date: Spring 2015

Project Duration: 3

Total Funding: $60,000

Bullet Points

- Treating turf with the black cutworm baculovirus is a highly effective control treatment for black cutworm larvae.
- Alternative microbial-based biological treatments (a Beauveria fungus or a Bacillus bacterium) were less effective for control of cutworm larvae.
- Mixing biological agents for application to turf did not provide synergistic pest control, which has been observed for other insect pests.

Summary text:

The black cutworm (BCW) is a pest of bentgrass turf planted for golf courses. Larvae feed on the plants and create divots in greens that affect game play. Biological control technologies are sought to provide effective pest control and reduce hazards associated with conventional chemical pesticides. Although not yet registered as a commercial product in the U.S., the insect specific virus known as AgipMNPV is one agent with high potential to serve as a biological insecticide.

Our research focused on documenting pest control efficacy of virus treatments with and without other microbial-based pest control agents in an effort to support biological control of BCW larvae in turf. This year, experiments evaluated treatments consisting of individual and combinations of known microbial agents for efficacy against BCW larvae. The unifying premise of these experiments was to determine if multiple agents would provide greater than expected mortality (synergistic effects) for control of cutworm larvae infesting managed turfgrass. A synergistic combination would provide effective pest control with lower application rates of the biological pesticides, effectively reducing treatment costs. Synergy between microbial agents has been documented for other insect pests that are closely related to the BCW.

Preliminary experiments were conducted at the USDA-ARS laboratory in Peoria, IL to identify appropriate application rates to determine a synergistic interaction among three insect pathogenic microbes. The three microbial agents were: 1) baculovirus = AgipMNPV, 2) fungus = *Beauveria bassiana* strain GHA, and 3) bacterium = *Bacillus thuringiensis kurstaki*. The fungus and bacterium are the active agents in BotaniGard (Bioworks, Inc., Victor, NY) and Deliver (Certis USA L.L.C., Columbia, MD) insecticides, respectively. Application rates targeting 30-40% mortality of exposed insects were determined for each microbe. This relatively low activity level was necessary to provide the opportunity to observe higher than expect mortalities for combined treatments. Selected application rates were as follows: virus = 1×10^{11} occlusion bodies (virus particles) per acre, fungus = 5×10^{12} spores per acre, bacteria = 908 g product (Deliver) per acre. Telstar (bifenthrin) was applied at the labeled rate of 227.8 ml per acre.

To evaluate the relative efficacy against newly hatched and later instar larvae, six biopesticide treatments (virus, fungus, bacteria, virus + fungus, virus + bacteria, fungus + bacteria) and a chemical standard (Talstar) were applied on field plots of creeping bentgrass maintained at 3/16 inch height and managed as a golf green. An untreated control was included. Treatments were replicated 4 times using a randomized complete block design. All treatments were applied as aqueous sprays at the rates listed above using a total spray volume of 2 gallons/1000 ft^2, and each treatment was replicated 4 times (Fig 1). Before application, two PVC cages (8 inch diameter) were installed in each plot and were artificially infested with either twenty neonates or ten 2^{nd}- 3^{rd} instar BCW larvae. Larvae were allowed to feed within the cages for 16 days after treatment before being flushed from the turf using a standard soapy water solution. Number of live larval, larval mass (mg/plot), and plant damage estimates (%) were recorded for each cage in a plot. BCW control percentage was calculated based on the number of larvae for each treatment relative to the number of larvae in the control treatment.

The biological treatments applied at low application rates provided significant pest control of newly hatched and 2^{nd}-3^{rd} instar BCW larvae when compared with the untreated control plots (Table 1). Only the fungus (*Beauveria bassiana*) alone plots and the combined virus (AgipMNPV) + bacterium (*Bacillus thuringiensis*) plots had significantly more 2^{nd}-3^{rd} instar larvae than the Telstar treated plots and were not significantly different from the untreated plots. Unfortunately, no synergistic effects were observed for applications of combinations of microbial agents, leaving the virus treatment as the best choice among these biopesticide treatments.

Plant damage ratings varied widely among plots and these highly variable data did not provide statistical differences among treatments. Generally, larger larvae, 2^{nd}-3^{rd} instar, in the untreated plot caused considerable feeding damage (Fig. 1, A), but minimal feeding damage was observed in treated plots (Fig.1, B). By contrast, newly hatched larvae did little damage to the grass in either treated or untreated plots, averaging about 10% feeding damage among all plots (Fig. 1, C and D).

In conclusion, the virus alone treatment provided good control of small and medium sized larvae, even when applied at this low rate. We did not observed a synergistic benefit by applying multiple microbial organisms, maintaining the more traditional single product application for pest control.

Table 1. Survival (n/10±SE), percent control, mean larval mass (±SE) and % plant damage by neonates and 2nd and 3rd instar black cutworm larvae in plots of creeping bentgrass treated with Talstar (bifenthrin) or virus (AgipMNPV) alone and in combination with other biological control agents. Plots were infested and products were applied on September 26, 2017. Cutworm survival, larval mass, and percent damage was determined on October 12, 2017.

Treatment	Survival ± SE (n/10)	% Control	Mean Larval Mass ± SE (mg)	% Damage ± SE
Newly Hatched				
Untreated	5.5±0.6b	0.0	41±10b	11.3±1.3a
Talstar	0.0±0.0a	100.0	0±0a	10.0±2.0a
virus	0.3±0.3a	95.5	6±6a	9.3±1.5a
fungus	1.8±0.9a	68.2	24±9ab	10.0±2.0a
bacteria	2.0±1.2a	63.6	21±14ab	10.0±2.0a
virus + fungus	1.3±1.3a	77.3	6±6a	10.0±2.0a
virus + bacteria	1.5±0.9a	72.7	27±18ab	10.0±0.0a
fungus + bacteria	2.3±1.4a	59.1	14±9ab	11.3±1.3a
2nd & 3rd Instar				
Untreated	8.5±0.6d	0.0	323±22c	52.5±24.5a
Talstar	0.0±0.0a	100.0	0±0a	11.3±3.1a
virus	1.8±1.0ab	79.4	14±9a	8.8±1.3a
fungus	5.8±2.0bcd	32.4	176±88abc	37.5±20.7a
bacteria	3.3±1.9abc	61.8	64±44ab	15.0±5.4a
virus + fungus	1.8±1.4ab	79.4	74±74ab	23.8±15.5a
virus + bacteria	4.5±1.8bcd	47.1	232±84bc	41.3±20.2a
fungus + bacteria	3.5±2.0abc	58.8	151±87abc	46.3±19.9a

Figure 1. Field research plot layout at the Daniel Turfgrass Research and Diagnostic Center**,** Purdue University, West Lafayette, IN, used to evaluate microbial biopesticides for control of black cutworm larvae feeding on bentgrass turf managed under putting green conditions (center). Examples of larval feeding damage after 16 days; A = 2^{nd}-3^{rd} instar untreated, B = 2^{nd}-3^{rd} instar treated, C = newly hatched untreated, D = newly hatched treated.

2016-22-572

Title: Developing Optimal Management Programs for Annual Bluegrass Weevil Populations with Different Insecticide Resistance Levels

Project Leaders: Albrecht M. Koppenhöfer, Olga S. Kostromytska, and Shaohui Wu

Affiliation: Department of Entomology, Rutgers University, New Brunswick, NJ

Objectives: The overall goal is to develop a better understanding of the degree and scope of insecticide resistance in ABW populations as a basis for the development of recommendations on resistance management. For this project in particular, the objective is: Compare field efficacy of typical insecticides used against ABW adults and larvae against four ABW populations representing the full scope of insecticide resistance levels observed to date.

Summary Text:
The annual bluegrass weevil (ABW), *Listronotus maculicollis*, is a serious and expanding golf course pest with demonstrated ability to develop resistance to a range of insecticides. Previous and ongoing in depth studies on ABW insecticide resistance have been restricted to laboratory and greenhouse studies. Field observations on resistance originated from product efficacy testing trials that are generally not designed to truly understand how resistance affects product efficacy. To understand how to put together optimal management programs for different resistance levels, we studied the individual tools separately (different products applied only once at specific times). We tested the efficacy of individual applications of the commonly used adulticides and larvicides on fairways at four golf courses representing the full spectrum of pyrethroid-resistance as clearly characterized in our lab studies. Resistance ratios (RR_{50}s) to the pyrethroid bifenthrin at the four courses were 2, 30, 100, and 343.

Insecticide applications targeting adults were tested in separate experiments from those targeting larvae to keep the size of experiments manageable. Adulticides (Table 1) were applied at the optimal timing to control overwintered adults, i.e., when most adults have moved onto the short mown areas in spring but before females start laying eggs as determined by vacuum sampling of adults, degree day accumulation (base 50 °F) (120 GDD_{50}), and indicator plant phenology (forsythias half gold : half green). Larvicides (Table 1) were applied to target young larvae around late bloom of flowering dogwood (200 GDD_{50}) and mid-size larvae around full bloom of hybrid Catwba rhododendron, 400 GDD_{50}). Treatments were evaluated at around 700 GDD_{50} when most developmental stages were around the 5th instar. Data from two years of field study with two trials conducted at each resistance level were combined for analysis, and year did not interact with insecticide resistance level or treatment.

For adulticides, we observed no interaction between resistance level and insecticides. Control at 2x and 30x resistance was higher than at 100x, and control was the lowest at 342x. All insecticides caused significant control. Talstar gave higher control than Provaunt, but Dursban and Conserve did not differ significantly from either. At 2x and 30x, all insecticides significantly reduced ABW populations; at 100x only Talstar caused significant reduction; and at 343x none of the insecticides caused significant reduction (Fig. 1, left). All adulticides were significantly affected by resistance.

For larvicides (Fig. 1, right), timing of application did not affect efficacy of Acelepryn, Ference, and Arena except that at the 100x level Arena was less effective when applied against the young larvae. Resistance level and insecticide interacted significantly. Ference and Conserve were not affected by resistance level, Provaunt was significantly less effective at the 343x level, and all other insecticides were significantly less effective at the 100x and 343x levels. At the 2x and 30x resistance levels, Ference, Conserve, Provaunt and Dylox were the most effective insecticides, whereas Arena and Acelepryn were the least effective insecticides. At 100x, Ference was the most effective insecticide followed by Provaunt and Conserve, whereas Acelepryn (late application), Arena (late application) and Dylox provided only 30-42% control, and the early applications of Arena and Acelepryn provided no significant control. At 343x, only Ference and Conserve provided significant control.

Summary Points:

- Efficacy of Talstar, Dursban, Provaunt, and Conserve against ABW adults declines with pyrethroid-resistance level, starting around the 100x resistance level, and they are completely ineffective against highly resistant populations.
- Dursban is not an effective replacement for pyrethroids in control of ABW adults.
- Ference, Acelepryn, and Arena appear to be similarly effective if applied against young larvae or mid-size larvae.
- Ference and Conserve as larvicides appear to be unaffected by resistance to date.
- Provaunt is effective up to the 100x level but completely ineffective against highly resistant ABW larvae.
- Acelepryn, Arena, and Dylox are strongly affected by resistance starting around the 100x level.

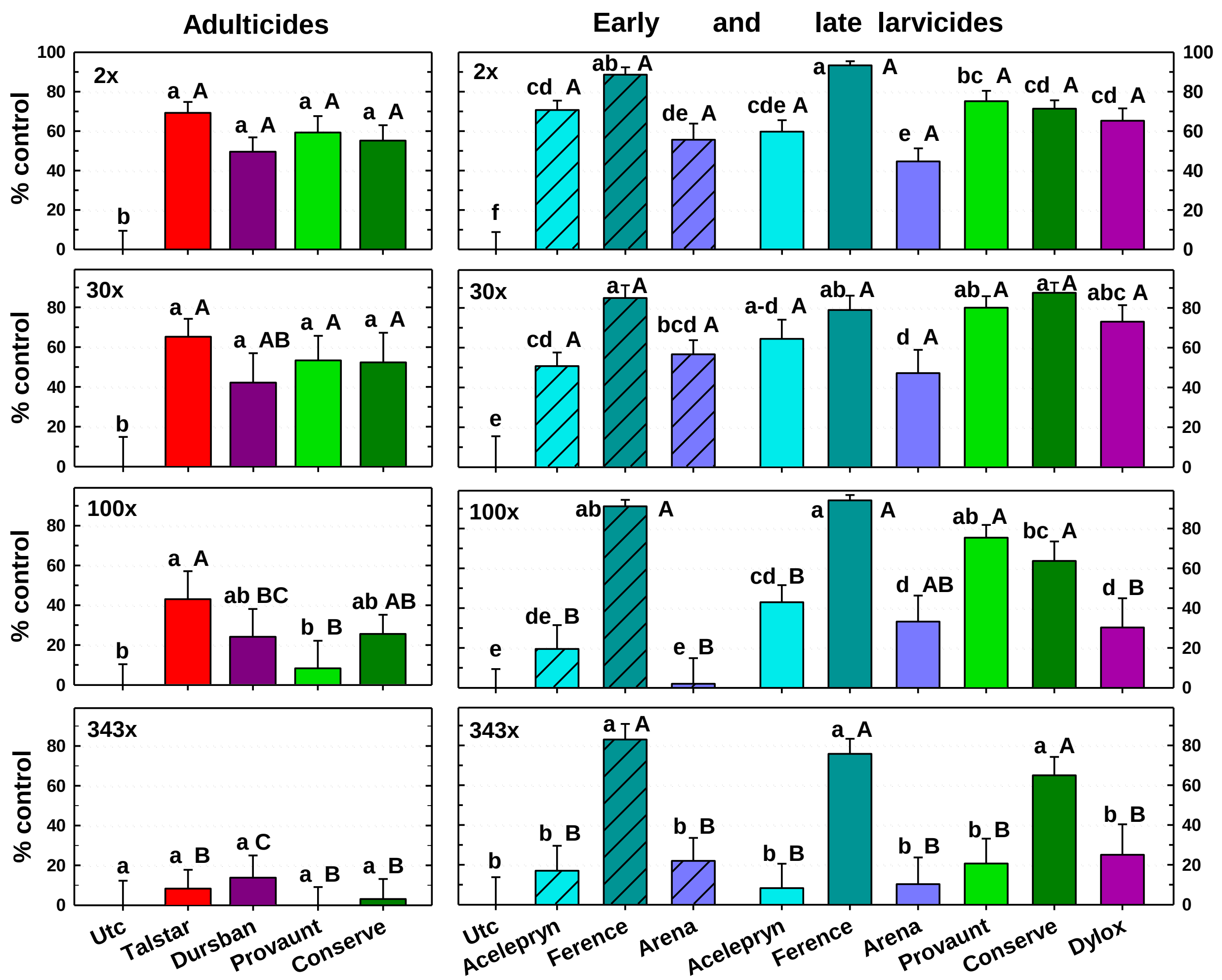

Fig. 1. Effect of pyrethroid resistance level (2x, 30x, 100x, 343x) on control of annual bluegrass weevil developmental stages in early June (peak 4th to 5th instar) in golf course fairways treated in spring with adulticides at peak densities of overwintered adults (forsythias half gold : half green), with early larvicides targeting young larvae (late bloom dogwood), or with late larvicides targeting mid-size larvae (full bloom rhododendron). Data are combined from two trials over two years for each resistance level. Means within product and timing (vertical) followed with the same capital letter did not differ significantly ($P > 0.05$). Means within each panel with the same lower case letter did not differ significantly ($P > 0.05$).

Table 1. Insecticides tested against adults (Ad) and young (L1-2) and older (L2-4) ABW larvae.

Insecticide class	Active ingredient	Trade name	Rate (lb ai/ac)	Targets
Pyrethroid	Bifenthrin	Talstar	0.100	Ad
Organophosphate	Chlorpyrifos	Dursban	1.000	Ad
	Trichlorfon	Dylox	6.000	L2-4
Spinosyn	Spinosad	Conserve	0.400	Ad, L2-4
Oxadiazine	Indoxacarb	Provaunt	0.225	Ad, L2-4
Anthranilic diamide	Chlorantraniliprole	Acelepryn	0.156	L1-2, L2-4
	Cyantraniliprole	Ference	0.156	L1-2, L2-4
Neonicotinoid	Clothianidin	Arena	0.247	L1-2, L2-4

2016-23-573

Effects of mowing height and nitrogen fertilization on annual bluegrass weevil oviposition, larval development, and turfgrass damage

Dr. Benjamin A. McGraw; Pennsylvania State University

Start Date: 2015
Duration: 3 years
Total funding: $45,000

Objectives:

(1) Determine the effects that putting green mowing heights have on ABW adult survival, diel activity, larval growth and development, and turfgrass damage
(2) Determine the impacts that early-season N fertility regimes have on adult preference and larval development; characterize the interactions between mowing height and fertility on larval abundance and turfgrass damage expression

The annual bluegrass weevil (ABW), *Listronotus maculicollis*, is the most destructive insect pest of golf course turf in eastern North America. Golf course superintendents primarily manage the insect with sequential applications of chemical insecticides, typically covering a majority of, if not all short-mown surfaces. Putting greens (which receive the most frequent insecticide applications) are rarely damaged, yet collars adjacent to the same putting greens are commonly damaged. These observations led our laboratory to investigate the effects that putting green cultural practices have on the ability for ABW populations to establish in low mowing heights.

Objective 1*: Determine the effects that putting green mowing heights have on ABW adult survival, diel activity, larval growth and development, and turfgrass damage*

Greenhouse studies demonstrated that between 26 and 38% of adults were removed when turf was mowed at 2.54 mm (0.100”), but the effect diminished with increasing mowing heights. The majority of adults survived mowing, indicating a potential for adults to reinvade turf stands adjacent to areas where grass clippings are discarded. Females oviposited in all mowing height treatments in laboratory and field experiments. However, behavior was influenced by plant height, as significantly fewer eggs were placed inside of the turfgrass stem at the lowest mowing height (Figure 1). Larval development was not affected by egg placement or turf height, and significant numbers of larvae were capable of developing to damaging stages (fourth- and fifth-instar larvae) in all treatments.

Field studies were initiated in 2017 to compare the effect of double-cutting versus the effect of a single mowing. Height-of-cut, but not frequency, had a significant effect on the number of adults removed with the lowest treatment capable of removing ~ 50% of infested adults (Figure 2). The greatest benefit to adult removal with double cutting was observed at the 3.8 mm (0.150”) treatment. Both mowing frequency treatments had minimal impacts on adult mortality, though significantly more adults were killed in double cutting treatments with increasingly lower mowing heights.

Laboratory studies using time lapse photography revealed that temperature has a significant effect on adult activity on top of the canopy. Activity was greatest between 15 and 20^{o} C and only low percentages were observed on top of the canopy when temperature were 10^{o} C or less. A novel mark-release technique, combining fluorescent marks with still photography allowed for an hourly census of adult activity in the field. Adult activity on top of the turfgrass canopy was greatest during the day and strongly correlated with temperature early in the season (April, May). However, adult activity in June was highest briefly after sunrise, then declined once temperatures exceeded 20^{o} C. A polynomial regression model predicts that adults are most active on the surface between 14 and 20^{o} C. Timing mowing events around these conditions in spring may lead to improved removal.

Objective 2*: Determine the impacts that early-season N fertility regimes have on adult preference and larval development; characterize the interactions between mowing height and fertility on larval abundance and turfgrass damage expression*

ABW ovipositional preference and larval development was assessed for three early-season N-fertility regimes. In choice-assays, significantly more adults were found in high-N plots (48.8 kg N ha^{-1} mo^{-1} or 1 lb N M^{-1} mo^{-1}) in 2015, but not in 2016 studies. However, significantly more eggs were detected in the medium-N treatments (19.5 kg N ha^{-1} mo^{-1} or 0.4 lb N M^{-1} mo^{-1}) in both years. This is the rate currently recommended for managing anthracnose (*Colletotrichum cereale*) in *P. annua* greens in the Northeast. No significant differences were detected between N fertility treatments in the field for either late-instar larval (4th and 5th instars) or pupal densities. Although statistical differences were not detected, more larvae were recovered from the low-N treatment (4.9 kg N ha-1 mo-1 or 0.1 lb N M-1 mo-1). Additionally, larval fitness (as measured by 5th instar weight) was not affected by N-fertility treatment.

The effect of nitrogen fertility and plant growth regulation (PGR) on *L. maculicollis* oviposition/larval survival was assessed in no-choice field studies in 2017. A 3 (fertility) × 4 (regulation) factorial design was employed to determine the effect of each variable as well as the combined effect on larval abundance. No significant differences were detected between nitrogen treatments, though strong statistical differences were found between PGR treatments as well as N × PGR (Figure 3). Fewer larvae were found in plots treated with trinexapac-ethyl (Primo) than those treated with ethephon- (Proxy) or those without growth regulation. No significant differences were detected between Primo- and Primo + Proxy-treated plots. More studies are needed to further elucidate mechanisms behind the differences (e.g. nutritional differences, plant architecture) in larval abundance in regulated treatments.

Bullet Points (2015-17):

1. Moderate percentages of ABW adults (~ 40%) were removed with a single, low mown treatment (2.5 mm or 0.100”). The effect of mowing on adult removal diminished with increasing mowing heights. Most adults (> 96%) survived mowing (all heights combined).

2. Females were capable of ovipositing into the lowest putting green heights, though more eggs were placed outside the turfgrass stem or sheath as mowing height decreased.

3. Adult activity on top of the turfgrass canopy was greatest when temperatures were between 14 and 18° C (57 and 64° F).

4. Significantly more eggs were collected from moderate-fertility (0.1 lb N M^{-1} wk^{-1}) treatments than low- or high-N treatments in choice tests. However, nitrogen fertility did not affect larval abundance in no-choice field studies.

5. Larvae were capable of developing in all mowing height and fertility treatments. No significant differences in larval fitness were detected between treatments.

6. Significant differences were detected in larval abundance (but not fitness) in plant growth regulated turf (trinexapac ethyl, trinexapac ethyl + ethephon) compared to untreated plots.

Figure 1. Differences in adult oviposition behavior was noted between putting green-height and taller turfgrass. Left: eggs are deposited inside the stem of the plant at fairway-height (12.5 mm/0.500"). Right: Many of the eggs deposited in putting-green heights (< 3.8 mm/ 0.125") were loose or outside of the plant.

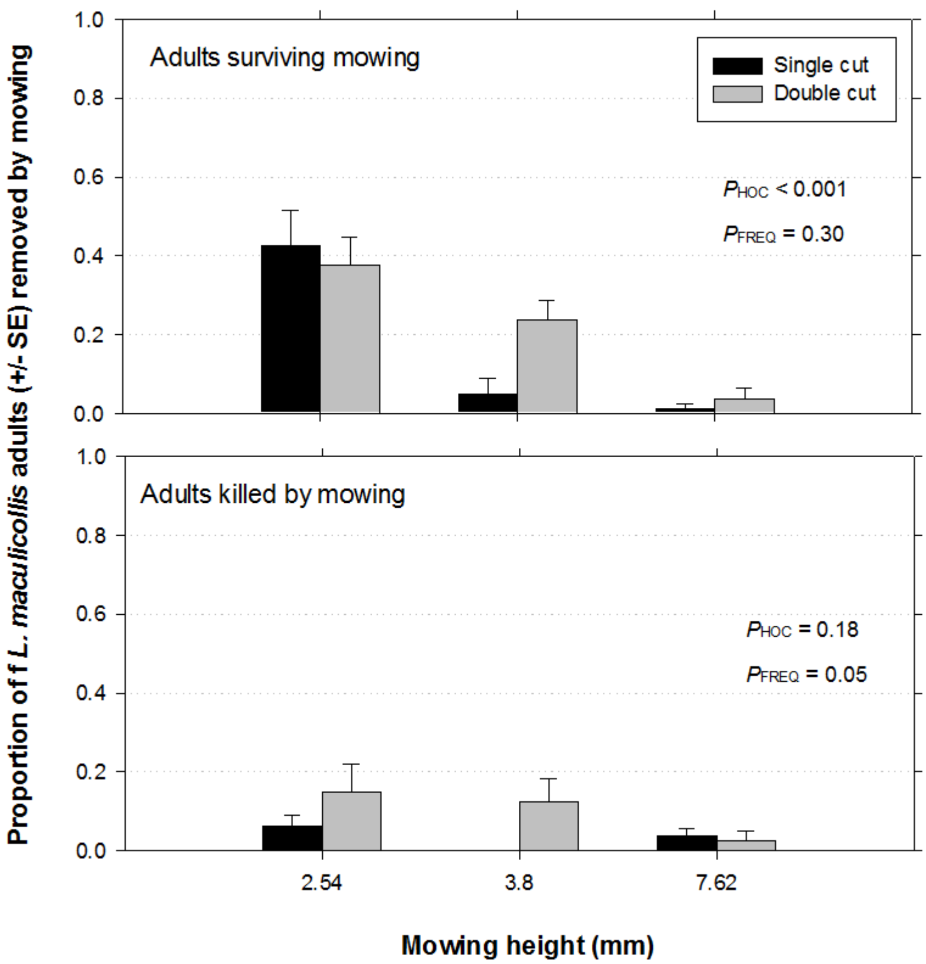

Figure 2. Effect of putting green mowing height-of-cut (HOC) and frequency (single and double cut) on the removal of *L. maculicollis* adults (2017). Polynomial contrasts were performed where ANOVA revealed significant effects at $\alpha = 0.05$ level.

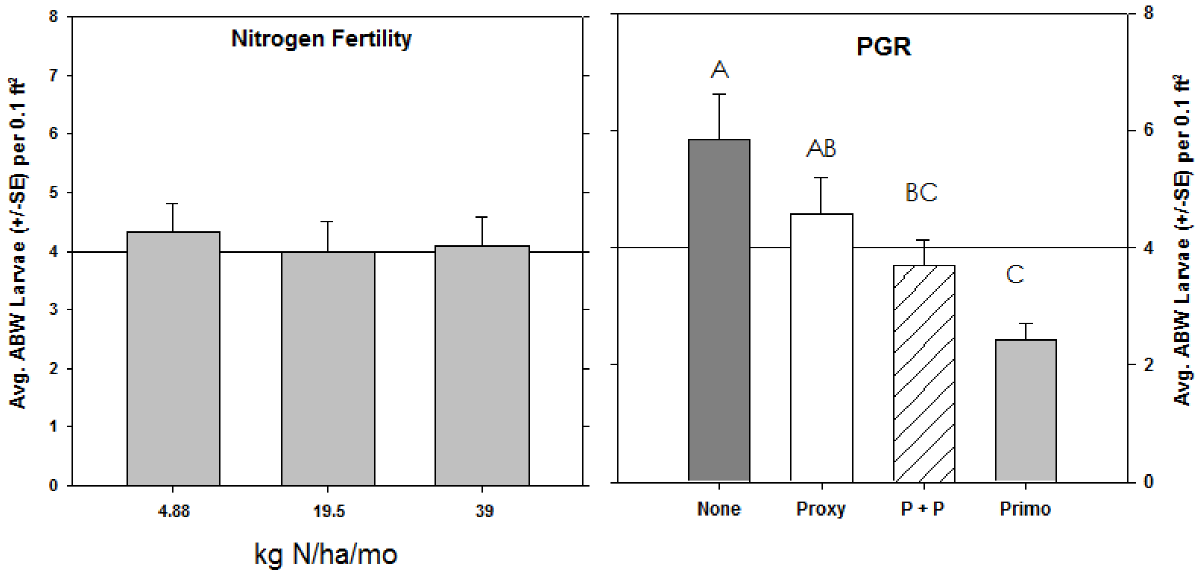

Figure 3. Effect of early-season nitrogen fertility and plant growth regulation on *L. maculicollis* larval abundance in no-choice field studies (2017). No significant differences were detected for fertility treatments. Significant differences were detect between PGR treatments and PGR × Fertility treatments. The solid line represents the damage threshold for *L. maculicollis* (40 larvae/ft^2).

2017-08-618

Title: Biological Control of Annual Bluegrass Weevil with novel Formulation Types and Application Systems for Entomopathogenic Fungi: Microsclerotia-based formulations and Hydrogels

Project Leaders: Albrecht M. Koppenhöfer[1], Olga S. Kostromytska[1], Shaohui Wu[1], Ann E. Hajek[2]

Affiliation: [1]Department of Entomology, Rutgers University, New Brunswick, NJ; [2] Dept. Entomology, Cornell University, Ithaca, NY

Objectives: The goal is to develop a granular formulation of microsclerotia of *Metarhizium brunneum* F52 as an effective and viable biological control option for ABW. Specifically, we want to determine:

1. Compatibility of formulation with commonly used golf course fungicides.
2. Efficacy of formulation against ABW adults and externally feeding larvae.
3. Effect of hydrogels on efficacy and persistence of formulation and compatibility with golf course turfgrass.

Summary Text:

The annual bluegrass weevil (ABW), *Listronotus maculicollis*, is a major pest of short-mown golf course turf in eastern North America. Its ability to develop resistance to a wide range of insecticides warrants the development of alternative control methods. Products based on the conidial spores of entomopathogenic fungi have thus far given unreliable control of ABW adults and larvae in the field, but the use of fungal microsclerotia may improve economy and efficacy of fungus-based products. Microsclerotia are survival structures naturally formed in soil by fungi. Applied microsclerotia granules produce infective conidial spores over several weeks, thus prolonging the residual effect of the fungus application. Improvements in conidia production by microsclerotia in soil can be made by the addition of hydrogels. Hydrogels have a capacity to hold large volumes of water when moistened and can slowly release this retained water over time, making it available to plants, fungi and other organisms.

The compatibility of *Metarhizium brunneum* F52 microsclerotia with common golf turf fungicides from different classes (Banner Maxx II: 14.3% propiconazole; Chipco 26 GT: 23.3% iprodione; Daconil WeatherStick: 54% chlorothalonil; TwinLine: 12% pyraclostrobin and 7.4% metconazole; Stratego: 11.4% propiconazole and 11.4% trifloxystrobin) was tested in the laboratory. The fungicides were incorporated into 1.2% water agar at rates that included and exceeded typical field rates. Clay-based microsclerotial granules were added to each Petri dish and incubated at 26 °C for 9 days before the number of viable spores produced was determined. Chlorothalonil did not inhibit fungal growth; iprodione was slightly inhibitory at higher concentration; propiconazole, Twinline and Stratego strongly inhibit fungal growth except at the lowest concentration (Fig. 3).

Based on our laboratory findings, three fungicides were applied at two rates (propiconazole: 0.5 and 1.8 kg ai/ha; iprodione: 1.5 and 6 kg ai/ha; chlorothalonil: 2.2 and 8.6 kg ai/ha) to pots with creeping bentgrass in the greenhouse. Microsclerotia granules had been applied to the pots 1 day earlier. After 10, 20 and 30 days, the number of fungal colony forming units (CFUs) in the top 2.5 cm of soil and the grass was determined. There was no effect of evaluation time and no significant interactions between treatment and evaluation date. Only propiconazole significantly inhibited fungal growth (F = 8.20; df = 6, 187; P < 0.0001).

In greenhouse experiments to date, different rates of *M. brunneum* microsclerotia had no significant effect on survival of ABW adults and larval population densities. However, in a field experiment, microsclerotia and the insecticide imidacloprid provided additive control, albeit at a low level (44%). Future experiments in greenhouse and field will compare the control efficacy of microsclerotia with that of commercial conidial spore formulations alone and in combinations with hydrogel and/or imidacloprid.

Summary Points:

- *M. brunneum* microsclerotia are compatible with the turf fungicides iprodione and chlorothalonil.
- The fungicide propiconazole has a suppressive effect on *M. brunneum* spore production.
- *M. brunneum* microsclerotia alone did not significantly suppress ABW adult and larval populations.
- Combinations of *M. brunneum* microsclerotia with the insecticide imidacloprid provided additive control of ABW larval populations in the field.

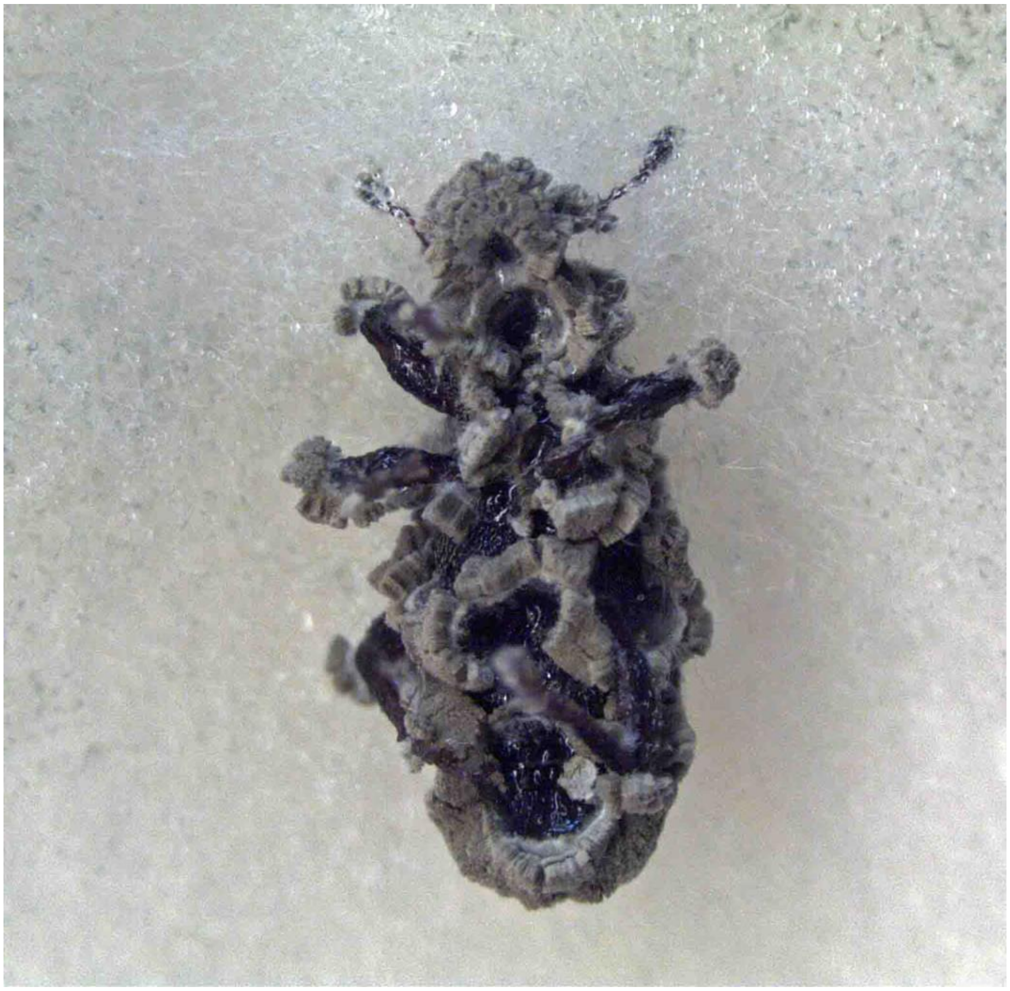

Fig. 1. ABW adult infect with *Metarhizium brunneum* F52.

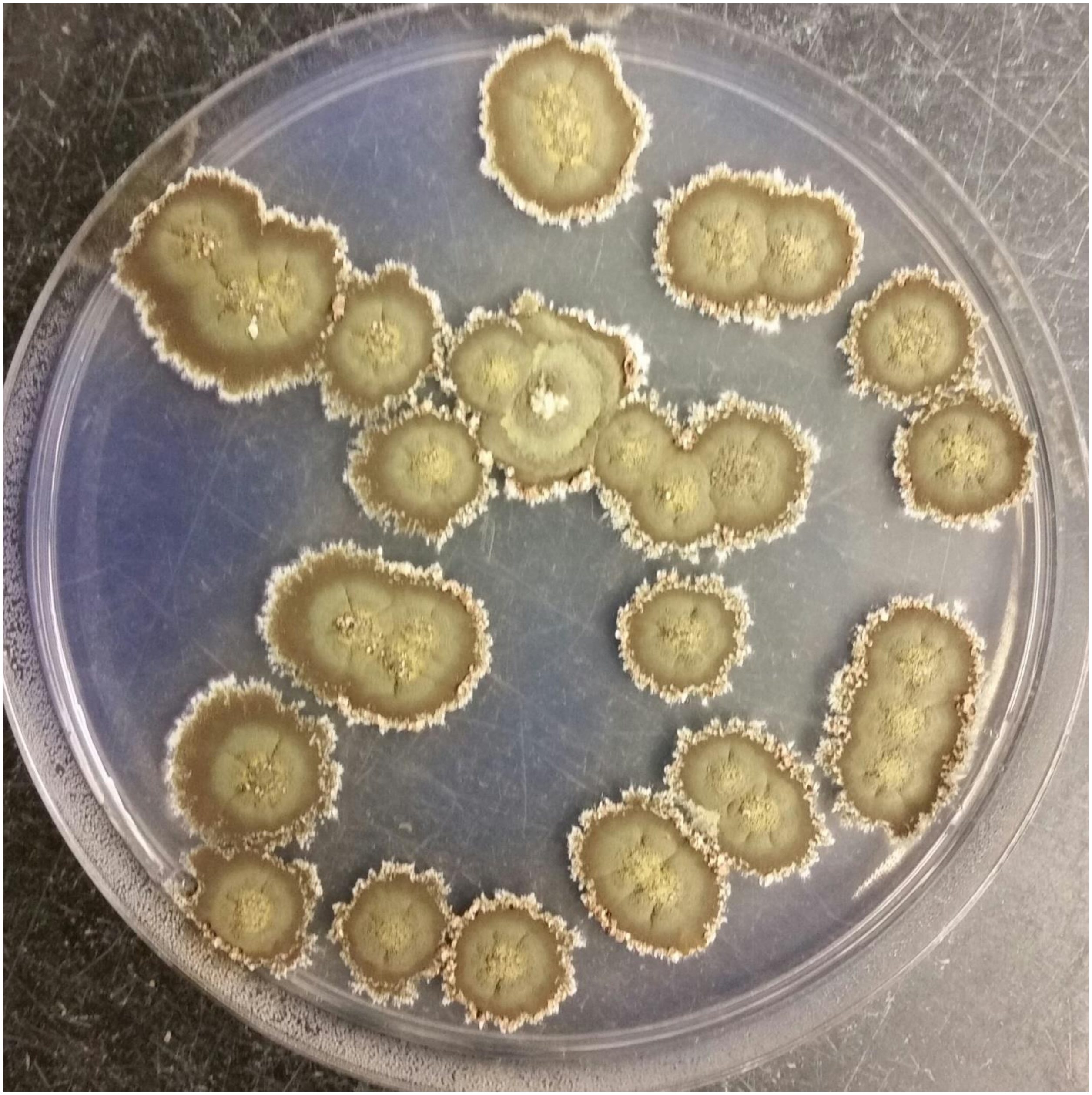

Fig. 2. *Metarhizium brunneum* F52 colonies growing on agar plate.

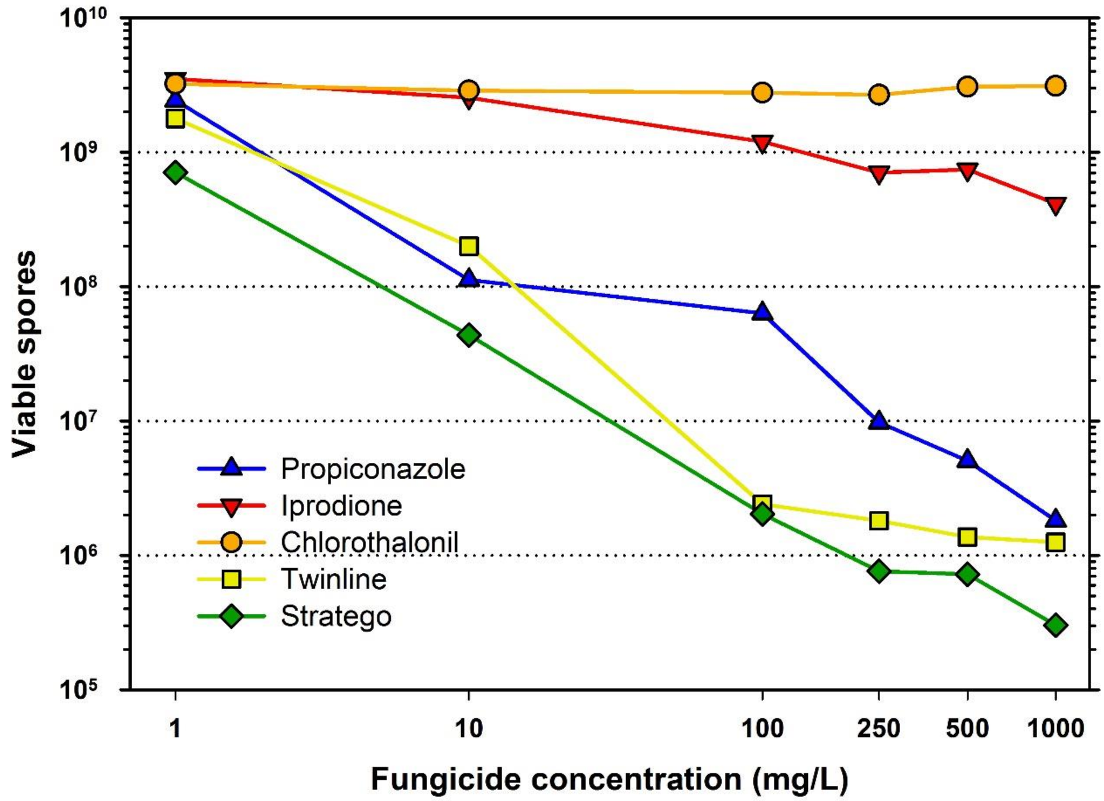

Fig. 3. Number of viable spores per gram of *Metarhizium brunneum* microsclerotia after incubation for 9 days at 26 °C on water agar containing different concentrations of five fungicides.

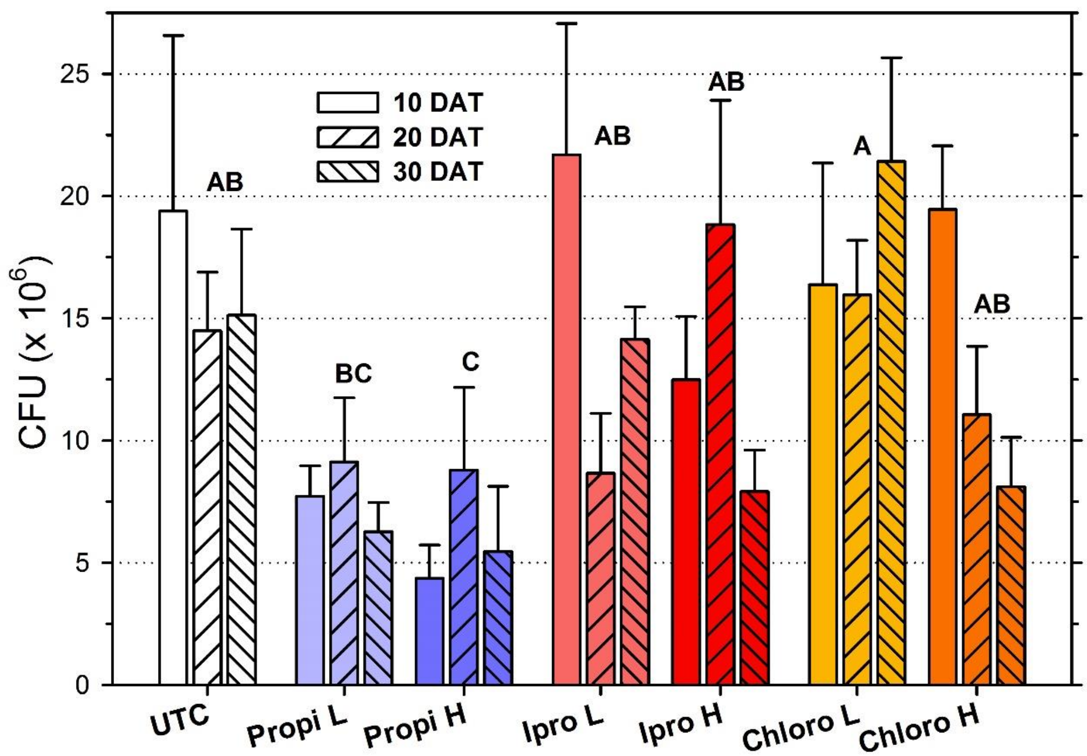

Fig. 4. Number of *Metarhizium brunneum* F52 colony forming units (CFUs) recovered from top 2.5 cm of soil and grass in pots treated with water only (untreated control = UTC), and a low (L) and a high (H) rate of the fungicides propiconazole (Propi), iprodione (Ipro) and chlorothalonil (Chloro) at 10, 20 and 30 days after treatment (DAT). Means (evaluation dates combined by treatment) with same letter did not differ significantly from each other ($P \geq 0.05$).

2016-12-562

Title: Developing a Rapid Method for Diagnosing Herbicide Resistance in Annual Bluegrass

Project Leader: James T. Brosnan and Jose J. Vargas

Affiliation: University of Tennessee

Objectives: Determine if agar-based rapid diagnostic tests can be used to diagnose herbicide resistance in annual bluegrass populations harvested from golf course turf.

Start Date: 2016

Project Duration: Two years

Total Funding: $57,156

Summary Text: Reports of herbicide resistance in annual bluegrass (*Poa annua* L.) are greater than any other weed species commonly found in turf. Annual bluegrass phenotypes resistant to mitotic inhibitors (e.g., prodiamine), acetolacatate synthase inhibitors (ALS; e.g., foramsulfuron, trifloxysulfuron, etc.), photosystem II inhibitors (PSII; e.g., simazine), and enolpyruvylshikimate-3-phosphate (EPSP) synthase (e.g., glyphosate) inhibitors have been identified on golf courses following continued use of the same pre- or postemergence herbicides in lieu of diversified weed management programs.

Traditional means of testing annual bluegrass for herbicide resistance can be labor intensive, costly, and time consuming. Rapid diagnostic tests have been developed to confirm herbicide resistance in weeds of agronomic cropping systems that correlate well with traditional whole plant bioassays. These tests involve transplanting weed seedlings of resistant and susceptible populations into petri plates filled with agar and discriminatory rates of herbicide. This technique has successfully been used to provide farmers confirmation of rigid ryegrass (*Lolium rigidum*) populations resistant to both ALS and acetyl co-A carboxylase inhibiting herbicides, as well as Italian ryegrass (*Lolium multiflorum*), goosegrass (*Eleusine indica*), horseweed (*Conzya canadensis*), and common waterhemp (*Amaranthus rudis*) populations resistant to glyphosate.

Research was conducted at the University of Tennessee during 2016-2017 to determine if agar-based rapid diagnostic tests could be used to confirm herbicide resistance in annual bluegrass harvested from golf course turf. Separate experiments were conducted using annual bluegrass phenotypes resistant to ALS and PSII inhibiting herbicides and glyphosate via target site mutation; an herbicide susceptible control was included in each for comparison. Single tiller plants were washed free of growing media and transplanted into autoclavable polycarbonate plant culture boxes filled with 65 mL of murashigee-skoog media amended with glyphosate (0, 6, 12, 25, 50, 100, 200, or 400 μM), trifloxysulfuron (6.25, 12.5, 25, 50, 75, 100, or 150 μM), or simazine (0, 6, 12, 25, 50, 100, 200, or 400 μM). Treatments were arranged in a completely randomized design with 50 replications and repeated in time. Mortality in agar was assessed 7 to 10 days after treatment (depending on herbicide) and compared to responses observed after treating 98 individual plants of each phenotype with glyphosate (560 g ha^{-1}), trifloxysulfuron (27.8 g ha^{-1}) , or simazine (1120 g ha^{-1}) in an enclosed spray chamber. Fisher's exact test (α =

0.05) determined that mortality in agar with 100 µM glyphosate was not significantly different than treating whole plants via traditional spray application. Similarly, mortality in agar with 12.5 µM trifloxysulfuron was not significantly different than spraying whole plants with herbicide. Mortality with all concentrations of simazine in agar was significantly different than that observed after treating resistant and susceptible phenotypes via traditional spray application. Our findings indicate that an agar-based diagnostic assay can be used to detect annual bluegrass resistance to ALS- or EPSPS-inhibiting herbicides in less than 10 days; however, additional research is needed to refine this assay for use with PSII-inhibiting herbicides.

Summary points:

- Herbicide-resistant annual bluegrass is becoming increasingly problematic on golf courses throughout the transition zone and southern United States.
- Traditional means of confirming herbicide resistance in annual bluegrass can be labor intensive, costly, and time consuming leaving superintendents with little guidance regarding proper management in-season.
- A rapid diagnostic assay in agar culture can now reliably diagnose annual bluegrass resistance (or susceptibility) to glyphosate or trifloxysulfuron in 10 days or less.

Figure 1. Herbicide-resistant annual bluegrass (*Poa annua*) following two broadcast applications of glyphosate at 1120 g ha^{-1} during winter dormancy in Rockford, TN.

Figure 2. Autoclavable polycarbonate plant culture box used to diagnose annual bluegrass (*Poa annua*) resistance to herbicides in agar culture.

Figure 3. Response of three annual bluegrass (*Poa annua*) phenotypes to 12.5 µM trifloxysulfuron in agar culture. Note that the two resistant phenotypes on the left are not affected by trifloxysulfuron while the susceptible phenotype on the right shows severe tissue discoloration 7 days after treatment.

2016-19-569

Project Title: **Characterizing growth and life history of silvery-thread moss in cool-season putting greens: assessing vulnerability to stress in the life cycle**

Principal Investigator(s): **Lloyd Stark, Steve Keeley, Zane Raudenbush**

University: **University of Nevada, Las Vegas (UNLV), Kansas State University (KSU), and Ohio State University ATI (OH)**

Address: **School of Life Sciences, University of Nevada, 4505 Maryland Pkwy, Las Vegas, NV 89154-4004**

Telephone: **702-895-3119** e-mail: **LRS@UNLV.nevada.edu**

Summary

During 2017, we successfully cloned (pure plant lines) 17 genotypes of silvery-thread moss (STM, *Bryum argenteum* Hedw.) from golf course putting greens and 17 genotypes from native habitats. As of our last report (Oct 2016), we had initiated an experiment comparing the life history and growth dynamics of 7 golf course + 7 native habitat lines of STM. During 2017 we completed this experiment using all 34 clonal lines (17 golf course + 17 native habitat genotypes). Last year we reported preliminary results, and at present we have the final data from this comprehensive experiment. The primary differences between the golf course vs. the native genotypes of STM revolve around an ability to germinate rapidly, grow vigorously, and to produce a mat of brown rhizoids that serve to anchor the shoots to the substrate. Interestingly, the golf course putting green environment appears to select for this group of traits from plants dispersing into the putting green from native habitats. Evidence for this selection pressure is the presence of several clonal lines collected from native habitats exhibiting similar growth characteristics to STM lines derived from putting greens. This finding suggests that traits exhibited in putting green mosses are present in native habitats yet seldom expressed in native habitats.

Overview

The purpose of this project is to address a biological concern in golf course greens, the silvery-thread moss (STM), known scientifically as *Bryum argenteum*. This moss has infested golf course putting greens across the USA, and golf course superintendents have expressed concerns regarding effective eradication approaches. We initiated this project with these goals:

1. Accumulate representative collections of STM from a variety of golf courses and representative collections of STM from non-golf course habitats, place these genotypes into pure culture, and compare their life history and stress responses. In essence, we wish to determine how different the golf course strains of this species are compared to populations <u>not</u> in golfing greens. Understanding these differences will help us formulate better treatment plans for eradication.

2. Evaluate the effectiveness of administering specific stresses, including the application of carfentrazone, at various points in the life cycle of STM. These life cycle stages include (in sequence from juvenile to adult) protonema, rhizoid, juvenile shoots, adult shoots, and asexual reproductive structures.

Progress to Date for Year 2 (2017)

1. Completed the establishment of 34 genotypes of STM at the University of Nevada, Las Vegas. As of October of the previous year (2016), we had successfully cloned to pure lines 12 genotypes of STM from golf course greens and 10 genotypes of STM from "off golf course" habitats. We refer to these locations as "*Green*" and "*Native*" habitats, respectively. We now have 34 pure cultures of STM: 17 from golf courses across N. America, and 17 from *Native* habitats from across N. America. These *Green* golf course samples include STM from courses in (numbers of genotypes in parentheses) Alberta (1), California (6), Colorado (1), Illinois (1), Minnesota (1), Nevada (1), Ohio (3), Oregon (1), and South Dakota (2). The *Native* samples include mosses (STM) from localities in the following states: Arizona (2), California (2), Georgia (1), Kentucky (1), Massachusetts (1), Nevada (4), New Mexico (1), Oregon (3), Pennsylvania (1), and Washington (1). Once this process was completed, we made a set of "backup" cultures of each of the 34 genotypes and placed these under low light conditions in sealed Petri dishes for long term storage.

2. Completed Experiment 1: Comparing the Growth Dynamics of Golf Course STM to "Off Course" STM. The major conclusions of this experiment indicate that *Green* STM mosses incorporate a markedly different set of life history (growth) traits compared to *Native* STM mosses. We show these differences by including several figures taken from our draft MS (**Figures 1–5**). **Figure 1** shows the differences visually (the habitat and taller shoots). **Figure 2** shows how shoot induction (the time to the first shoot production in culture) is significantly faster in *Green* mosses. **Figure 3** shows how the *Green* mosses produce many more shoots over the first 21 days in culture compared to *Native* mosses. **Figure 4** shows the dramatic difference in rhizoid production in *Green* mosses, which indicates to us that rhizoid production may be critical in the moss holding its position in the putting green. **Figure 5** shows the tendency of *Green* mosses to devote less energy to asexual reproduction through bulbils (detachable shoot fragments) than *Native* mosses. This indicates a tradeoff is present wherein *Green* mosses put their energies into shoot production instead of specialized asexual reproduction.

3. Developed a draft manuscript titled, "*Divergence in Life History and Developmental Traits in Bryum argenteum Accessions from Golf Course Putting Greens*". The authors of the manuscript (MS) are, Zane Raudenbush, Joshua Greenwood, Nicholas McLetchie, Sarah Eppley, Steven Keeley, Richard Castetter, and Lloyd Stark. We anticipate completing the statistics for the MS and submitting the MS early in next year's cycle, ideally before January of 2018. The abstract of this draft MS follows.

Abstract

●*Premise of the study:* Silvery thread moss, *Bryum argenteum*, is an undesirable invader of golf course putting greens across North America, establishing colonies and proliferating despite practices to minimize its existence. In order to understand the growth dynamics of this species, our goal was to grow genotypes of "*green*" (growing in putting greens) and "*native*" (growing in habitats outside of putting greens) of *B. argenteum* in a common garden experiment and assess life history traits.

●*Methods:* Seventeen collections of *green* and 17 collections of *native B. argenteum* were cloned to single genotypes, decontaminated through subculturing, and raised through a minimum of two asexual generations in the lab. A culture of each genotype was initiated using a single

detached shoot apex and allowed to grow for 6 months under conditions of inorganic nutrients present and absent. Observations included protonemal germination, extension rate and cover, first shoot induction and number of shoots, shoot height, gemma and bulbil production, aerial rhizoid cover, sex expression and number of inflorescences, and chlorophyll fluorescence and content parameters.

●*Key results:* Genotypes of *B. argenteum* from putting greens exhibited earlier shoot regeneration and shoot induction, faster protonemal extension, longer (higher) shoots, produced fewer gemmae and bulbils and greater aerial rhizoid cover, and showed similar tendencies of chlorophyll fluorescence properties and chlorophyll content. Cultures receiving no inorganic nutrients exhibited lower chlorophyll content, much reduced growth, and bleaching of shoots.

●*Conclusions:* Mosses from putting greens establish and grow faster and yet do not produce as many specialized asexual propagules. Rhizoid production is much greater in putting green mosses. The highly managed putting green environment has either selected for a suite of traits allowing the moss to effectively compete with grasses, or genotypic diversity is very high in this species, allowing a set of specialized genotypes to repeatedly colonize the putting green from native habitats.

4. Conducted a pilot experiment on the desiccation tolerance of the rhizoid mat of *Bryum argenteum* clonal lines (genotypes) from Golf Course Putting Greens. Preliminary results indicate that this portion of the life cycle is critical to the establishment of STM in greens. Rhizoids are nonphotosynthetic extensions from the shoot that anchor the shoot and maintain the integrity of the colony of shoots against incursion from grasses. Our pilot data indicate that rhizoids are capable of producing new rhizoids and are indeed tolerant to drying out entirely, and therefore deserve our attention as a focus of research.

Plans for Year 3 (2018)

1. Submit our first Manuscript developed with USGA funding. We are currently completing the statistical section and then will complete the Introduction and portions of the Discussion.

2. Initiate our Second Major Experiment on STM incorporating 3 Factors: (1) Desiccation Tolerance, (2) Carfentrazone Treatment, and (3) Nutrient effects. Using a subset of the 17 *Green* + 17 *Native* STM genotypes, we will initiate a series of 2-factor experimental treatments to determine the effects of desiccation, carfentrazone, and nutrient additions, on the health of STM plants.

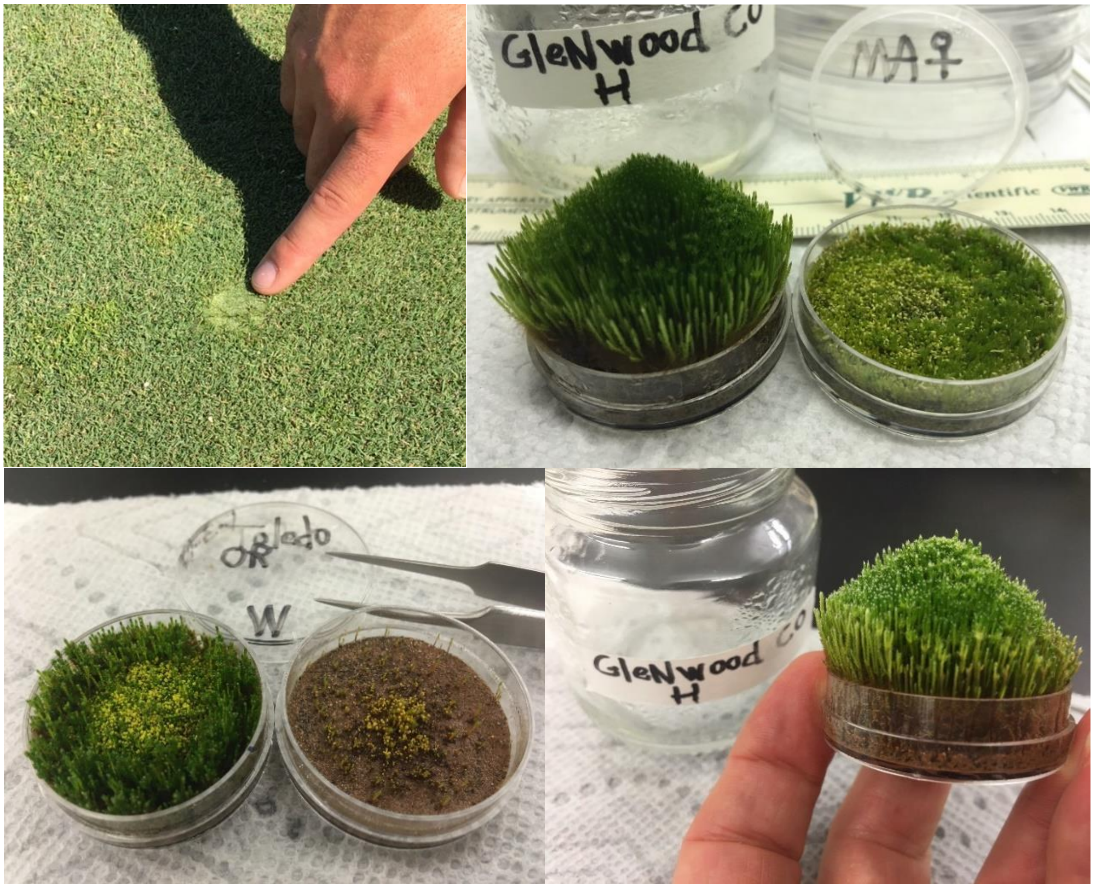

Figure 1. The visual differences in life history traits (habitat and taller shoots) between *Green* and *Native* mosses.

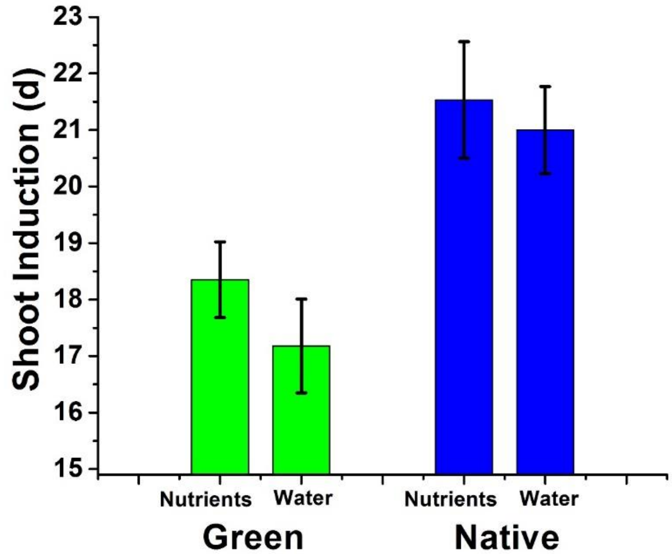

Figure 2. Shoot induction (the time to the first shoot production in culture) is significantly faster in *Green* mosses.

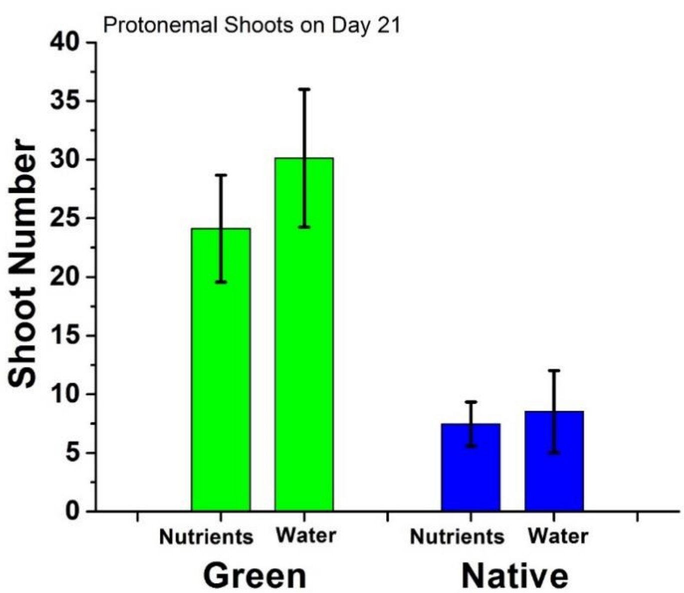

Figure 3. *Green* mosses produce many more shoots over the first 21 days in culture compared to *Native* mosses.

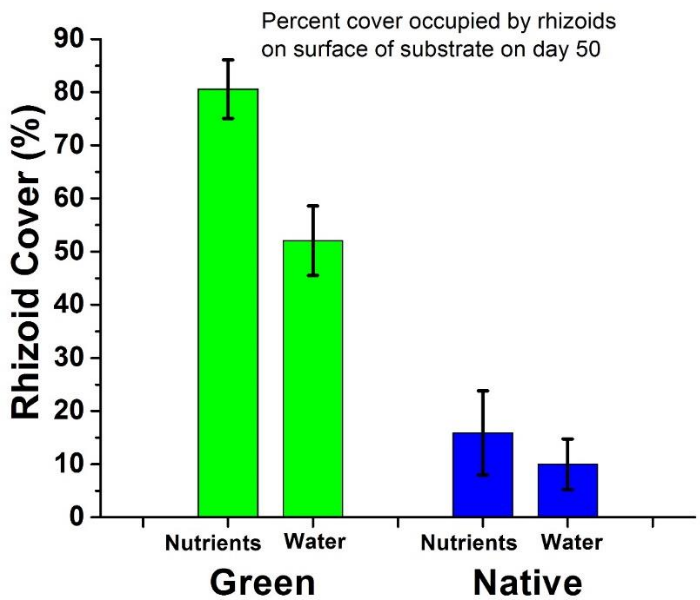

Figure 4. The difference in rhizoid production in *Green* mosses, which indicates to us that rhizoid production may be critical in the moss holding its position in the putting green.

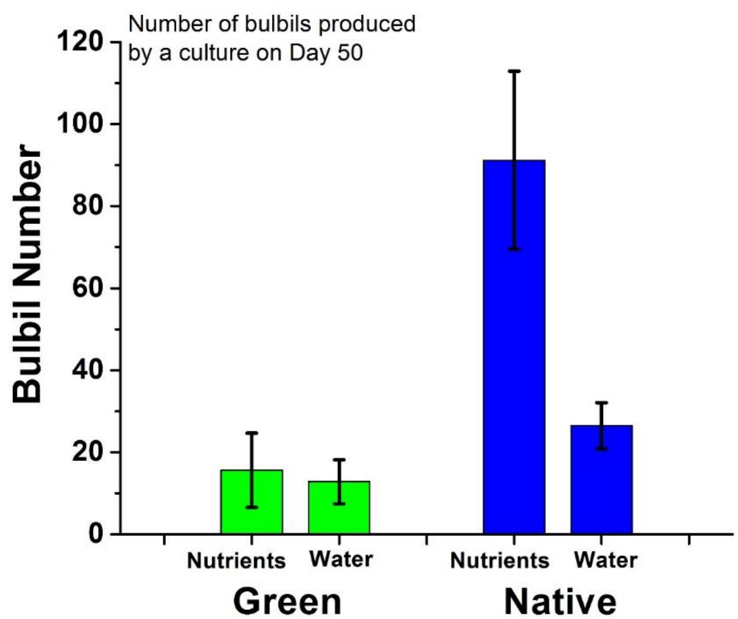

Figure 5. The tendency of *Green* mosses to devote less energy to asexual reproduction through bulbils (detachable shoot fragments) than *Native* mosses.

2017-03-613

Title: Use of Fraze Mowing and Herbicides to Eradicate Bermudagrass in Putting Greens or Production Fields

Project Leaders: Mike Richardson[1], John McCalla[1], Jim Brosnan[2], and Greg Breeden[2]

Affiliation: [1]University of Arkansas; [2]University of Tennessee

Objective: Determine the effects of aggressive dethatching (fraze mowing) on the efficacy of herbicides for bermudagrass control.

Start Date: 2017
Project Duration: 1 year
Total Funding: $10,000

Summary Text:
When golf courses decide to switch bermudagrass fairway or putting green surfaces to a newer cultivar, it is imperative that the existing bermudagrass be eradicated completely to ensure a pure stand of the new cultivar. Sod producers also must have sites completely free of other bermudagrasses before starting production with an ultradwarf or any improved bermudagrass cultivar. Historically, methyl bromide was commonly used to fumigate sites and was a very effective means of controlling bermudagrass (Edwards and Barnes, 1958). However, methyl bromide was phased out of production in 2005 due to environmental concerns and alternative fumigants have not proven as effective for controlling problematic weeds, especially bermudagrass (Unruh and Brecke, 2013). As such, the use of herbicides remains a common method of removing an existing bermudagrass turf prior to planting a new cultivar.

Herbicide control options for bermudagrass include non-selective herbicides such as glyphosate, as well as selective grass herbicides such as fenoxaprop and fluazifop (Boyd, 2000; Johnson, 1988; Teuton et al., 2005). Regardless of the herbicide(s) used, effective bermudagrass control can only be achieved with multiple (2-4) applications of the herbicides, typically on a 3-4 week interval (Boyd, 2000; Teuton et al., 2005). As such, bermudagrass eradication is a long-term process that can take a minimum of 6-8 weeks to complete all the herbicide applications.

Over the past few years, a new mechanical dethatching system called “fraze mowing” has been introduced into the golf and sports turf industries. These machines are designed to aggressively remove thatch down to a maximum depth of approximately 5.0 cm (Fig. 1). The cultivation practice was originally introduced to aggressively dethatch turf areas, but also has been used to reduce weed seed populations (Neil Stubley, All England Lawn Tennis Club, personal communication), prepare sites for seeding (Hansen and Christians, 2015), and may even be useful for controlling pathogens such as spring dead spot (Miller et. al, 2015).

One aspect of fraze mowing that has not been investigated is whether aggressive fraze mowing might influence the efficacy of certain herbicides. Our hypothesis is that if a high percentage of the growing points (crowns, stolons, and possibly some rhizomes) of a bermudagrass are physically removed with fraze mowing, the remaining growing points may be more easily eradicated with various combinations of selective and non-selective herbicides. The objective of this proposed work is to investigate various, single application herbicide treatments for bermudagrass eradication, applied either prior to or after fraze mowing.

Materials and Methods

This study was conducted on two sod production farms, including Modern Turf in Rembert, SC and Bayou Bend Turf Grass in Bastrop, LA. The study was set up as a split-split plot design with fraze mowing treatments being assigned to the whole plots and herbicide timing and treatments applied as the split plots. The experiment was conducted on two cultivars at both locations (Table 1), including one common fairway type of bermudagrass (Celebration or Tifway) and one ultradwarf cultivar (MiniVerde or Tifeagle). For brevity, this report will only present the results from the fairway cultivars. Dates of pre-fraze herbicide applications, fraze mowing, and post-fraze herbicide applications are outlined in Table 1.

The fraze mower was a Koro Field Top Maker 1200 (Campey Turf Care Systems, Cheshire United Kingdom) set to a depth of 3.75 cm. Herbicide treatments included the following:

1. Roundup Pro at 7.7 L ha^{-1}
2. Roundup Pro at 7.7 L ha^{-1} + Fusillade II at 1.75 L ha^{-1} + nonionic surfactant (0.25%)
3. Untreated control

Data collection involved both visual and digital image analysis of bermudagrass coverage. Recovery and reappearance of bermudagrass in plots was monitored until the end of the growing season. For this report, results will primarily focus on the end-of-season, bermudagrass control observations.

Results

- There were significant 2-way interactions at both locations, including fraze mowing by herbicide timing, fraze mowing by herbicide treatment, and herbicide timing by herbicide treatment. The 3-way interaction of fraze mowing x herbicide timing x herbicide treatment was not significant at either location (data not shown).
- Regardless of herbicide timing, the use of fraze mowing improved bermudagrass control at both locations (Table 2). At the SC location, herbicides applied before fraze mowing were not significantly different from herbicides applied 3 weeks after fraze mowing.
- There were no differences in bermudagrass control between Roundup Pro and Roundup Pro + Fusilade II within either of the fraze mowing treatments (Table 3). However, the best control with both products was observed when the herbicides were used in conjunction with the fraze mowing treatment.

- When comparing timing of herbicide application, both the Roundup Pro and Roundup Pro + Fusilade II treatments provided better control when sprayed 3-4 weeks after fraze mowing compared to applying the herbicide before the fraze mowing (Table 4).

Overall, these results demonstrated that fraze mowing, especially prior to applying herbicides, can significantly improve bermudagrass control. It should be noted that these trials only investigated a single application of herbicide and those treatments failed to produce 100% control of bermudagrass. Future studies should investigate multiple applications of herbicides, either before and/or after fraze mowing, in an effort to achieve 100% bermudagrass control in a timely fashion.

Acknowledgements
The authors gratefully acknowledge support received from the two sod companies and their staff that hosted these experiments, including Tom and Gabe Carpenter of Bayou Bend Sod and Hank Kerfoot, B.J. Haunert, and Jerome Dodson of Modern Turf. The authors especially appreciate the efforts of Mark Langner and Aqua Aid for providing the fraze mowing equipment to each site to conduct the study.

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Unruh, J., and B. J. Brecke. 2013. Advances in identifying an effective alternative to methyl bromide in turfgrass systems. South. Weed Sci. Soc. Proc. 66:12.

Figure 1. Fraze mowing operation at Bayou Bend Sod Farm in Bastrop LA.

Table 1. Site descriptions and application dates for herbicide timing and fraze mowing treatments.

Location	Cultivar	Pre-fraze herbicides	Fraze mowing	Post-fraze herbicides
		--------------------	date applied	-----------------
Modern Turf, Rembert SC	Celebration	6/5/2017	6/13/2017	7/11/2017
Bayou Bend Sod, Bastrop LA	Tifway	6/30/2017	7/10/2017	7/31/2017

Table 2. Bermudagrass control, as affected by fraze mowing and timing of herbicide application.

Fraze treatment	**Herbicide timing**	**Bastrop LA 'Tifway'**		**Rembert SC 'Celebration'**	
		----------- Bermudagrass control (%) ---------			
Fraze mowed	1 wk before fraze mowing	88.0	A	19.2	B
	3 wks after fraze mowing	86.4	A	61.3	A
No fraze mowing	1 wk before fraze mowing	31.9	C	0.0	C
	3 wks after fraze mowing	62.6	B	22.9	B

Within each location, means followed by the same letter are not statistically different at the 0.05 level of probability according to Fisher's protected least significant difference test.

Table 3. Bermudagrass control, as affected by fraze mowing and herbicide treatment.

Fraze treatment	Herbicide	Bastrop LA 'Tifway'		Rembert SC 'Celebration'	
		----------- Bermudagrass control (%) ---------			
Fraze mowed	Roundup Pro	97.6	A	58.8	A
	Roundup Pro + Fusilade II	98.0	A	57.5	A
	Untreated control	66.0	B	4.4	CD
No fraze mowing	Roundup Pro	62.1	B	13.8	BC
	Roundup Pro + Fusilade II	79.6	AB	20.6	B
	Untreated control	0.0	C	0.0	D

Within each location, means followed by the same letter are not statistically different at the 0.05 level of probability according to Fisher's protected least significant difference test.

Table 4. Bermudagrass control, as affected by herbicide timing and herbicide treatment.

Herbicide timing	Herbicide	Bastrop LA 'Tifway'		Rembert SC 'Celebration'	
		----------- Bermudagrass control (%) ----- ----			
1 wk before fraze mowing	Roundup Pro	64.3	B	13.8	B
	Roundup Pro + Fusilade II	79.6	AB	11.9	B
	Untreated control	36.0	C	3.1	B
3 wks after fraze mowing	Roundup Pro	95.5	A	58.8	A
	Roundup Pro + Fusilade II	98.0	A	66.3	A
	Untreated control	30.0	C	1.3	B

Within each location, means followed by the same letter are not statistically different at the 0.05 level of probability according to Fisher's protected least significant difference test.

3. Product Testing

The goal of product testing is to support and direct independent research designed to provide consumers unbiased information regarding product efficacy. This information will help consumers make financially and environmentally sound product purchasing and usage decisions. The program also will provide USGA Green Section agronomists scientific information to support recommendations about products that have limited scientific information about agronomic benefits. Product testing projects could include:

- Organic vs. conventional agronomic products for turfgrass nutrition
- Alternatives to pesticides for disease or insect problems
- Biostimulants
- New technology with limited information on turfgrass applications
- Recycled materials
- Soil amendments

PROJECT TITLE:

Grass Roots Exhibit

PROJECT LEADER:

Kevin Morris, Executive Director
National Turfgrass Federation
P. O. Box 106
Beltsville, Maryland 20704

START DATE:

2014

PROJECT DURATION:

Five years

TOTAL FUNDING:

$125,000

SUMMARY TEXT:

The 2017 season was the third season of the 'Grass Roots' exhibit at the U.S. National Arboretum in Washington, DC. While initially scheduled for four full seasons as a "temporary exhibit", the National Arboretum informed us that 'Grass Roots' will continue through the 2019 season. The Arboretum will be hosting the national meeting of the American Public Garden Association that year and our hope is that the exhibit will inspire other public gardens to consider installation of educational turfgrass displays on their facilities.

In July 2017, full-time 'Grass Roots' coordinator Geoff Rinehart began a full-time faculty position at the University of Maryland. Geoff remains as the coordinator in a part-time capacity, managing the 'Grass Roots' Facebook and Twitter social media accounts and supervising part-time workers. The coordinator position will be re-evaluated and a new coordinator will be hired in early 2018.

During 2017, 'Grass Roots' hosted approximately 30,000 visitors, similar to past years. Typical 'Grass Roots' exhibit visitors include families with school-age children, new homeowners seeking information about properly caring for their first lawn, tourists from within and outside the U.S., Master Gardeners, and landscape designers seeking to learn more about different grass varieties.

We continue to publicize the exhibit and its contributions to communicating the importance of turfgrass benefits to the public. Articles in the European Turfgrass Society newsletter, *Turf News*, and the *International Turfgrass Research Journal* highlighted accomplishments. In addition, updates were provided during presentations at the International Turfgrass Research Conference and the Turfgrass Producers International summer meeting.

As in the past, homeowner lawn care workshops in spring and fall were conducted. Master Gardener training was also conducted on two occasions by the Coordinator, with elementary and middle school students being engaged and educated on a Virginia golf course as well. In addition to conducting homeowner-oriented events, we also hosted several professional academic meetings/events this year.

Since the Initiative's inception it has been our goal to provide a high-profile venue for academic and professional turfgrass industry meetings. In February, we hosted a committee meeting for the newly formed Mid-Atlantic Sports Turf Managers of America (MASTMA) chapter. In March, we hosted a 2-day University of Maryland-organized turfgrass phytobiome research meeting. The International Turfgrass Research Conference tour group visited 'Grass Roots' in July. Finally, 'Grass Roots' hosted the National Turfgrass Research Initiative summit in September.

And again in 2017, 'Grass Roots' collaborated with the National Cherry Blossom Festival, the National Park Service, and BicycleSPACE to conduct the 3rd annual National Greenscape Corridor Bike Ride. This year almost 50 participants rode throughout Washington, D.C. visiting historic sites and learning about turf and landscapes, including 'Grass Roots'.

We continue to enhance 'Grass Roots' by making additions and improvements to the exhibit. As the turf and ornamental grasses have matured, visitors can note changes to the landscape and its aesthetic appeal. In addition, the crop plants are rotated so that visitors can not only see, but touch crops that they may not realize are also grasses, such as sugar cane and millet. Also, during 2017, we added new display features to the 'Grass Roots' exhibit, including an interpretive banner on *Danthonia spicata*/fine fescue mixes, and TifTuf™ bermudagrass sod in a 4' x 4' "turf module".

In 2017, we expanded the 'Grass Roots' Initiative by installing a 1-acre 'Grass Roots' exhibit at the Maryland Soccerplex, located approximately 35 miles NW of Washington, DC in Boyds, MD. This 24-field complex sees over 600,000 visitors annually that either participate in, or are spectators of soccer and lacrosse games. Therefore, this exhibit location focuses more on sports turf and home lawn applications. A $40,000 USDA-NIFA Specialty Crop block grant was secured to fund the materials cost of exhibit construction. In addition, about $60,000 of donated products and services from the turf industry were needed to complete the exhibit. Constructed adjacent to the complex's stadium, this site features 10 interactive educational displays while using a similar format to the Arboretum's 'Grass Roots' exhibit. The exhibit had a soft opening in November 2016, with a formal grand opening being held in May 2017. Local media coverage of the event helped to promote this exhibit site.

The visitation pattern of the SoccerPlex 'Grass Roots' exhibit is substantially different than visitation at the National Arboretum. Weekends are by far the busiest visitation days for this location, due to large soccer tournaments and National Women's Soccer League games

(Washington Spirit) . One of the highlight events for the SoccerPlex exhibit occurred on June 13, 2017 as a sellout (capacity: 5,000) crowd attended the U.S. Open Cup match between DC United (Major League Soccer) and Christos FC. Since the exhibit is located directly outside the entrance gates, fans waiting in line had a chance to examine the lawn, history, and irrigation displays. In addition, many youth played pick-up games on the mini-sports fields.

- A second ‘Grass Roots’ site, located at the Maryland SoccerPlex in Boyds, MD opened in November 2016. A USDA grant, along with donated products and services by the turf industry funded the construction.
- The Arboretum ‘Grass Roots’ exhibit hosted an estimated 30,000 visitors in 2017. The ‘Grass Roots’ website (www.usna.usda.gov/Education/turfgrass.html) complements the educational concepts in the exhibit and contains information about the benefits of turfgrass, basic lawn care information, and links to each state’s turfgrass extension education website.
- Coordinator Geoff Rinehart conducted four lawn care workshops and hosted tours for several groups visiting the exhibit.
- ‘Grass Roots’ hosted a regional STMA committee meeting in February, a regional turfgrass phytobiome research meeting in March, a stop on the International Turfgrass Research Conference tour in July, and a national-level USDA turfgrass summit in September.
- Two new display features were added in 2017: An interpretive banner communicating ongoing *Danthonia* research plots and the addition of a turf module containing TifTuf™ bermudagrass on a major pedestrian thoroughfare overlooking the exhibit.

Figure 1. National Greenscape Corridor bike tour stops at National Mall.

Figure 2. Grass Roots Maryland Soccer plex site.

Figure 3. Grass Roots at Arboretum.

Figure 4. Aeration services donated by Turf Equipment & Supply.

Figure 5. Capitol Columns at National Arboretum.

2013-17-478

PROJECT TITLE:

Evaluation of Warm-Season Grasses for Putting Greens

PROJECT LEADER:

Kevin Morris, Executive Director
National Turfgrass Evaluation Program (NTEP)
BARC-West, Bldg. 005, Rm. 307
Beltsville, MD 20705

START DATE:

2013

PROJECT DURATION:

Five years

TOTAL FUNDING:

$90,000

SUMMARY TEXT:

With the increased interest in the use of bermudagrass on greens, a project was developed to evaluate three warm-season grass species on USGA specification putting greens at eleven locations across the southern and mid-western U.S. Trial sites include university locations (7) and golf courses (4). The trial parameters dictate a higher mowing height and a less intensive management regime as compared to typical ultradwarf bermudagrass management, while targeting green speeds of 9-10 feet.

The trial consists of twenty-eight total entries, with fourteen bermudagrass, eleven zoysiagrass and two seashore paspalum entries. Trials were planted anywhere from mid-June to mid-August 2013. As explained in past reports, winter injury from 2013-14 was significant at some locations. This winter injury caused NTEP to replant some or all entries at four locations in summer 2014. The winter of 2014-15 was also colder than normal in some locations, which delayed some entry development and hence, collection of some of the more advanced data parameters. Also, various issues led to the unfortunate abandonment of the trial at Tequesta, FL.

'MSB-264' and 'MSB-285', experimentals from Mississippi State University continued to perform well, finishing in the top statistical group for turf quality at five and six (of nine) locations, respectively. '11-T-861' also performed well, finishing in the top statistical group at five locations, but only the southern sites. Other experimentals such as '08-T-18', 'OKC-13-78-5' and 'JK 110521' demonstrated good turf quality at several locations, with top statistical group performance at four sites. Significant differences in genetic color, density, leaf texture and fall color retention were noted among entries, which largely led to the quality ratings separation.

For zoysia in 2016, several experimental entries, particularly from the Texas A&M-Dallas (DALZ) University research program, produced turf quality that rivaled many of the bermudagrasses. 'DALZ 1308', one of the best zoysia entries in 2015, showed consistent performance in 2016 with top statistical group finishes in eight of nine trial locations. 'DALZ 1306' and 'DALZ 1307' also performed well with top statistical groupings at eight and seven locations, respectively. Performing well enough to gain the top statistical group at five locations in 2016 include 'DALZ 1309', 'DALZ 1304' and 'ZOYSIU'.

The two seashore paspalum entries again showed good turf quality. As in 2015, 'UGA 1743' and the standard entry 'SeaDwarf' performed very similarly at almost locations in 2016. Dollar spot tolerance was higher in 'UGA 1743' than 'SeaDwarf' at the Jay, FL location.

Ball roll measurements were collected at several locations in 2016. Most locations did not record ball roll distances that met our minimum threshold of about 100 inches of roll (250 cm) using the stimpmeter (on at least one rating date). Mississippi State, MS was the only location to achieve ball roll distances on bermuda of at least 100 inches on any rating date. The bermuda entries 'Tifeagle', 'FAES 1302', 'Mini-Verde', 'Tifdwarf' and 'CTF-B10' delivered 100- inch ball rolls on both rating dates.

In prior years, none of the zoysia or seashore paspalum entries rolled at least 100 inches, however, that changed in 2016. At Tucson, AZ, several of the zoysia entries had greater ball roll distances than the bermuda entries, with '10-TZ-74' rolling greater than 100 inches on both rating dates. 'DALZ 1305' and 'DALZ 1307' showed ball roll distances of 100 inches on one of two rating dates in Tucson. And '10-TZ-74' was the only entry to roll greater than 100 inches at the Richmond, VA location. The seashore paspalum entry to measure a 100 inch or greater ball roll in 2016 was 'SeaDwarf', on one rating date at Tucson, AZ.

SUMMARY POINTS

- In 2016, several new or experimental bermudagrasses again produced turf quality equal to or better than established standards 'Tifdwarf', 'Tifeagle' and 'Mini-Verde'.
- Several zoysia entries also performed very well in 2016, producing turf quality rivaling the best bermuda entries. The two seashore paspalum entries performed similarly in 2016, however, 'UGA 1743' did demonstrate better dollar spot tolerance than 'SeaDwarf'.
- Data from 2017 did not show a significant increase in ball roll, with only a few bermuda entries demonstrating ball roll of least 100 inches at one location under this medium maintenance regime.
- Ball roll distances for some seashore paspalum and zoysia entries did increase in 2016, as ball roll measurements of 100 inches were noted in a few instances in Tucson, AZ and the Richmond, VA sites.

Figure 1. 'DALZ 1309' zoysia and 'UGA 1743' seashore paspalum entries in January 2017 at a site in Tucson, AZ. Note improved color of zoysia (photo courtesy Brian Whitlark).

Figure 2. Site in Griffin, GA in May 2017. Note exceptional plot differences.

2016-24-574

PROJECT TITLE:

On-Site Testing of Grasses for Overseeding of Bermudagrass Fairways

PROJECT LEADER:

Kevin Morris, Executive Director
National Turfgrass Evaluation Program (NTEP)
BARC-West, Bldg. 005, Rm. 307
Beltsville, MD 20705

START DATE: 2016

PROJECT DURATION: Three years

TOTAL FUNDING: $90,000

SUMMARY TEXT:

Even though golf course overseeding usage is declining, resort courses and some private and public facilities will continue the practice into the future. Therefore, this project was developed to address issues related to overseeding of bermudagrass fairways. A focus of this project is the use of saline/low quality water or sites that reduce water use by irrigating with lower evapotranspiration (ET) replacement rates.

The trial consists of not only single cultivars, but also blends and mixtures of various species Therefore, twenty-two entries were submitted that consist of ten ryegrass blends, nine single perennial ryegrass cultivars, one intermediate ryegrass, one annual ryegrass and one *Poa trivialis*. Three standard entries were also added to the trial (one each of perennial ryegrass, intermediate ryegrass and *Poa trivialis*).

Entries were established in 100 sq. foot plots, replicated three times where fairway traffic is evident, but also outside of landing zones. Trials were planted in fall 2016 and were rated for establishment rate, color and quality. Winter ratings focused on percent cover of overseeding grass, color, quality, texture and growth rate. Spring and summer 2017 ratings consisted of color, quality, texture and growth rate, with additional ratings of density and percent green cover of bermuda and overseeding grass during the transition back to 100% bermuda. In fall 2017, each trial location was reseeded with the same entries at the same physical location, with the same data collection protocols as in 2016.

Year one data has been published on the NTEP web site at http://www.ntep.org/reports/os16/os16_17-9/os16_17-9.htm with year two data being published in late summer or fall 2018. Data is for use by cooperators, extension personnel, seed companies and golf course superintendents in making recommendations or purchasing decisions.

Results from the Fall 2016 - Spring 2017 growing season were analyzed and published separately by location. As in past overseeding trials, entry performance varied significantly from

one location to another. However, when reviewing all nine locations, ‘Landmark Winterseed 5 Blend’ and ‘Stellar 5GL’, both perennial ryegrasses, finished in the top statistical group for overall turfgrass quality at every location. ‘LTP-3-PR-Blend’, ‘Allsport 5’, ‘SPR Spreading Ryegrass Overseeding Mix)’, ‘PPG-PR-308’, ‘Natural Knit’ and ‘LCP-186’also performed well at all locations, finishing in the top statistical grouping (turf quality) at eight of the nine sites.

Considering only the five ET-based locations, ‘SPR Spreading Ryegrass Overseeding Mix’, ‘Stellar 5GL’, ‘Landmark Winterseed Blend 5’, ‘PPG-PR-308’ and ‘Allsport 5’ had mean turf quality ratings in the top statistical group at each site. For the three saline irrigation based locations, the entries in the top statistical grouping at each location include ‘Champion GQ’, ‘Natural Knit’, ‘Landmark Winterseed Blend 5’, ‘LCP-186’, ‘Futura 3000’, ‘LTP-3-PR Blend’, ‘Ringles’ and ‘Stellar 3GL’.

It is notable that all of the top entries listed in this report are either single perennial ryegrass entries or a blend of perennial ryegrasses. None of the two *Poa trivialis* entries delivered good turfgrass quality at any location. Entries containing anywhere from 30-100% intermediate ryegrass or annual ryegrass did not perform well overall, with a few exceptions. ‘Futura 2500’, a mix containing 30% intermediate ryegrass, 70% perennial ryegrass, performed well at the Las Cruces, NM and Lubbock, TX locations. The intermediate ryegrass entry ‘Transist 2600’, was a good performing entry with turf quality in the top statistical group at Stillwater, OK. It is also notable that one of the main selling points for annual or intermediate ryegrass is potentially a better spring transition back to bermudagrass. Therefore, less than top turf quality ratings may not the only determining factor for choosing one of these entries.

Since performance varied by locations in the first year, it will be interesting to see how the weather patterns of the 2017/2018 growing season affect these entries, and impact their ratings.

SUMMARY POINTS:

- This trial focuses on cultivar, blend and mixture performance of twenty-five entries, primarily under reduced (ET based) water rates or the use of saline (low quality) irrigation water.
- Nine golf course sites, chosen based on geographic location and maintenance characteristics, were established in fall 2016 via large plots on fairways.
- Entries containing perennial ryegrass had the best overall turfgrass quality in the Fall 2016 - Spring 2017 growing season.
- There was some variation in performance of entries at the ET-based reduced irrigation locations vs. the saline irrigation locations.
- Plots were reestablished in fall 2017, in the same physical location and with the same entries, for year two of data collection.

Figure 1. Entries were established in 100 sq. foot plots, replicated three times where fairway traffic is evident, but also outside of landing zones.

Table 1. Trial locations were selected in important use areas and/or locations with challenging environments or unique characteristics.

Golf Course	Location	Cooperator	University
Lonnie Poole @ NC State [1]	Raleigh, NC	Dr. Grady Miller	N.C. State
The Rawls @ Texas Tech [1]	Lubbock, TX	Dr. Joey Young	Texas Tech
Lakeside [1]	Stillwater, OK	Dr. Charles Fontanier	Oklahoma State
New Mexico State Univ. [1]	Las Cruces, NM	Dr. Bernd Leinauer	New Mexico State
Tucson Country Club [2]	Tucson, AZ	Dr. David Kopec	Arizona
Lost Key [2, 3]	Pensacola, FL	Dr. Bryan Unruh	Florida
Texas A&M Univ. Campus [2]	College Station, TX	Dr. Casey Reynolds	Texas A&M
Mississippi State Univ.	Starkville, MS	Dr. Wayne Philley	Mississippi State

[1] *Uses reduced water rates via ET replacement.*
[2] *Utilizes saline irrigation water.*
[3] *Lost Key has seashore paspalum fairways, all other sites have bermudagrass fairways.*

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2015-19-534

The Effects of Mowing Delay on Proxy Efficacy for Poa annua Seed Head Suppression

Alec Kowalewski, Brian McDonald, and Micah Gould
Oregon State University

Research Summary (Year 3)

- Year 3 investigated the effects of mowing 1, 2, 3, 4, 6, 8, and 24 hours after a Proxy application. Year 1 and year 2 research did not show meaningful differences when delaying mowing prior to application and 1, 2, and 3 days after the application.

- Hourly mowing timing had the following impacts on annual bluegrass seed head counts:
    - Mowing 24 hours after the Proxy application had the fewest seed head counts when averaged across all rating dates, however, it was not significantly different than most of the other mowing timings.
    - Mowing 1 hour after the Proxy application appeared to reduce the length of seed head suppression as these plots had average seed head counts that were not significantly different than the untreated control on the last two rating dates – June 15th and June 22nd.

- All treatments with Proxy resulted in fewer seed heads and better turf quality vs. the untreated.

Introduction

Annual bluegrass seed head production on putting greens results in a number of detrimental effects including, but not limited to, reduced putting green speed and consistency, and reduced aesthetics. As a result, herbicides and plant growth regulators are often used to suppress seed head flushes. Research and practical field applications have shown that Embark (mefluidide) and Proxy (ethephon) provide the best reduction in seed head production. However, because of the phytotoxicity that often occurs with Embark (and it was recently removed from the market), Proxy has become the product of choice for suppression of annual bluegrass seed heads, however, its effectiveness - especially in the Midwest - is often inconsistent. Recent research conducted in the greenhouse has shown that Proxy absorption and translocation from the flag leaf substantially improves seed head suppression. However, daily mowing removes the flag leaf.

Year 1 Objective and Findings (Spring 2015):

Objective

- The initial objective was to determine if mowing delays prior to and following the application of Proxy will affect the seed head suppression of annual bluegrass during the spring flush. In year 1, we investigated all daily combinations of the last mowing prior to the application from 3 days prior to and beginning mowing again 1, 2 and 3 days after application.

Findings

- Results obtained in 2015 suggest mowing should be delayed the day of Proxy application until after the product is applied (data not shown).

Year 2 Objective, Materials and Methods, and Findings (Spring 2016):

Objective

- The objective of year two research was to determine if increasing the number of days the last mowing occurred before the application of Proxy would impact seed head suppression. Letting the turf grow for 3, 6, 9, and 12 days would allow for the development of a larger flag leaf prior to the application of Proxy. In this trial, we did not investigate timing of mowing after the Proxy application (i.e. all plots were mowed 24 hours after the Proxy application).

Findings

- No differences in seed head suppression were observed when the last mowing was 0, 3, 6, 9, or 12 days prior before the Proxy application.

- Regardless of the mowing timing, Proxy decreased seed head production in comparison to the control.

Year 3 Objective, Materials and Methods, and Findings (Spring 2017):

Objective

- The objective of year three research was to determine if mowing immediately after (ranging from 1 to 24 hours) the application of Proxy reduced the effectiveness of seed head suppression.

Materials and Methods The trial was initiated at the Oregon State University Lewis-Brown Horticulture Farm in Corvallis, Oregon. The trial site was an annual bluegrass putting green built in April of 2009 by placing annual bluegrass sod (Bos Sod, Canada) over 12 inches of USGA specification sand. The sand was placed on flat drain lines which lay on 'Malabon' series silty clay loam soil.

The trial was initiated on May 9th (the historical peak of seed head flowering in Corvallis) by applying Proxy across the entire trial area at 8 am. The untreated plots were covered with plastic. Before the trial, the green was mowed five times per week at 0.125 inches with a Jacobsen Eclipse 322 triplex. Mowing treatments were applied with a Jacobsen Eclipse walk mower set at 0.125 inches beginning 1 hour after the Proxy application.

The trial was set up as a Randomized complete block design with four replications. The plot size measured 20 inches wide (1 mower pass) by 9 feet long. Visual Quality and Seed Head Ratings were taken on May 26th and 31st, and June 8th, 15th, and 22nd. Seed head counts were made on May 31st, June 8th, June 15th, and June 22nd. To count the seed heads, a cup cutter sized hole (12.6 in^2) was made in a small piece of plywood. The plywood was lightly tossed on each plot 3 times (i.e. 3 subsamples per plot) and the seed heads were counted. The three counts were then averaged for each plot.

Treatments were as follows:

Trt #	Mowing Timing	PGR
1	1 hour after application	Proxy @ 5 oz
2	2 hours after application	Proxy @ 5 oz
3	3 hours after application	Proxy @ 5 oz
4	4 hours after application	Proxy @ 5 oz
5	6 hours after application	Proxy @ 5 oz
6	8 hours after application	Proxy @ 5 oz
7	24 hours after application	Proxy @ 5 oz
8	24 hours after application	No Proxy

Results

Mowing timing did not have an impact on turf quality on plots treated with Proxy. All plots treated with Proxy had significantly better turf quality than the untreated control as the untreated control had more seed heads. However, the untreated plots were slightly darker in color as Proxy tends to lighten turf color slightly (data not shown).

On 4 of the 5 rating dates, there were no differences in visual seed heads on plots treated with Proxy. On the first rating date, May 26th, the plots mowed 24 hours after application had statistically fewer visual seed heads (1.8 percent seed head cover) than all the other treated plots which ranged from 2.5 to 3.8 percent seed head cover. The untreated control had 7.8 percent visual seed head cover on this date (data not shown).

Additionally, the plots mowed 24 hours after application had the lowest average seed head counts across all dates. In fact, the order of treatments with the three lowest seed head counts from low to high was 7, 6, 5 (24 hours, 8 hours, and 6 hours after application, respectively). This result gives some indication that there is a negative effect from mowing too soon after application, but the effect is small.

When looking at seed head counts on June 15th and June 22nd, mowing 1 hour after application was not any better than the untreated control. This result implies that not all of the Proxy applied was absorbed at the time of application which reduced the length of control (Table 1).

Based on these results, waiting 24 hours after a Proxy application would be recommended. However, if that timing is not possible, waiting at least two or three hours to mow a putting green after a Proxy application would be the next best option. Lastly, if putting greens needed to be (or accidentally were) mowed 1 hour after the Proxy application, the next Proxy application should be made two weeks earlier than normal, if seed head pressure is expected to continue.

Figure 1: Trial site 23 days after treatment on May 31, 2017.

Table 1: Effects of mowing time after the Proxy application on analysis of variance and mean for separation for seed head counts observed on 31 May and 15 June, 2017 in Corvallis, OR.

			31-May	15-Jun
Source of Variation	Num DF	Den DF	*Pr* > F	
Mowing after Proxy application	7	21	**	*

Mowing ¥ prior to Proxy application¥	31-May		15-Jun	
	Seed Heads per 12.6 inch^{2ǂ}			
1 hour after application	53.4	b	70.8	ab
2 hours after application	60.5	b	56.7	bc
3 hours after application	49.8	b	58.3	bc
4 hours after application	54.8	b	59.7	bc
6 hours after application	52.3	b	57.9	bc
8 hours after application	51.1	b	50.8	c
24 hours after application	43.1	b	56.3	bc
24 hours after app - **No proxy**	93.1	a	86.0	a

* Significant at a 0.05 level of probability; ** Significant at a 0.01 level of probability; ǂ Surface area of a 4 inch diameter cup cutter;
¥ Proxy applied at 5 oz./1,000 ft^2 on 9 May 2016, except where noted; ¥ Mowing applied beginning May 9^{th}; ± lower case letters represent a significant difference at a 0.05 level of probability. Mean separations were obtained using Fisher's LSD.

2016-26-576

Title: The Impact of Putting Green Management on Visible Wear Caused by Golf Cleat/Sole Designs

Project Leaders and Affiliations:
Thomas A. Nikolai, Ph.D., Michigan State University
Douglas Karcher, Ph.D., The University of Arkansas

Start Date: 2016
Project Duration: 2 years
Total Funding: $57,161

Summary Text and Objectives:
In recent years, some superintendents and golfers have protested that newer golf cleat/sole designs are too aggressive on their putting surfaces. Trade journal articles have quoted individuals claiming that some of these newer designs are worse than banned spikes from the past. Conversely, golf course clientele in similar regions have not reported any putting surface disruption caused by any cleat/sole designs. Given this conundrum, there appears to be a need for scientific evidence regarding how putting green management may affect visible damage caused by foot traffic from various cleat/sole designs.

To address the issue a two-year study to quantify the impact of putting green management on the visible wear caused by golf cleat/sole designs was initiated at Michigan State University(MSU) in partnership with The University of Arkansas(UA) in the summer of 2016. Objectives of the research include:

1) **identify particular components of golf cleat sole designs that result in the least to greatest perceived differences in regard to green friendliness**

2) **identify putting green management practices that negate the visible damage caused by the most intrusive and/or destructive of the current golf cleat/sole designs and**

3) **search for correlations between surface firmness (as measured by a TruFirm device) and TDR measurements (0 to 1.5 inches) when collecting data regarding turfgrass management practices.**

To address Objective 1, golf cleat/sole traffic studies were performed at 20 locations (Michigan, Arkansas, Florida and Scotland) with over 20 cleat/sole designs. The studies were conducted on various cultivars and ages of creeping bentgrass, annual bluegrass, ultradwarf bermudagrass, seashore paspalum, and fine fescue putting greens. At each location, 3 x 3 foot plots were trafficked with different cleat/sole designs, with each design designated as a treatment. Each plot received 30 simulated rounds of golf with the exception of a non-trafficked treatment. Following traffic, golfing clientele rated the putting surface smoothness using the following scale:

1 = Excellent; no visible traffic
2 = Very good; I think I see foot traffic
3 = Good; some visible foot traffic but I would not mind putting on the surface
4 = Fair; visible foot traffic that would most likely deflect my putt and
5 = Poor; terrible putting conditions recommend banning the cleat/sole from our golf course.

To address Objectives 2 and 3 research putting greens at MSU and UA were managed under identical cultural and mechanical practices. Management treatments included different levels of grooming (none

vs. 3x weekly), lightweight rolling (none vs. 3x weekly), sand-topdressing (none vs. every other week), and fertility (low N vs. high N). Research putting greens at MSU included a 1-year old ‘Declaration’ creeping bentgrass green grown atop a USGA specification root zone and a 11-year old push-up annual bluegrass putting green. At UA a 1-year old ‘Pure Distinction’ creeping bentgrass established on a USGA root zone and a ‘Tifeagle’ ultradwarf bermudagrass putting green established on a 10 inch sand cap (sand particle size is within USGA recommendations). Each green was evaluated for foot traffic tolerance on at least three occasions during both years of the study. Other data collection included green speed measurements, total biomass (measured in place of thatch thickness) from surface to a one inch depth, surface firmness as measured with the Spectrum Tru-Firm, and volumetric water content to a 1.5 inch depth using a Spectrum TDR 300.

Summary Points:
The most repeatable observation from Objective 1 was:

1. golf sole and cleat designs from the 20th century (including but not limited to the 8 and 6 mm) resulted in more visible foot traffic at most every site compared to the most aggressive of today’s cleat/sole designs (Fig. 1).

Results from Objective 2 and 3 include:

1. When statistical difference occurred, topdressing on creeping bentgrass and annual bluegrass resulted in less visible wear following 20 simulated rounds of golf.
2. Topdressing also resulted in firmer (less ball mark depression measured with the Tru Firm) on creeping bentgrass and annual bluegrass at MSU
3. Topdressing also decreased VWC on creeping bentgrass and annual bluegrass.
4. Annual bluegrass plots that were not groomed or topdressed resulted in the greatest ball mark depression compared to all other treatments as measured with the Tru Firm.
5. On creeping bentgrass high fertility resulted in greater ball mark depression (less firm surfaces) as measured with the Tru Firm.
6. Although there was a significant relationship between VWC and Tru Firm measurements, VWC explained less than 30% of the variability among Tru Firm measurements. Therefore, predicting Tru Firm values from VWC alone is not practical.

In summary, little if any visual differences were apparent among mechanical and cultural treatments with the exception of days the plots were trafficked, however, data suggest proper cultural and mechanical practices can minimize wear from the most destructive golf cleat/sole designs and from ball marks (Fig. 2).

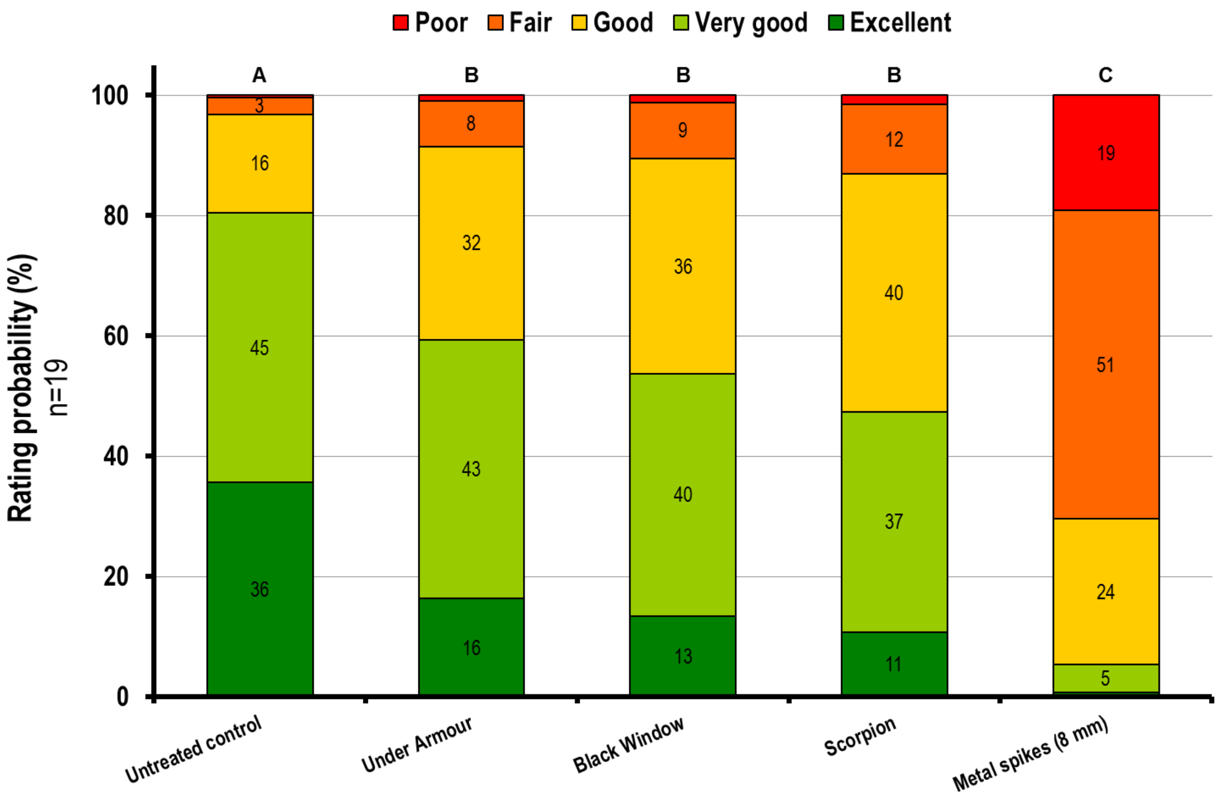

Figure 1. Predicted probabilities of spike treatments to be rated as either "Excellent", "Very Good", "Good", "Fair", or "Poor". Probabilities were estimated using logistic regression analysis of data collected from 3 replicate plots evaluated on St Andrews Golf Club Jubilee, St. Andrews Scotland on a 10-year old fine creeping red fescue, colonial bent and *Poa annua* mix putting green April 4, 2017. Data was generated from 19 raters and bars that do not share a letter are significantly different ($\alpha = 0.05$).

Figure 2. Though statistical differences resulted from measuring devices among the treatments, the plots were visually similar until traffic was applied.

4. Environment

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December 21, 2017

Golf Course Habitat Restoration Pilot Program: A Project Between the US Golf Association and The Nature Conservancy

Final Report

Andrew J. Peck, PhD
FRESHWATER PROJECT MANAGER

Introduction

As golf has become more popular, people have become interested in how golf courses affect land resources and the environment. For the past 25 years, the United States Golf Association (USGA) has supported more than 90 university research projects to evaluate the relationship between golf and the environment. Based on factual, unbiased university research, the results indicate that the turf, trees, and natural areas commonly found on golf courses provide several environmental benefits. Some of these golf course ecosystem benefits include topsoil erosion control, wildlife habitat, stormwater retention, improved air quality, and damaged land restoration.

The USGA recognizes that the ecological impacts of golf courses and the cost associated with course maintenance are limiting factors to the sustainability of the game, particularly in the realm of water management. It is estimated the more than 2 billion gallons of water per day are used across the US for green and fairway irrigation. Additionally, the USGA recognizes that there are areas of golf courses that are rarely used by players, yet are intensely managed to maintain course aesthetics. The USGA has a strong desire to improve the efficiency of water use and reduce overall course management costs, while improving environmental stewardship of course lands. However, successful implementation of these efforts is limited by the golf course decision maker’s technical capacity associated with the implementation of more efficient irrigation techniques or appropriate restoration and maintenance of native ecological communities.

The Nature Conservancy has a long history restoring and maintaining native ecological communities, as well as a history of engaging industries, such as agriculture, chemical producers, oil and gas, to develop and implement environmentally responsible business practices. The Conservancy is also highly engaged in water issues around the globe and has developed a wealth of ecological restoration and maintenance expertise through the protection of nearly 119 million acres globally.

The USGA Green Section and The Nature Conservancy are partnering to develop an implementation program that improves course-level capacity relative to the operation and maintenance of sustainable course management systems. This partnership will bolster the course-level experience with design, construction, and management of ecological community restoration and management projects.

The intent of this partnership is to build internal, transferrable capacity within the USGA and member courses to improve the sustainability of course management while maximizing the potential ecological benefits those courses provide.

The Neversink River

The Nature Conservancy has been working in the Neversink River Watershed for more than 20 years. Our on-the-ground efforts have resulted in the removal of the Cuddabackville Dam and the establishment of the Neversink Preserve comprised of two significant parcels. Currently, we are conducting a berm removal to reconnect the mainstem of the Neversink to its floodplain and between 2015 and 2016 we planted more than 15,000 saplings in an effort to re-establish a functional floodplain forest on abandoned agricultural fields. These efforts have contributed to improved ecological function in the watershed, but social challenges associated with natural flood events are prevalent and generally occur through two pathways. The first pathway is through surface run-off caused by locally intense storms. The second, and less common, pathway is through high water levels in the mainstem of the Delaware River which can effectively stop the discharge of Neversink River flows. When the Neversink Valley experiences a locally heavy precipitation event, and the Delaware River is also at, or approaching, flood stage, major damages to private property and public infrastructure are likely to occur as the floodwater begins to access the constricted floodplain.

The Lynx at Riverbend

The Lynx at Riverbend, a privately-owned golf course but open to the general public, is situated on a 124 acre parcel (Figure 1) in the last, largely undeveloped, floodplain complex along the Neversink River before it joins the Delaware River. The course contains several natural oxbow pond complexes developed as the Neversink channel shifted its course over thousands of years. The course also receives significant run-off from the Shawangunk Ridge which runs along the southern border of the golf course property. The soils located on the course are quite permeable and allow water to percolate into the groundwater quickly. However, when the groundwater table is high, the Neversink River is generally approaching bank-full flow or flood stage. The natural function of the floodplain is to store water during these kinds of events and then slowly release it as the mainstem falls back within its banks. Receiving both flood water from the Neversink and surface run-off from the Shawangunk Ridge, means The Lynx at Riverbend is highly vulnerable to flooding with "worst case scenario" events occurring three times in the past 15 years. As precipitation events are expected to intensify in the future, significant flooding impacting the course is expected to become more frequent.

Figure 1. Aerial image of the 124 acres parcel that comprises The Lynx at Riverbend in Port Jervis, NY.

The most recent event occurred in 2011 with Tropical Storm Irene and Tropical Depression Lee. The course was open for play within a day or two of Tropical Storm Irene. However, as the flood pulse from Irene began to raise the Delaware River to flood stage, water began to back up into the Neversink River. Then, when Tropical Storm Lee hit a few days later, the course was inundated with more than 15 feet of water for more than a week. The impacts of these flooding events included deposition of significant sediment loads into the course water features, oxbow ponds, fairways and greens while also distributing seed material of both native and invasive species. The damage to the course was both extensive and persistent.

The Opportunity

Repair and mitigation funding were made available to the region following the trio of storms which included previously mentioned Irene and Lee and the remarkable Superstorm Sandy. The Lynx at Riverbend was able to secure $200,000 of this support to not only repair damaged infrastructure (e.g. cart paths, fairways and greens) but was also able to implement proactive measures likely to reduce damage from future storms (e.g. pond dredging and naturalization areas). The Nature Conservancy and the US Golf Association mutually agreed to invest resources into the Lynx at Riverbend as a pilot project to inform feasibility of a more robust collaboration in the future.

The Nature Conservancy's involvement focused on developing a scientific understanding of how the Neversink River interacts with the floodplain which encompasses the golf course, development of project design, assistance with permitting the project and design implementation. The US Golf Association provided not only the resources to execute a project but also technical assistance relative to the game of golf that were not well understood by Conservancy staff and provided the capability to track course users during individual rounds. The Lynx at Riverbend was responsible for managing the federal and state resources, consulting on design measures and species lists, and implementation.

Project Execution

The project team agreed on five necessary components for a successful project. The first component was a hydrologic evaluation and inundation analysis to better understand how, where and when storm and/or flood water interacted with the course. The second was to identify low-use areas of the course that could be naturalized without significant impact to course use or maintenance operations. The thrid was development of a project design to include a species list comprised of native grasses, plants, shrubs and trees as well as the development of plant distribution scheme. The third phase was applying for and securing the necessary permits. The final phase was implementing the agreed upon design in strict accordance with the terms and requirements of the secured permits.

Figure 2. Moderate Flooding around the 18th hole of The Lynx at Riverbend. All areas left of the pine trees and inundated in the photo were naturalized in the Fall, 2017.

Inundation Analysis Summary

Being that flooding is the most significant management concern for the Lynx at River Bend, a fundamental step in the design process for the full repair, mitigation and naturalization project was to determine how floodwaters access and flow through the floodplain in which the course is embedded. Milone & MacBroom, Inc. (MMI) was contracted to conduct the hydrologic and inundation analysis to provide a better understanding of how the Neversink River and the floodplain interact under various flow conditions and, more specifically, indicate the pathways by which the floodplain becomes inundated (Appendix 1). Due to the topographic nature of the area around the course and the challenges of modeling surface run-off, only floodwaters originating from the mainstem of the Neversink were analyzed and the resulting analysis does not take upland surface run-off into account.

Initial data collection methods included field surveys as well as accessing public, remote sensing data. In this case, we accessed stream gauge information developed and maintained by the US Geologic Survey, soil maps developed and maintained by the USDA Natural Resource Conservation Service, and various GIS data available from the New York State GIS Information Clearinghouse. MMI conducted a series flood frequency analysis using these data resources and was able to effectively develop an inundation model for the golf course over a range of flood magnitudes; in this case 1-year to 20-year return intervals.

This analysis revealed that no reasonable grey or nature-based approaches to stormwater management or flood protection were going to be effective at eliminating future flood-induced impacts. With a 1.25-year flood interval event, a 98.75% chance of occurring in any given year, the course experiences some super-saturation and high water around existing waterbodies and oxbows, but play and operation is easily managed at this magnitude. With a 2-year event, a 98% chance of occurring in any given year, the northern pond complex becomes inundated and the eastern oxbow begins to impact cart paths and fairway fringes. Both of these areas are directly connected to the mainstem of the Neversink by underground piping. During low intensity, high frequency events these stormwater outfalls become inundated and stream water flows back up the pipes to the course while standing water in the ponds is not able to discharge from the pipes. These scenarios cause very minor course flooding condtions.

The 5-year flood event, with a 95% chance of occurring in any given year and a stage of only 9.5 feet at a nearby USGS Stream Gauging Station, is when significant impacts being to occur and the course

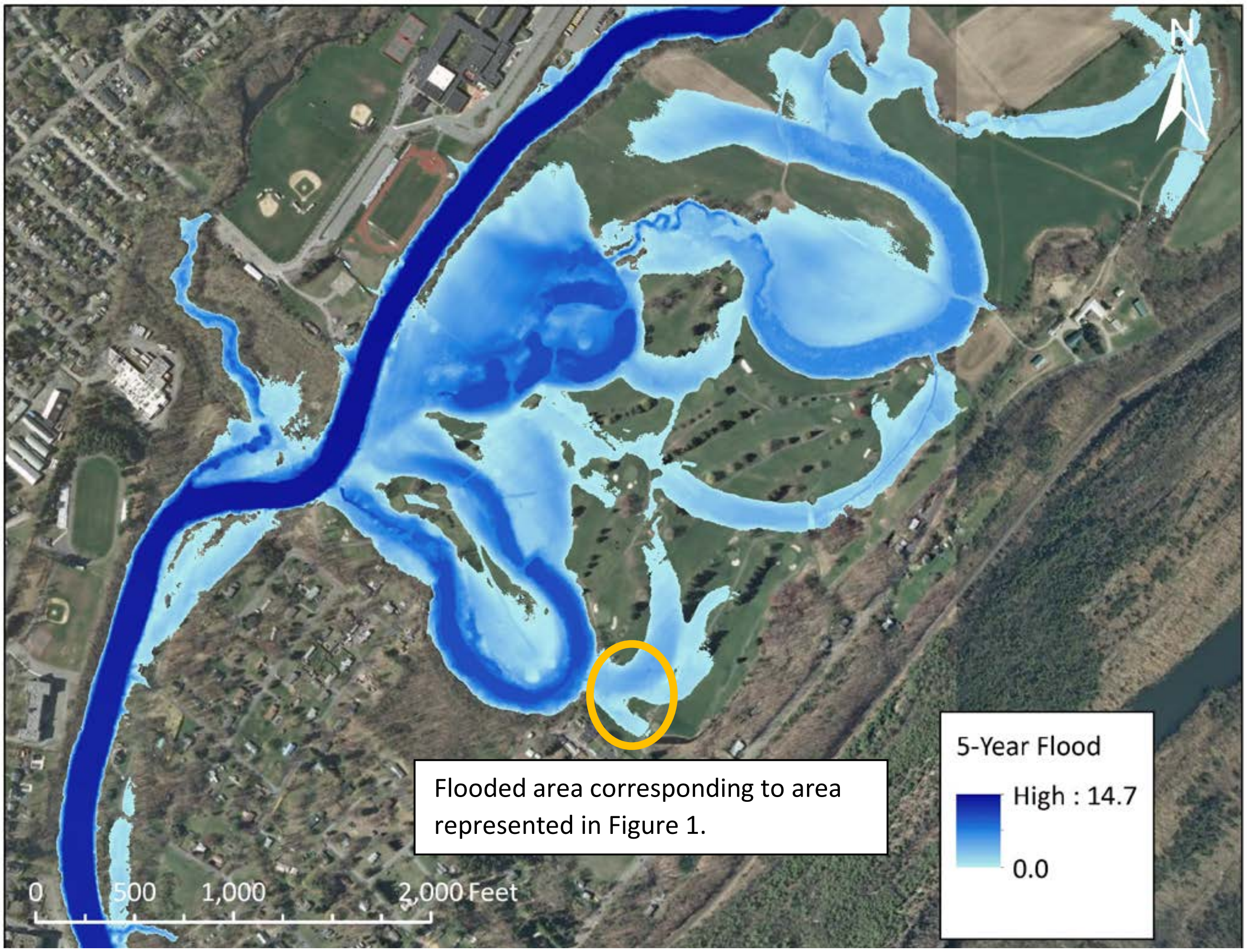

Figure 3. Inundation Modeling results for 5-year flood event (95% chance of occurring in any given year) for the Lynx at Riverbend. The area within the yellow circle is depicted in the Figure 1 photograph. The darkest blues represent the deepest water depths (14.7 feet) while lighter blues indicate shallower inundation depths.

becomes unplayable and unsafe (Figure 2.). During an event of this magnitude, all of the existing waterbodies become inundated and begin accessing the floodplain and cover approximately 50% of the course. A 10-year flood event, with a 90% chance of occurring in any given year, practically impacts the entire course. The highest elevations likely become super-saturated while the lowest elevations may be may be inundated by nearly 12 feet of standing water or more.

Because of the high impact of relatively common flow conditions, the project team quickly concluded that very little could be done from a floodwater or stormwater management perspective that would meaningfully enhance protection of the course and its associated infrastructure. The best management strategy was to better prepare the course to receive floodwaters and improve the ability, and rate, of the course to recover from those impacts. The attention of the project team began to immediately focus on nature-based solutions that reduce the acreage under active management as a way to both reduce recovery time and cost, but also improve maintenance efficiency and habitat conditions on the course.

Identification of Possible Naturalization Areas

In order to identify where actively managed areas with low intensity use by golfers existed, we deployed Global Positioning System (GPS) technology provided by the Green Section of the US Golf Association. The GPS Transmitters were deployed over two-month period during the 2015 Season and tracked 90 rounds of play. This user tracking exercise resulted in the identification of 16 areas suitable for naturalization throughout the course and comprised of more than 35 acres (Appendix 1); more than 25% of the entire course property. It wasn't feasible to tackle all 35 acres with the allocated budget, so, in collaboration with course management, we prioritized four areas to be completed with US Golf Association resources, totaling approximately 3.75 acres, based on their likelihood to become inundated, improve course management efficiencies, improve water quality and improve the overall course experience.

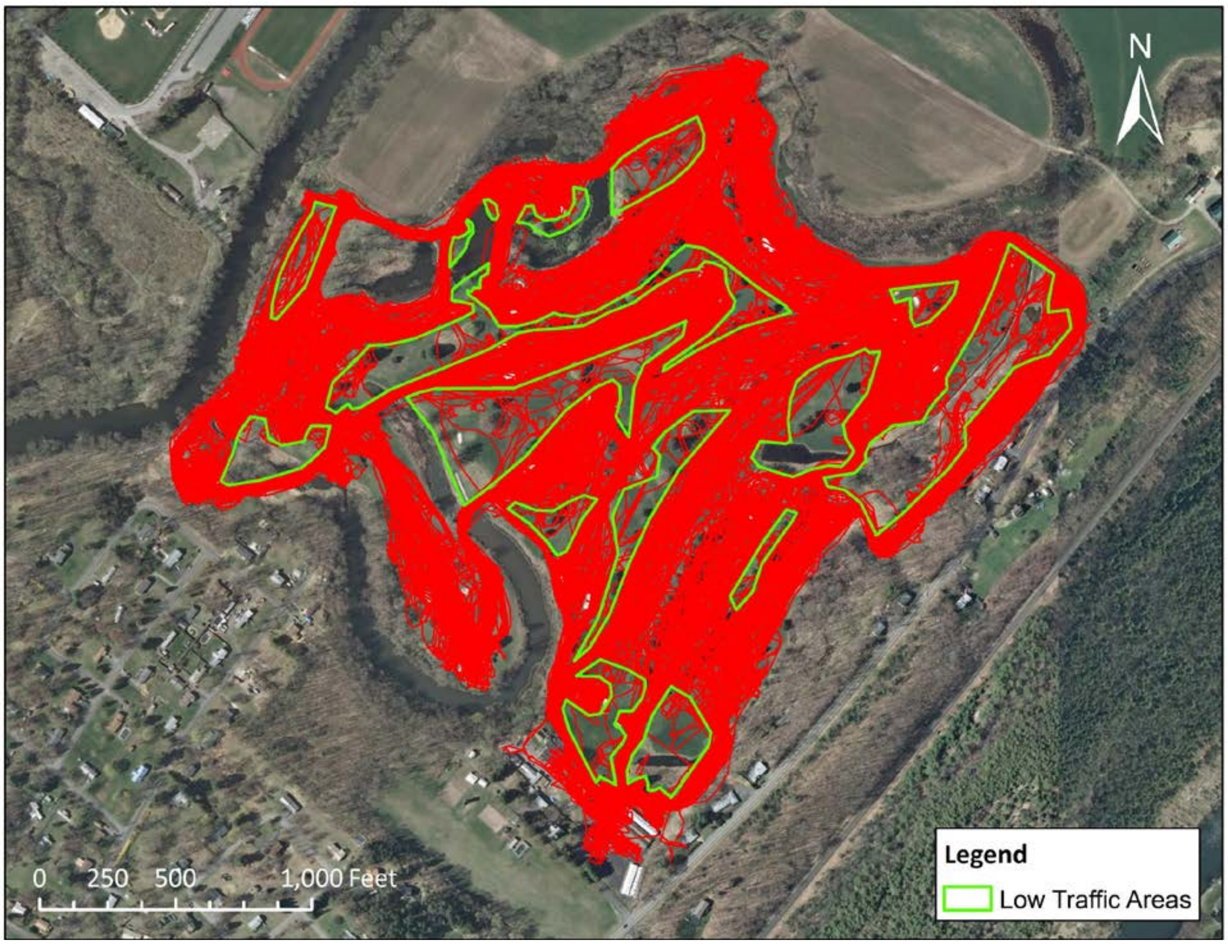

Figure 4. Areas in red represent the 90 tracks used by golfers that were fitted with Global Positioning Systems tracking devices provided by USGA Green Section. Areas inside of the areas with green borders where identified as possible naturalization areas. In total theses 16 plots represent 35 acres and more than 25% of the course property.

Naturalization Design and Course Modifications

Due to familiarity with the naturalization project through the inundation analysis and their extensive restoration experience in floodplain and wetland areas, MMI was contracted to develop a preliminary design for the previously mentioned four priority areas. MMI was able to provide a recommended planting scheme and species list which included grasses, sedges, reeds, shrubs, and trees (Appendix 2). Through a generous review period, the project team members were able to refine the proposed planting scheme and original species list. This step was necessary because New York State has instituted an invasive species management law which provides a list of prohibited and regulated invasive plant species whose sale, and subsequent planting, is either banned or regulated within the state (Appendix 3). This statute required some changes to the proposed species list while project team was also able to incorporate some preferred species. Due to the topography of the course, each priority area had some combination of perennially wet, seasonally wet, riparian/floodplain, and/or upland habitat types which is reflected in the species list (Appendix 2).

Appropriate species and seed mixtures were selected for the appropriate moisture and anticipated inundation conditions and positioned to accentuate species diversity while not interfering with play. This was accomplished using 24” spacing between plugs and shrubs with shorter species around the perimeter and taller species being more concentrated toward the interior of each area. Additionally, course management agreed to adjust out-of-bounds markers and lines to ensure the naturalized areas are not impacted by cart or foot traffic following project completion. Shifting boundaries was not insignificant, but did not result in changes to hole par ratings. Tee boxes were also shifted on at least two holes, which was done largely to improve pace-of-play and used materials excavated from the naturalized areas and pond dredging.

<u>Permitting</u>

Upon completion and acceptance of the naturalization design, initial permit applications were compiled by The Nature Conservancy. Due to the location of golf course in a federally regulated floodway and floodplain and both state and federal funds being used to significantly augment USGA resources, an extensive permitting process was required. Federal and state disaster assistance funds were being used for extensive but separate activities (e.g. fairway reseeding, replacement of greens, cart path repair and additional naturalization) on the same parcel requiring that the entire project be permitted at the same time. This determination, as well as identification of lead agency, delayed the TNC/USGA portion of the project almost an entire year. Because both state and federal funds where being used for the project, a project application first needed to go through both the National Environmental Policy Act (NEPA) and the New York State Environmental Quality Review Act (SEQR) process which identifies the all the potential concerns and resulting necessary permits from the various regulatory agencies required to move forward with implementation and construction. Several federal, state and local permits were identified including:

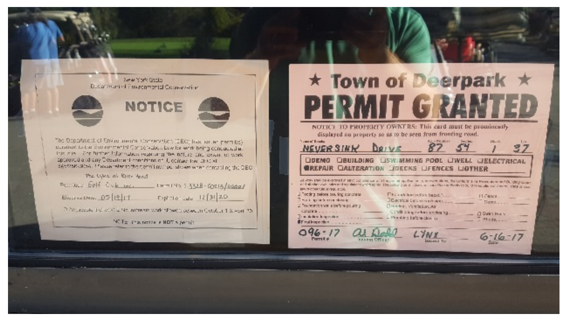

Figure 5. Required NYS Department of Environmental Conservation and Town of Deerpark Floodplain permits displayed in clubhouse windows as required.

1. Nationwide Permit #27: Section 404 Clean Water Act
2. Water Quality Permit: Section 401 Clean Water Act
3. NYS Uniform Procedures: Water Quality Certification
    a. State Pollution Discharge Elimination System Stormwater – Construction
    b. NYS Erosion and Sediment Control Plan
4. Local Floodplain Management Permit

Several project components were restricted or eliminated to avoid further permit requirements, delays and costs. For example, to mitigate impacts to nesting and migratory Bald Eagles, construction activity was only allowed to occur between April 1 and November 30 to avoid impacts to this recovering species. The project team had also considered expansion of existing water features but these concepts were withdrawn due to the high likelihood of finding native artifacts and the stringent federal and state permit requirements related to historical preservation. Ultimately, the permitting process did cost more than anticipated and did somewhat alter our original planning but the reconciled activities were all ultimately permitted and the project allowed to proceed (Appendix 4).

Project Construction

Preparations to begin the implementation process were instituted in late spring/early summer 2017 with plans for intense on-the-ground activities beginning in Fall 2017. The process began by staking of naturalization areas and realigning out-of-bounds markers and boundaries to get course users accustomed to the new layout of affected holes. These new out-of-bounds areas were then removed from active management and allowed to grow to gain a sense of how future course management activities and costs might be eliminated.

Site Preparation

In early September 2017, during the regions typical drought period, the course superintendent, a certified and licensed herbicide applicator, applied glyphosate to all the areas identified for naturalization. The herbicide areas were rested for roughly three weeks to ensure all existing turf and other plant material had been neutralized. We broke ground on the naturalization areas on September 25, 2017. The glyphosate treated turf was pulled up using a “Harley Rake” attachment on a wheeled mini-excavator (Figure 7). This not only pulled up the turf but also loosened the ¼” of remaining soil (Figure 6). The resulting turf material was then incorporated into new tee boxes or otherwise incorporated on-site.

Figure 6. Resulting planting area conditions following removal of turf by “Harley Rake.”

Figure 7. All equipment used in the turf removal and disposal process. Light brown areas have been treated with glyphosate, but not yet “Harley Raked.” Mini-excavator and “Harley Rake” used to remove turf (upper left corner. Dump truck and front-end loader used to transport removed turf to final destination.

Plant Material and Planting

Plant material was delivered to the course on September 27, 2017. An inventory of delivered material was taken and condition of the plants were checked. The majority of plugs and plants were delivered in very good condition, but not all. A reconciliation was made with supplier to our satisfaction and replacement plants were delivered within three days. Seeding began immediately using both native seed mix for the appropriate moisture conditions and oats as an erosion and sediment control measure. All seeded areas were then drug using a steel mesh mat to ensure good soil to seed to contact conducive to seed germination.

Figure 8. Plug, shrub and Tree staging area following delivery on September 27, 2017.

Planting of plugs occurred over two periods, September 28 – October 3 and November 2 - November 6. A third-party contractor and a volunteer group from the Albany Pine Bush assisted in planting more than 12,000 plugs along with 117 shrubs and trees on nearly 4 acres.

Although soils were dry during the initial planting period, we received moderate precipitation shortly after which allowed for initial germination to be observed on October 10, 2017. The Erosion and Sediment Control inspections identified good germination rates across all sites with some small areas benefiting from additional seeding. In these small areas, a supplemental mix of winter rye and oats were seeded. Germination continued to be observed through mid-November as weather conditions were very favorable.

Figure 9. Contractor planting plugs in naturalization area in front of 18th Hole using an approximately 24-inch layout scheme.

Lessons Learned

As previously identified, the permitting process was extensive and cumbersome, due in large part to the Federal Disaster Recovery and Mitigation funds that were being matched by US Golf Association resources. This process caused a delay of more than a year and required unanticipated erosion and sediment control inspection costs. Although combining the efforts did cause administrative delays, the final product was far more than would have been accomplished with solely US Golf Associated resources. The federal and state resources allowed the project team to double the number of trees planted, naturalize an additional 3-4 acres, dredge three ponds to hold more surface run-off, relocate two new tee boxes, repair cart paths, and top-dress and reseed several fairways and greens.

In preparing the sites to be naturalized, we opted to try a new technique to The Nature Conservancy. The contractor recommended the use of a “Harley Rake” attachment for a mini-excavator. This was expected to save a tremendous amount of time and effort in turf removal. However, the maintenance crew failed to mow the areas, which had been allowed to grow, uncontrolled, for nearly 3 months, before glyphosate application. This produced a significant amount of turf material that needed to be managed. Although the “Harley Rake” worked extremely well, the areas should have been mowed first with a brush hog and then again with a mower prior to glyphosate treatment to reduce the amount of material requiring disposal management. We were able to develop a “beneficial use” plan for this material, as well as the pond dredge material, by incorporating both into new tee boxes.

Initial expectations were that naturalizing several acres of the Lynx at Riverbend would save both money and resources associated with day-to-day course management and, perhaps, improve profit margins. However, preliminary evidence indicates the management resource savings are likely not realized. Rather the same amount of management resources are still needed, but they are likely redistributed to other management activities. This does yield improved management efficiencies and results, but reducing management input costs through naturalization is not likely to improve profitability margins. Further, sufficient time has not elapsed to determine how this effort will influence the number of rounds played per year, nor has there been a flooding event to indicate a reduction in damage recovery time or cost.

Budget

The total cost of the naturalization project was overbudget by $14,554.28. These additional costs were largely associated with the extensive permitting process and the need to hire a planting crew, which was unexpected and largely a product of necessary project management changes associated with permit requirements, resulting design changes and a much more condensed implementation schedule. Reimbursement for the unbudgeted costs will not be requested. Total costs on a per acre scale were approximately $28,000 per naturalized acre, which beg the question of where can efficiencies be found and what is a feasible price point to increase use of naturalization practices on more acres and on more courses.

Category	Budgeted	Actual	Pending	Difference
Salary	$10,000.00	$8,360.65		$1,639.35
Fringe	$4,200.00	$3,684.10		$515.90
Travel	$1,500.00	$118.78		$1,381.22
Equipment (<$5,000)	$500.00	$2,720.59		$(2,220.59)
Contractual	$70,007.00	$81,820.68	$2,107.23	$(13,920.91)
Communications		$203.65		$(203.65)
Total Direct Expenses	$86,207.00	$96,908.45	$2,107.23	$(12,808.68)
In-direct Cost Reimbursement	$13,793.12	$15,505.00	$33.72	$(1,745.60)
Total Expenses	**$100,000.12**	**$112,413.45**	**$2,140.95**	**$(14,554.28)**

Conclusion

This pilot project between the US Golf Association and The Nature Conservancy on the Lynx at Riverbend, was a valuable learning experience. Many of our watershed management efforts around the world are influenced by golf courses of various types and sizes. The Conservancy has purchased courses no longer in operation and implemented extensive restoration of the parcel (Pennsylvania Chapter), but we do not have a history of engaging active facilities to improve resilience, habitat, water quality or water usage. This relatively small endeavor greatly expanded our knowledge and capacity to engage active golf facilities in a new and constructive way by highlighting the limitations course managers have to modify existing facilities due management constraints and patron expectations. The effort also provided a more accurate representation of what is necessary and feasible to successfully undertake a full-course naturalization effort. The final benefit of this initiative is that the local community supporting the work of the Conservancy may be growing and their perspectives of our efforts may also be shifting in a very meaningful way.

The Conservancy is grateful for the opportunity to partner with the US Golf Association and we look forward to discussing additional opportunities for partnership and collaboration, as warranted.

Figure 10. Initial germination of oats on October 10,2017 in front of the 18th green (foreground) and on a steep slope in front of the clubhouse (background). Plant plug material is interspersed, but difficult to identify.

2016-36-606

Title: Operation Monarch for Golf Courses: Developing Protocols for Monarch Butterfly Conservation Plantings in Golf Course Naturalized Roughs

Project Leader: Daniel A. Potter; Co-Investigators: Adam Baker (PhD student), Carl Redmond, Gregg Munshaw

Affiliation: University of Kentucky

Objectives:

1) Evaluate methodology for establishing milkweed for monarch butterfly conservation in golf course naturalized roughs
2) Document effectiveness of milkweed stands, with or without wildflowers, for attracting and sustaining monarchs, native bees, and honey bees on golf courses
3) Promote golf courses for monarch butterfly conservation through outreach education, webinars, conferences, trade journal articles, and media releases

Start Date: 2017

Project Duration: 2 years

Total Funding: $46,400

Summary:

The monarch, an iconic beloved butterfly renowned for its spectacular long-distance migrations, is threatened by loss of wild milkweed, its sole larval food plant, to the extent that habitat restoration may be essential to the species' survival. Golf courses can take a leadership role in helping to save the monarch by creating milkweed refuges in out-of-play areas. We evaluated 8 species of native milkweeds for their conservation value to monarchs and bees, and for suitability for use in different golf course settings. All 8 species were suitable as larval food, but the taller species (common, swamp, showy, and narrow-leaf milkweed) were most attractive to the egg-laying butterflies and yielded the most monarchs. Common, showy, and narrow-leaf milkweeds spread by rhizomes and tillers, so they are the most suitable species for establishing large stands in naturalized roughs. Swamp and butterfly milkweeds "stay put" (do not tiller) so they are better suited for more formal plantings along cart paths and similar settings.

The different milkweed species attracted different assemblages of bees; e.g., common and swamp milkweed were particularly attractive to larger bee species (honey bees, bumble bees, and carpenter bees) whereas butterfly and narrow-leaf milkweed attracted more diverse bee assemblages with greater representation of smaller native bees. Surveys of pre-existing milkweed stands on golf courses verified usage by monarchs. Trials conducted at three golf courses and at the UK Turf Research Farm, evaluated several methods for establishing milkweed in naturalized roughs. Plots were prepared by scalping, verticutting, or fraze mowing, treated with a grass herbicide, and the seeds of three species of milkweeds were sown by hand

or drill-seeded into the soil. Plots were established with or without a wildflower strip. Procedures that worked well for establishing wildflowers were not very effective for milkweeds. The following guidelines reflect what we have learned so far: 1) Sowing milkweed seed in roughs is unreliable; it is better to transplant seedlings. Purchase your plants locally, when possible, to ensure that they will do well in your climate. Ask the supplier for seedlings grown from more than one genotype to ensure they will be able to outcross and produce viable seeds in the field, and get 2-year plants when available. 2) Use milkweed species that produce tillers to fill in naturalized roughs, and non-tillering species for more manicured sites; 3) Scalp down competing vegetation, plant in spring, and water seedlings for best establishment. 4) Mow in autumn after milkweed senesces, 5) your milkweed will attract and help to sustain both monarchs and bees.

Results from the first summer of this work were presented at Field Days and reported in a feature story on TurfNet (https://www.turfnet.com/news.html/_/research-aims-at-establishing-monarch-friendly-protocols-r902). Further studies to evaluate best practices for establishing milkweeds from one or two-year old transplants are planned for 2018, including evaluations of growth, tillering, seed set, and usage by monarchs. We are also writing an article for Golf Course Management, and working on on-line materials with guidelines to help superintendents interested in establishing monarch habitat as part of their course environmental plan.

Summary Points:

- Transplanting seedlings was more reliable than seeding for establishing milkweed stands
- All eight species of milkweeds evaluated were suitable for larval growth but the taller species (common, swamp, and showy milkweed) yielded the most monarchs
- Common, swamp, butterfly, and narrow-leaf milkweeds were the best for supporting bees
- Common, showy, and narrow-leaf milkweeds spread from tillers making them the best suited species for establishing large stands in naturalized roughs
- Swamp and butterfly did not spread so they are better suited for use in high-profile sites
- Value of golf courses for monarch conservation was publicized in national media

Fig. 1. Monarch butterflies and bumble bees like swamp milkweed(photo credit: J. Hudgins).

Fig. 2. Common milkweed along cart path helps to sustain monarch caterpillars.

Fig. 3. Student worker checks for monarchs on common milkweed in naturalized rough.

Fig. 4. One of the replicated garden plots in which 8 milkweed species were compared.

2017-27-637

Project Title: Examining the Response of Golf Course Lentic Ecosystems to Insecticide and Nutrient Additions Using Survey and Experimental Approaches

Project Leaders: Joe Milanovich, Ph.D and Martin Berg, Ph.D

Affiliation: Loyola University Chicago

Objective: The objectives of this research are to: 1) conduct a survey to quantify water quality and biotic communities of lentic turfgrass ecosystems across 25 courses within the Chicago Metropolitan area, and 2) use data from survey efforts to inform an experimental design to mechanistically examine whether additions of pesticides and/or nutrients (nitrogen and phosphorus) have measurable impacts on turfgrass lentic water quality and ecosystem communities.

Start Date: 2017
Duration: 3 years
Total Funding: $82,053

Summary:
Golf courses in the United States have long been considered to play a significant role in maintaining and enhancing local biodiversity – particularly when the adjacent landscape is dominated by anthropogenic land-use (e.g., urbanization, agriculture). In the face of global change, managed areas that can harbor native biodiversity are crucial for supplying source populations to adjacent areas and for maintaining ecological processes and ultimately, ecosystem integrity. During the first year of our study, we quantified water quality and chemistry, algal concentrations, and micro-and macroinvertebrate and amphibian diversity and density across 25 golf course lentic ecosystems (herein ponds) and compared those to the same parameters found in ponds located within adjacent forest preserves (n = 30; 15 permanent ponds with fish and 15 fishless ephemeral ponds). To date, we collected over 550 water quality/chemistry measurements per analyte/compound and over 600 samples each of micro-and macroinvertebrates and amphibians. *These data will help elucidate the degree to which golf course ponds harbor biodiversity compared to adjacent systems considered more natural*.

Water quality/chemistry and algae: We examined concentrations of 10 analytes (name, minimum detection limit [ppb]) within each of the 25 course ponds and seven accessible course inflows (e.g., courses with accessible wells or lotic systems filling course ponds): Azoxystrobin (0.50), Bifenthrin (0.20), α-Chlordane (0.20), γ-Chlordane (0.20), Chlorpyrifos (0.20), Cypermethrin (1.00), Oxadiazon (0.50), cis-Permethrin (1.30), trans-Permethrin (1.30), Fenvalerate (0.30). Azoxystrobin, α-Chlordane, and Oxadiazon were the only compounds detected above the detectable limit in any of the 25 courses or course inflows in August (Table 1), and no detections occurred in April samples. Nearly 30% of course inflows we examined (3/7) had detectable compounds that were likely contributing to the concentrations found in course ponds. Concentrations of chlorophyll *a* were only significantly different between ephemeral ponds and forest preserve/golf course sites in August (Fig. 1), whereas concentrations of phycocyanin (blue/green algae) were not measurably different between any pond type. Water quality variables taken with a YSI multi-probe meter show variation between golf course and ephemeral wetlands, but not between golf courses and forest preserve ponds (Fig. 2). Water chemistry values, i.e., nitrate, ammonium and phosphorus, are currently being analyzed. These data suggests golf course ecosystems function similar to adjacent permanent, fish-containing forested lentic systems in managed forest preserves.

Biotic assessment: We collected 9 or 15 samples per pond from April to August (3 or 5 each month) to quantify micro (zooplankton) and macroinvertebrate diversity and density. Organisms are currently being identified. Amphibian diversity was low across all ponds (golf course or nature preserve). From April to August, both golf course and permanent ponds with fish harbored an average of 0.4 (0-3 total species) amphibian species per pond whereas diversity at ephermal, fishless ponds was just 0.31 (0-3 total species) species per pond.

Future expectations: By summer 2018, we expect to submit a peer-reviewed manuscript detailing the comparison of water quality and chemistry of golf course and adjacent forest preserve ecosystems. We expect to have all micro-and macroinvertebrate samples enumerated and will begin construction of a manuscript detailing the biodiversity comparison of invertebrates and vertebrates across golf course and forest preserve (permanent and ephemeral) ponds by late summer 2018. In addition, as discussed in our proposal, in spring 2018 and 2019 we plan to utilize measures of Azoxystrobin, nitrogen and phosphorus to design and conduct mesocosm experiments investigating the response of biofilms (e.g., algae), zooplankton, Odonata nymphs and amphibians (American toads).

Summary Points:

- Concentrations of analytes (pesticides, fungicides, and herbicides) measured in golf course ponds were low and infrequently detected for 8/10 analytes examined. Azoxystrobin was the most widespread analyte measured.

- Amphibian diversity was low across the region and was similar in golf course ponds versus ponds located in forest preserve habitats.

- Concentrations of algae (both green [Chlorophyta and Charophyta] and blue-green [Cyanobacteria] algae) were similar across golf course and forest preserve ponds.

- Water quality measures were measurably different between golf course ponds and ephemeral wetlands, but not between golf course ponds and permanent forest preserve ponds containing fish.

- These results suggests golf course ponds provide similar aquatic ecosystems to more natural, forested ecosystems. Further examination is required to fully examine the degree to which these ecosystems are similar or different.

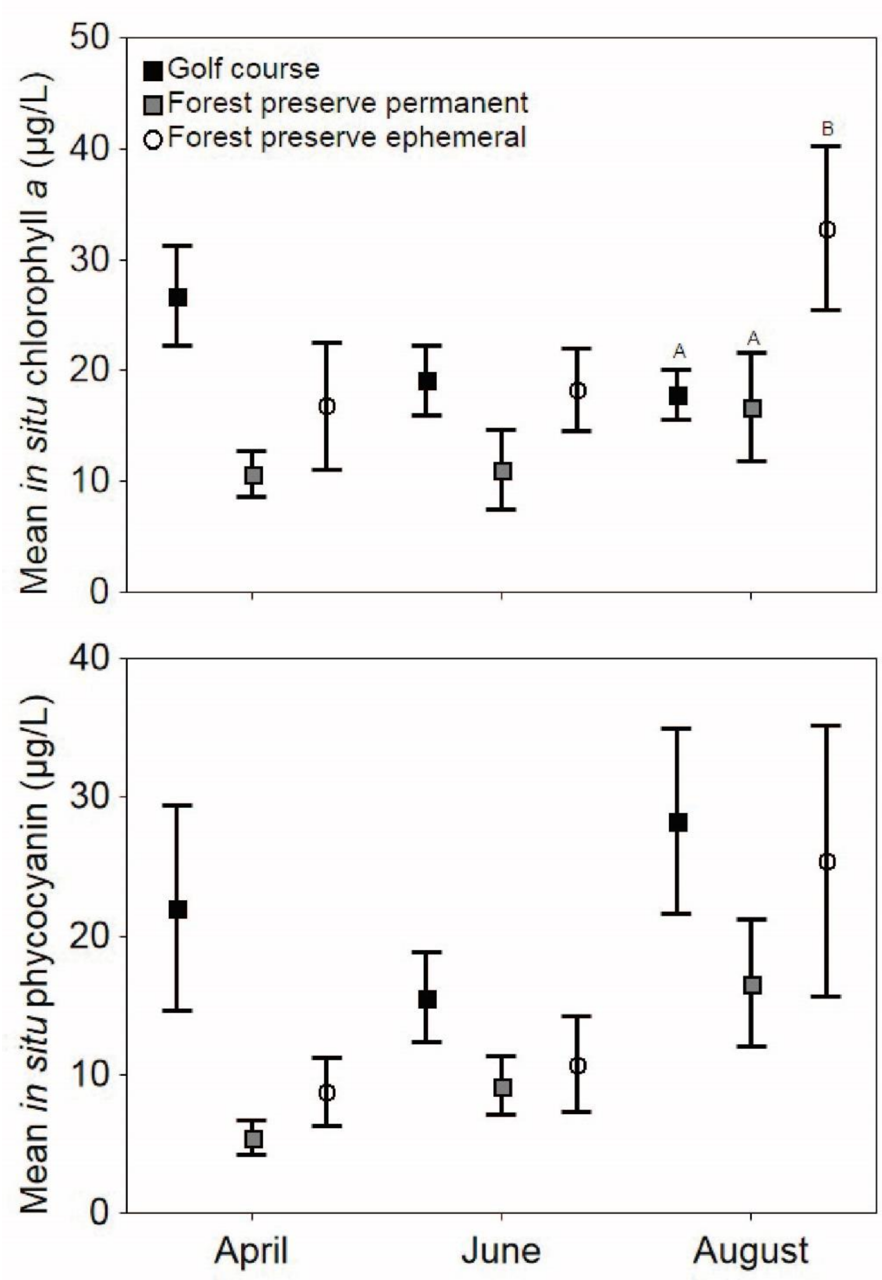

Figure 1. Mean (SE) *in situ* chlorophyll *a* and phycocyanin concentrations within sites across months. Different upper case letters suggest statistical significance ($p \leq 0.05$) within months using one-way ANOVAs and Tukey multiple comparison tests.

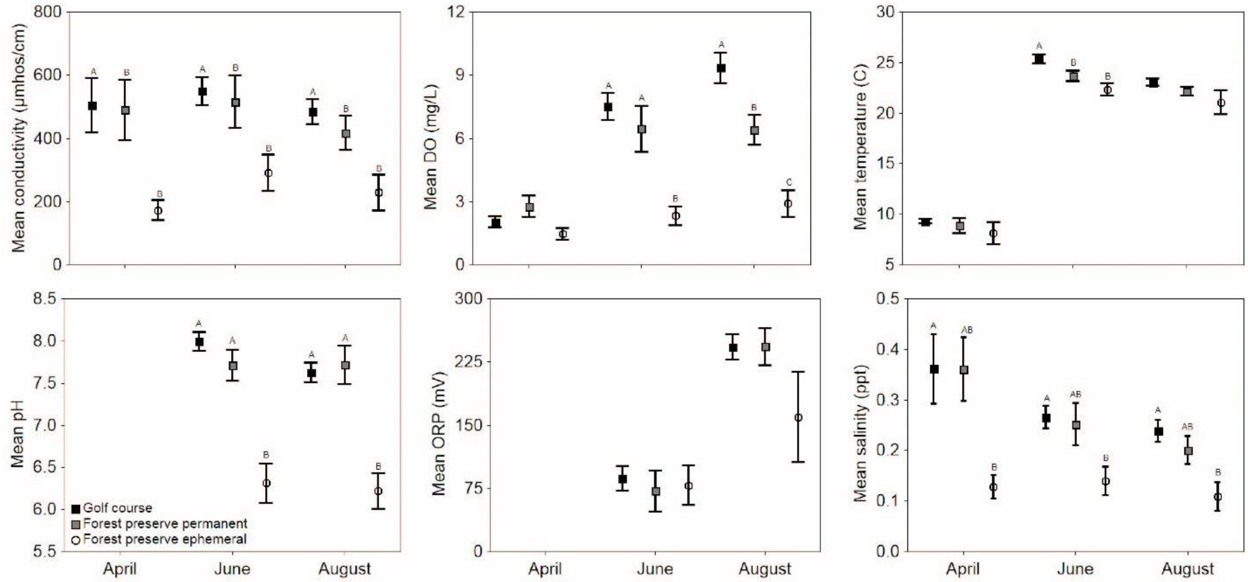

Figure 2. Mean (SE) values for water quality parameters within site types and across months (DO = dissolved oxygen, ORP = oxidation reduction potential). Different upper case letters represent statistical significance ($p \leq 0.05$).

Table 1. Concentrations of analytes within golf course ponds and course inflows. Mean, range, and sample size (n = number of courses where each analyte is found).

Analyte	Within course ponds				Course inflows			
	n	Mean	Std. error	Range	n	Mean	Std. error	Range
Azoxystrobin	11	2.21	1.05	0 –24.39	2	0.45	0.90	0 – 2.29
Bifenthrin	0	0	–	–	0	0	–	–
α-Chlordane	2	0.14	0.12	0 – 2.81	1	0.09	0.47	0 – 0.63
γ-Chlordane	0	0	–	–	0	0	–	–
Chlorpyrifos	0	0	–	–	0	0	–	–
Cypermethrin	0	0	–	–	0	0	–	–
Oxadiazon	2	0.16	0.11	0 – 2.22	1	0.11	0.52	0 – 0.77
cis-Permethrin	0	0	–	–	0	0	–	–
trans-Permethrin	0	0	–	–	0	0	–	–
Fenvalerate	0	0	–	–	0	0	–	–

5. Regional Grants

2016-29-579

Nitrogen Fertilization of Newer Bentgrass Cultivars

Elizabeth A. Guertal, Crop, Soil and Environmental Sciences, Auburn University, Auburn, AL and Freddie Clinton Waltz Jr., University of Georgia – Griffin Campus, Griffin, GA

Creeping bentgrass (*Agrostis palustris* Huds.) is the most common turfgrass used for putting greens in much of the northern United States. However, its high quality surface means that use will always be pushed southward, into areas for which it is marginally adapted. Newer cultivars of bentgrass are often underrepresented in research, and thus the objective of this work was to examine the performance of newer creeping bentgrass cultivars at two southern locations, when managed under varying nitrogen (N) fertilization rates.

Beginning in March 2016, experiments were conducted at the Atlanta County Club (ACC) (Marietta, GA) and University of Georgia – Griffin (Griffin, GA) on established (seeded Sept 2015) USGA-type putting greens consisting of 'Pure Distinction', 'AU Victory', '007', 'V8', 'T1' and a 'Penn A1/A4' mix. Nitrogen treatments were solution urea at 0, 0.2, 0.5, 1.0, 1.5 and 2.0 g N m^{-2} (0, 0.05, 0.10, 0.2, 0.3 and 0.4 lb N 1,000 ft^{-2}) sprayed every other week in a spray volume of 90 gpa (2 gallon 1,000 ft^{-2}). There were 4 replications of each N Rate/cultivar treatment. Collected data included relative color and quality, green firmness, and root and shoot densities.

General effect of N rate on turf quality: In the early spring (Feb-May) of 2016 bentgrass quality, color and shoot density generally increased as N rate increased, regardless of cultivar. However, with the onset of summer heat bentgrasses fertilized with the two highest rates of N were severely affected, with significant tissue damage and death. Thus, in 2017 N applications in the two highest treatments were adjusted to weekly applications. In 2017 application of the highest rates of N on a weekly basis prevented the damage observed in 2016.

Interaction of N rate and cultivar on dry weight of roots: The interaction of N rate and cultivar was not significant for root length, shoot density, and bentgrass color or quality, at either location. However, the interaction was significant for dry weight of bentgrass roots. This was because the cultivars T1, Pure Distinction, AU Victory and V-8 often had higher relative root dry weights when no N was applied, with a substantial reduction in dry weight when the top two N rates were applied. The cultivar 007 and the Penn A1/A4 blend were less affected by N additions, with lower root dry weights across all rates of added N.

Shoot densities of the selected cultivars: At the ACC June (2016) shoot density was highest in Pure Distinction, followed by AU Victory, and then shoot density in 007, Penn A1/A4, T1 and V8 were equal. June root length density was greatest in T1, followed by V8, with root length density in all other cultivars equal. Shoot density was often maximized at N rates of 2.2 to 2.8 g N m^{-2} mo^{-1} (0.5 to 0.6 lb N 1,000 ft^{-2} mo^{-1}), a total of approximately 2 lb N 1,000 ft^{-2} $year^{-1}$. But, root length often decreased as N rate increased. Shoot density of the cultivars occurred in this general order, from highest to lowest: Pure Distinction = AU Victory > 007 > Penn A1/A4 blend = T1 > V8. Root length of the cultivars was often the reverse of that observed with shoot density, with a general order (from longest to shortest) of: T1 > V8 > 007 = Penn A1/A4 blend = Pure Distinction = AU Victory.

Summary: Two years of observation revealed that cultivars tended to perform similarly across a range of N rates. The highest rate of N was not needed for the highest quality turf, and it significantly reduced root growth. Nitrogen rates of between 2.2 to 2.8 g N m^{-2} mo^{-1} were needed for best color, quality and shoot density, but those rates had to be applied as weekly split treatments to avoid summer damage via phytotoxicity.

Figure 1. Creeping bentgrass cultivars performed similarly across a range of N rates, and the highest rate was not needed for the highest quality turf.

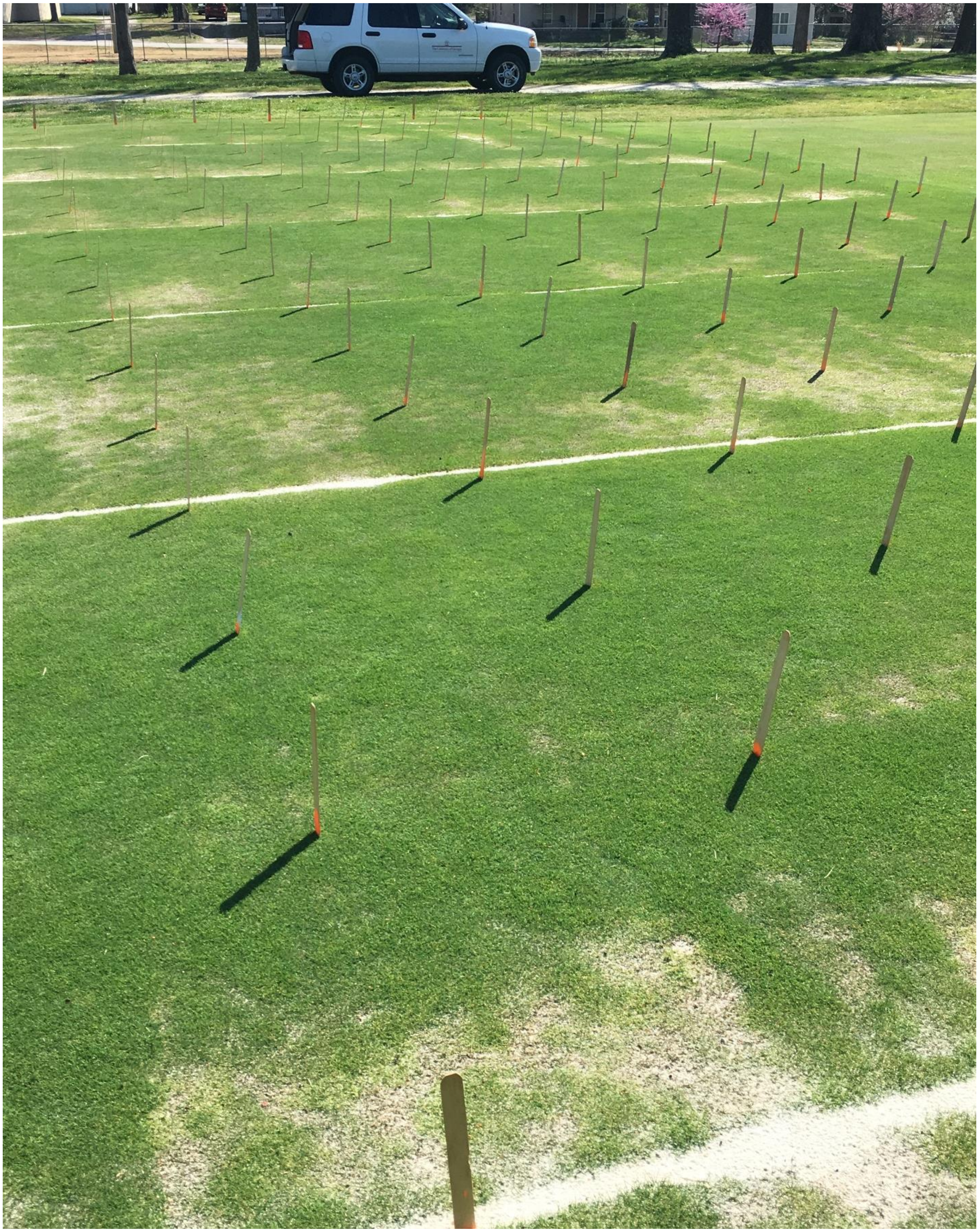

Figure 2. Nitrogen rates from 2.2 to 2.8 g N m^{-2} mo^{-1} were needed for best color, quality, and shoot density, but those rates had to be applied as weekly split treatments to avoid summer damage via phytotoxicity.

2017-25-635

Project Title: Evaluation of Spent Coffee Grounds as a Turf Fertilizer and Root Zone Amendment

Project Leaders: Benjamin Wherley, Kevin McInnes, and Garrett Flores

Affiliation: Texas A&M University, College Station, TX

Funding: $5,000 (Grant-in-aid)

Start Date: 2017

Summary:
Given the current and anticipated growth of the cold-brew coffee production industry nationally and worldwide (http://www.mysanantonio.com/business/article/Cold-brew-coffee-may-help-wake-up-tired-turf-12312763.php#photo-14436442), there is growing importance in evaluating the agronomic merits/demerits of spent coffee grounds for use in golf course turf applications. This is especially true in light of the growing environmental and ecological concerns relating to peat production. Considering that peat continues to be the predominant amendment utilized for golf course sands in many parts of the world, spent coffee grounds could offer an opportunity for use of a more sustainable, renewable resource in many regions.

Lab testing, greenhouse and field studies are currently underway at Texas A&M University to begin to explore the agronomic potential of spent coffee grounds in turf systems. This project will evaluate the potential benefits of both fresh and composted spent coffee grounds as a turf fertilizer and/or amendment (field testing) and/or sand-based root zone amendment (greenhouse testing). Specific objectives include:

1) Evaluating turf and soil health over time in response to spent coffee grounds application, as well as from experimental fertilizers containing spent coffee grounds and similar poultry litter-based organic and bridge fertilizers
2) Determining effects of spent coffee grounds particle size distribution and amendment ratios on physical properties of sand-based root zones
3) Determining N release rates through evaluating mineralization/decomposition rates following spent coffee grounds application to turf systems

Preliminary chemical analyses indicate many favorable properties of spent coffee grounds, including a ~2.4% N content, ~23:1 C:N ratio, slightly acidic pH of 5.6, and presence of many essential macro and micronutrients including S, Mg, Zn, Fe, and Cu. The highly porous nature of coffee beans will also presumably aid in soil water retention. Field studies were initiated in September 2017 on Celebration bermudagrass turf plots. Effects on turf and soil health are being monitored through evaluations of turf quality, percent green cover, soil moisture, and chemical/microbial analysis of soils to determine changes over time. Greenhouse studies are currently underway to determine effects on sand root zone physical properties.

As coffee production increases throughout the U.S. and world in the coming decades, spent coffee grounds could offer an agronomically suitable and renewable alternative to peat moss as an organic amendment for golf course sand topdressing and/or root zones. Through these studies, we seek to develop a more comprehensive understanding of its feasibility and best use as well as potential benefits relating to root zone physical properties, turfgrass growth and quality, and nutrient & water availability.

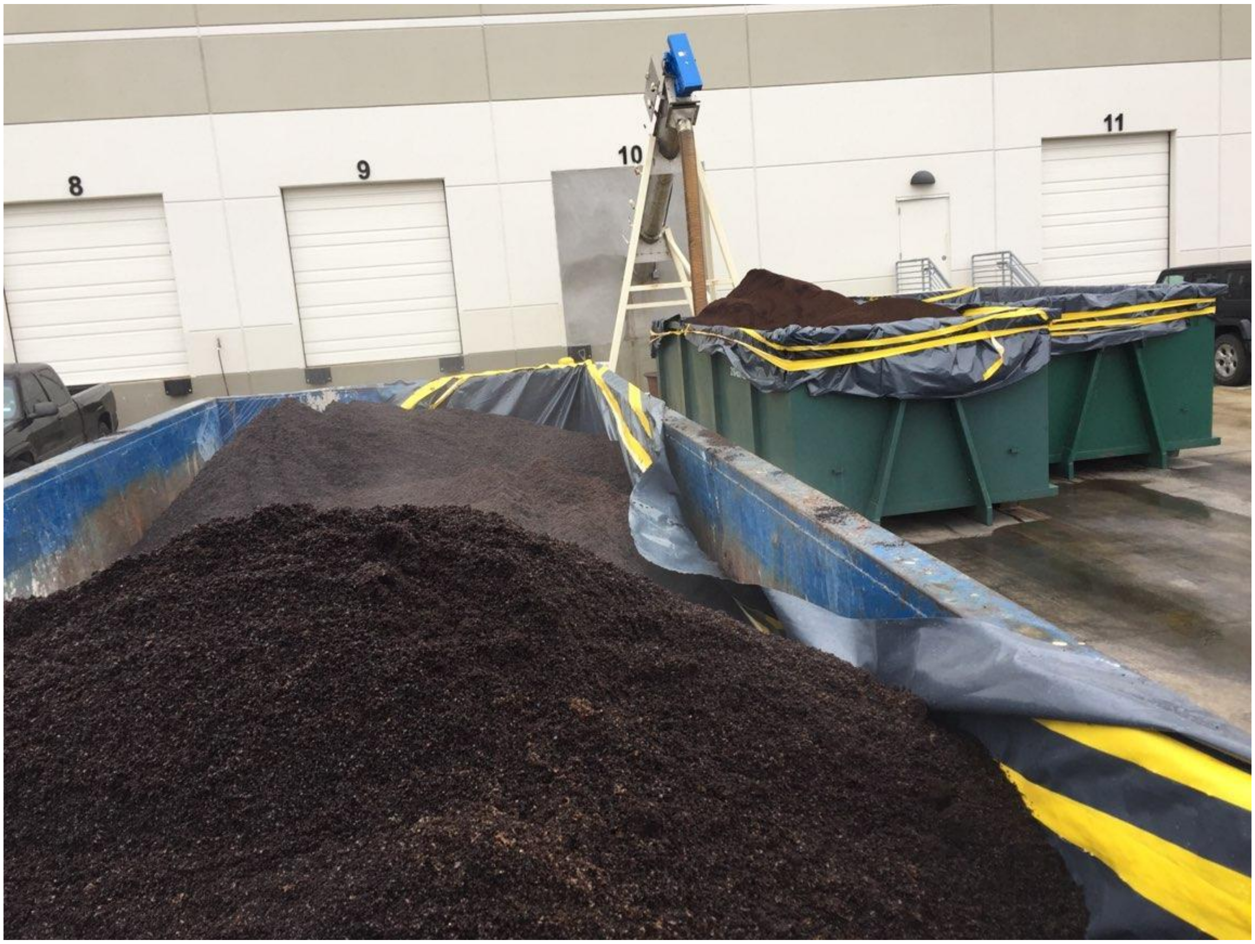

Figure 1. As coffee production increases throughout the U.S. and world in the coming decades, spent coffee grounds could offer an agronomically suitable and renewable alternative to peat moss as an organic amendment for golf course sand topdressing and/or root zones.

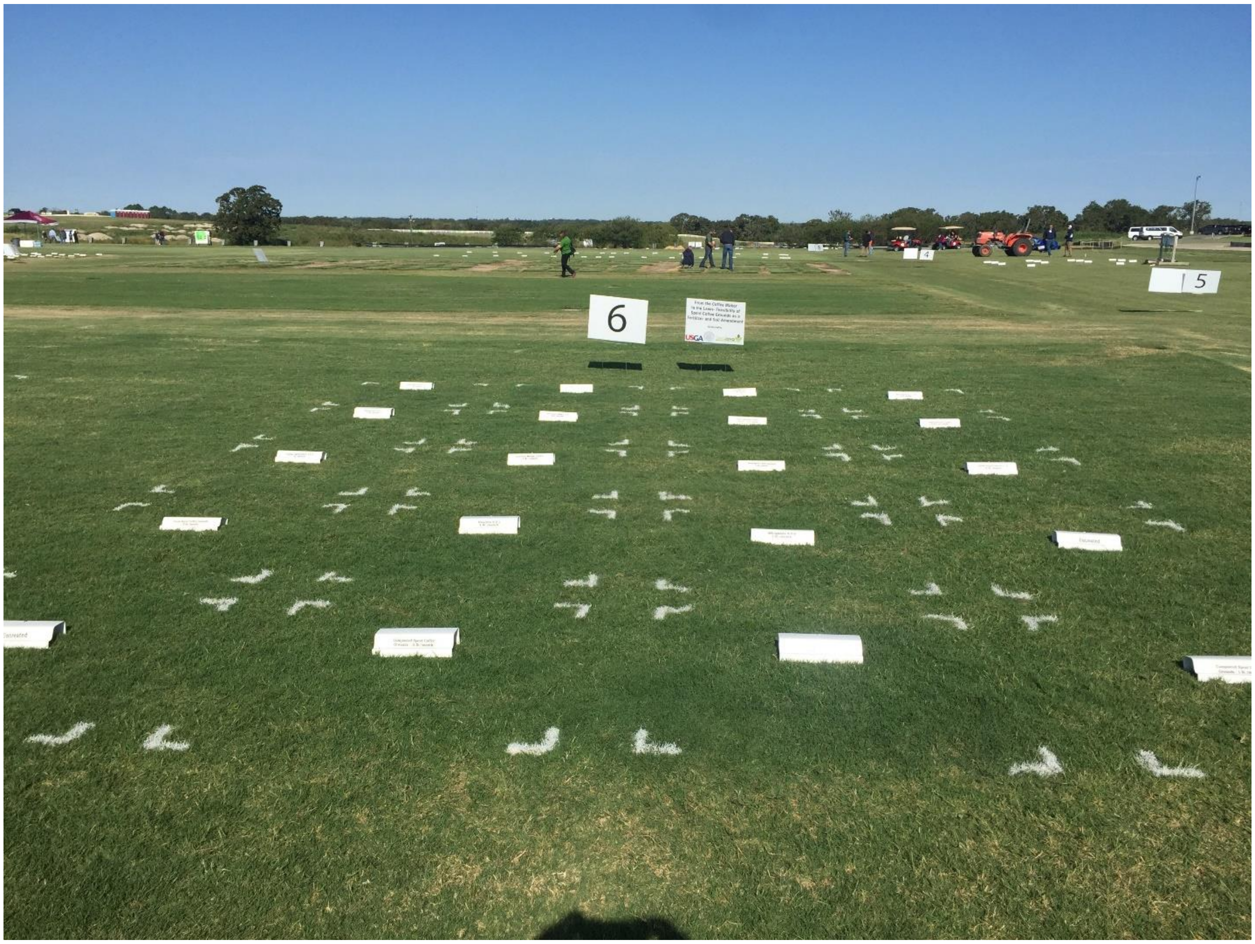

Figure 2. Field studies were initiated in September 2017 on ‘Celebration’ bermudagrass.

2017-28-638

Title: Establishing Portable X-Ray Fluorescence (PXRF) as a Rapid Soil Analysis Tool for Golf Courses

Project Leaders: Dr. Joseph Young and Dr. David Weindorf

Affiliation: Texas Tech University

Summary Text:
Portable X-ray fluorescence spectrometry (PXRF) has been used to identify soil pollution and contamination following natural disasters, estimate soil chemical and nutrient characteristics, and most recently to assess elemental levels within vegetation samples. Much of the work and progression of these evaluations have been conducted by Dr. Weindorf and colleagues in his time at LSU and Texas Tech. We set out to better understand how the instrument could provide information suitable for assisting golf course superintendents in rapidly obtaining soil nutrition data and estimating salinity levels, cation exchange capacity, or identify potential contaminants.

This initial work compared PXRF data to soil lab tests conducted at LSU's soil testing facility. Soil samples were obtained at a 6 inch depth from 50 geo-referenced locations spread over a golf course in Amarillo, TX; Midland, TX; and Hobbs, NM. The soil was prepared and a subsample was submitted to the soil testing facility, while a second sample was scanned with the PXRF.

A summary table of soil testing data is provided to demonstrate the variation in some factors from location to location. Linear or non-linear regression lines were fitted to each select soil test results and PXRF determination. The high correlations for these elements demonstrate the similarities in readings and the potential viability of the instrument to be used to rapidly estimate some of the same properties a golf course superintendent would obtain from various soil testing procedures. Removing outliers from the plots would further strengthen the relationship between soil test and PXRF results. It is important to realize that these data can be obtained in seconds from any soil obtained on the golf course in comparison to the time required to collect, ship, and wait for soil testing results.

Further analysis with data obtained and possibly expanding soil collections to a wider array of circumstances would allow for the development of simple conversion spreadsheets that could be provided to golf course superintendents who may be interested in this technology. Conducting multiple regression analysis is necessary to develop algorithms for determining more intricate soil physical and chemical properties based on PXRF output; however, Dr. Weindorf has developed a great research team with the capabilities of establishing these types of deliverables.

Figure 1. A portable X-ray fluorescence spectrometer.

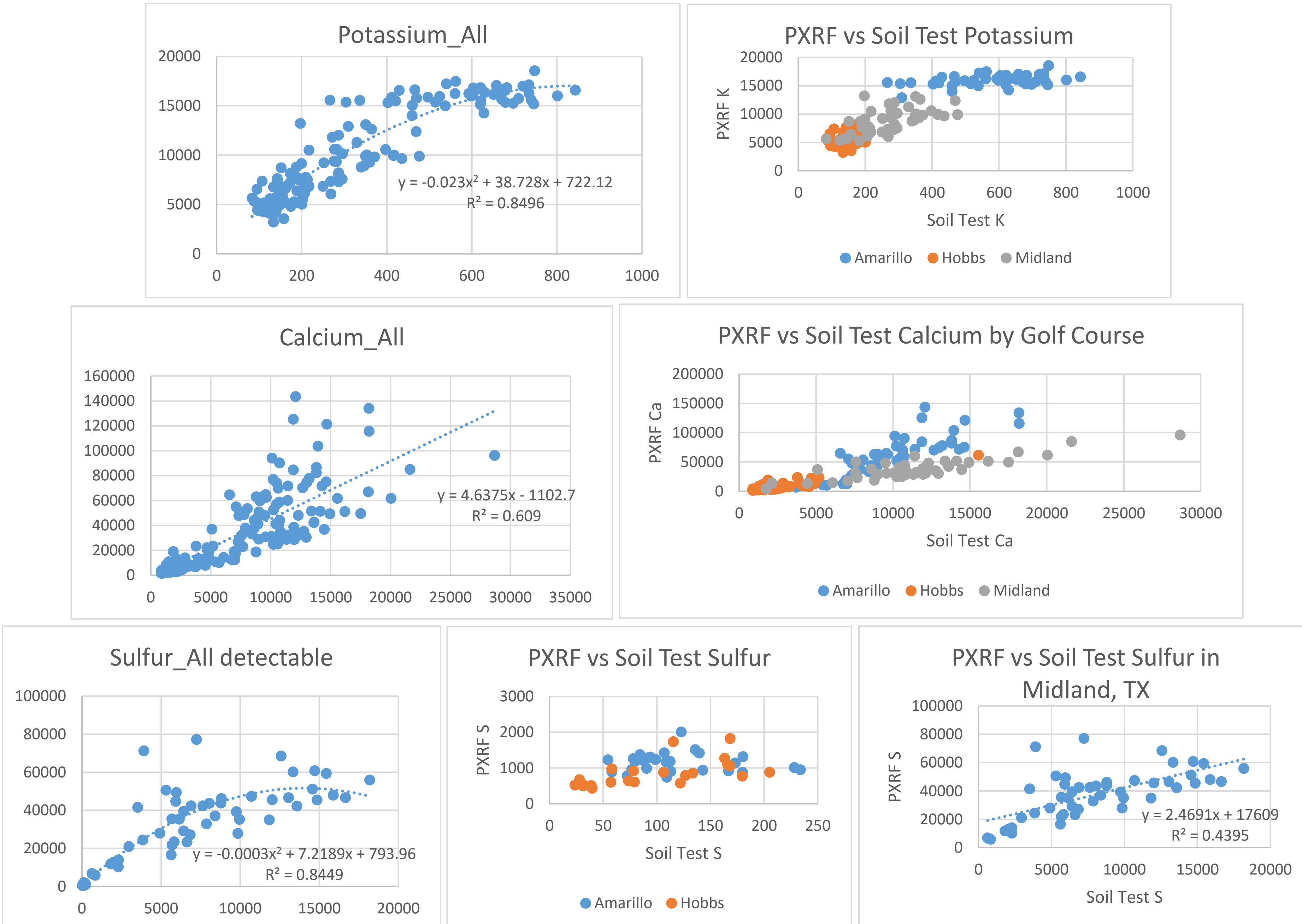

Figure 2. Linear or non-linear regression lines were fit to each select soil test results and PXRF determination. The high correlations for these elements demonstrate the similarities in readings and the potential for the device in the golf course industry.

Table 1. Minimum, maximum, and mean soil testing facility (LSU) results from soil obtained at three locations within the Southern High Plains.

		Amarillo	Hobbs	Midland
pH (1:1)	Range	7.86-8.31	7.96-8.52	7.13-7.86
	Mean	8.07	8.26	7.49
P (ppm)	Range	6.07-46.9	6.75-37.5	8.01-112
	Mean	17.4	14.3	49.4
K (ppm)	Range	266-843	87.3-285	83.2-476
	Mean	584	147	278
Ca (ppm)	Range	3,712-18,204	871-15,557	1,759-28,670
	Mean	10,068	2,625	11,510
Mg (ppm)	Range	685-1,633	96.6-310	200-927
	Mean	1,268	170	593
S (ppm)	Range	35.2-234	15.5-205	630-18,182
	Mean	110	70.1	8,105
Na (ppm)	Range	86.5-266	50.3-278	148-617
	Mean	170	108	367
Zn (ppm)	Range	2.89-89.6	0.65-3.07	1.23-13.7
	Mean	21.3	1.41	7.31

2016-30-600

Evaluating the Performance of Four Subsurface Drip Irrigation Systems Used on Creeping Bentgrass Tee Boxes at the Las Campanas Golf Course (Santa Fe, NM)

Bernd Leinauer[1], Matteo Serena[1], Elena Sevostianova[1], Brian Whitlark[2], Joel Krause[3], Wendell Egelhoff[3]

[1]New Mexico State University, [2]United States Golf Association, [3]The Club at Las Campanas

PROJECT DESCRIPTION

An irrigation trial was conducted at the Las Campanas Golf Course (Santa Fe, NM) to evaluate the effect of different subsurface drip irrigation systems (SDI) on turf quality, stress and water usage of creeping bentgrass tee boxes.

Objectives:

To evaluate the performance of four SDIs on visual turf quality, Normalized Difference Vegetation Index (NDVI), and water consumption of creeping bentgrass tee boxes.

MATERIALS AND METHODS

The study was conducted at the Club at Las Campanas, located in Santa Fe, NM [arid, 2133 m (7,000 ft) elevation] from April to November 2017. The championship tee boxes used for the study were constructed according to USGA specifications (sand based profile). The grass established was creeping bentgrass (*Agrostis stolonifera* L.) and the tee boxes were between 25 (Sunrise Course) and 18 (Sunset Course) years old.

The subsurface drip systems were installed in May of 2016 and consisted initially of two brands. One of them was the Toro Rootguard® DL2000™ (The Toro Co., Riverside, CA) delivering 2.0 l hr^{-1} (0.48 gal h^{-1}) and operating at 241 kPa (35psi). The other system was the Rainbird XSF with copper shield Technology (Rainbird®, Azusa, CA), delivering 2.0 l hr^{-1} (0.6 gal h^{-1}) and operating at 241 kPa (35psi). Both systems were installed at a depth of 10 cm (4 inches). Each system was installed in three tee boxes, one set at 23 cm (9 inches) of spacing between lines, and two tee boxes with 30 cm (12 inches) spacing. This decision was based on the lack of information on installation and performance of SDI on sand based profiles, and the team suspected that 30 cm spacing might be too far apart. Both systems were installed according to manufacture specifications. A filter and a pressure regulator were installed on each tee box before the main valve, in addition to an air release valve and an automatic flush valve. The team choose two approaches to install the SDI systems under pre-existing turfgrass. The first strategy was to remove the sod, and using a disk trencher, cut into the sand profile. After the system was installed, the sod was laid back into place, followed by topdressing and irrigation using the overhead sprinkler system. The second approach was to trench directly into the existing turfgrass. After the system was installed, the lines were re-compacted, the turfgrass was then topdressed, followed by irrigation with the overhead sprinkler system.

Due to the publicity and success of the first year of the study, two additional subsurface drip systems brands were installed during the summer of 2017. One of them was the Netafim™ Techline CVXR (Netafim Irrigation Inc., Fresno, CA) delivering 2.0 l hr^{-1} (0.53 gal h^{-1}) and operating at 344 kPa (50 psi). The second system was the Hunter® Eco-Mat® (Hunter Industries Inc., San Marcos, CA) delivering 2.0 l hr^{-1} (0.5 gal h^{-1}) and operating at 241 kPa (35psi). Both systems were installed at the depth of 10 cm (4 inches). Each system was installed with 30 cm (12 inches) spacing between lines. Three tee boxes were converted to the Netafilm system and one was converted to the Hunter system.

Two tee boxes irrigated with overhead sprinkler systems were designated as the controls. Irrigation audits were conducted twice during the course of the study. Each SDI system and the controls were equipped with water meters installed after the valves. Each tee box was measured, and the surface area was calculated. The amount of water delivered to each tee box was reported relative to the irrigated area.

Turfgrass maintenance was conducted by the maintenance crew at the Las Campanas golf course. This included irrigation at approximately 100% ETos, daily mowing, fertilization, topdressing and verticutting as needed. Due to concerns about potential damage to the irrigation systems, SDI tee boxes were not aerified.

List of tee boxes with corresponding irrigation systems:

1. Control on #14 Sunrise
2. Control on # 15 Sunset
3. Toro @ 9” on #5 Sunrise
4. Toro @ 12” on #13 Sunrise
5. Toro @ 12” on #18 Sunset
6. Rainbird @ 9” on #6 Sunset
7. Rainbird @ 12” on #11 Sunrise
8. Rainbird @ 12” on # 14 Sunrise
9. Netafim on #6 Sunrise
10. Netafim on #12 Sunrise
11. Netafim on #17 Sunrise
12. Hunter on #15 Sunrise

Data Collection

Visual turf quality, NDVI, and water meter readings were recorded monthly starting at the beginning of the growing period on March 8th, 2017. In addition to the readings, ground and aerial photographs using a drone were taken on each occasion.

KEY FINDINGS

Installation:

- SDI systems installed using the sod removal approach resulted in a faster recovery, and overall better turfgrass quality during the first months of the study. Therefore, the Netafim and Hunter tee boxes added in 2017 were installed with the sod removed.
- There was no visible difference between the 9” and 12” spacing in terms of water consumption, recovery and performance. Thus it appears that 12” spacing is sufficient to provide acceptable turfgrass quality even on a sandy rootzone.
- On a couple of occasions drip lines were inadvertently installed at the incorrect depth and spacing, resulting in unsuccessful establishment and ultimately led to the system being re-installed.
- With the help of the in-ground sprinkler system, turf stands recovered within a few months from post installation injury.

Performance:

- All the SDI systems installed performed equally well in terms of turfgrass quality, with little to non-visible signs of difference between systems.
- The NDVI values recorded did not show any differences in stress between the controls and the SDI-irrigated tee boxes
- The irrigation amounts used by SDI-irrigated tee boxes were remarkably lower from those used by the control tee boxes. Sprinkler-irrigated tee boxes received 3 to 5 times more water compared to the SDI-irrigated tee boxes. It appears that the higher irrigation amounts used by sprinkler systems were due in part to overspray. Pop-up heads irrigated beyond the tee box area and ended up irrigating the surrounding native vegetation. In contrast, the SDI systems delivered the water only to the designated area.
- The growth of the native vegetation surrounding tee boxes was significantly reduced in SDI-irrigated tee boxes (by not giving additional water), thereby reducing or eliminating the need for maintenance of those areas.

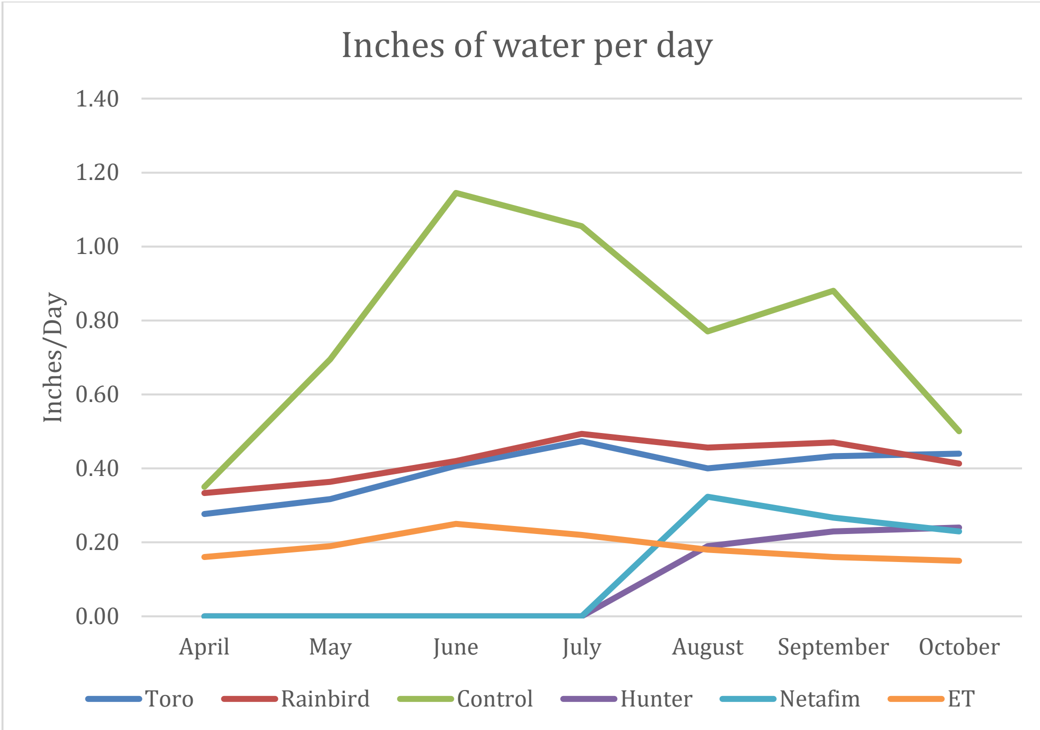

Figure 1. Amount of water distributed by each irrigation system.

Figure 2. Watering pattern typical of sprinkler irrigation, with water being distributed outside the tee area.

Figure 3. Process of installation with the existing turfgrass removed.

Figure 4. Recovery of turfgrass 4 months after sod removal installation.

Figure 5. Recovery of turfgrass 4 months after trenching into existing turfgrass.

Figure 6. Incorrectly installed subsurface drip irrigation.

Figure 7. Overall, all tee boxes look great by the end of 2017.

2017-29-639

Effect of Sulfuric Acid on Bicarbonate Concentration in Sandy Soil

Bernd Leinauer and Elena Sevostianova
New Mexico State University

PROJECT DESCRIPTION

Water sources used to irrigate turfgrass areas in the arid southwestern states of the US can contain high levels of dissolved bicarbonates. As a result, unsightly lime deposits can stain leaves, soil pH can increase, and soil permeability can be reduced. To address the problem, turfgrass managers inject sulfuric acid into the irrigation water. However, it is unclear, whether or not such an injection is useful and necessary to improve soil conditions. Sulfuric acid injection is believed to be helpful when bicarbonates are high enough to have Ca^{+2} and Mg^{+2} precipitating in the form of carbonates from the soil solution and, at the same time, Na^{+} content is also high to present a possible concern. However, when Na^{+} concentration is low, information is lacking whether or not bicarbonates alone pose a risk and if water acidification is necessary.

Objective:

To investigate the effect of injecting sulfuric acid into irrigation water on bicarbonate levels in the soil solution and several chemical and physical properties of an alkaline soil

Treatments:

1) Chemicals: sulfuric acid and untreated control
2) 2 levels of SAR: high and low

MATERIALS AND METHODS

To investigate the effect of injecting sulfuric acid into irrigation water on changes in bicarbonate level, pH, EC, and SAR of an alkaline soil (loamy sand, a sandy skeletal mixed thermic Typic Torriorthent), a column experiment using water with a “high level” of bicarbonates (280 ppm) and a SAR of either high (15) or low (2.4) has been conducted at New Mexico State University. High bicarbonate and Sodium Adsorption Ratio levels were obtained by adding sodium bicarbonate and sodium chloride to tap water. Twelve soil columns measuring 10 cm in diameter and 35 cm in depth were filled with 5 cm deep gravel and loamy sand was placed over the gravel (Figure 1).

The columns received one of four irrigation water qualities:

- control, high bicarbonates, low SAR
- control, high bicarbonates, high SAR
- high bicarbonates, low SAR + sulfuric acid
- high bicarbonates, high SAR + sulfuric acid

The treatment containing sulfuric acid was adjusted to a pH of 6.5. Main chemical constituents of the irrigation water are given in Table 1. Irrigation water was applied by adding 275 mL of corresponding solution to each container twice a week. At the end of the 6 month research period, each container received 1820 mm or 71.6'' of irrigation water, which reflects an amount that matches the annual ETos for the Las Cruces area. To collect leachate, Soil Solution Access Tubes (SSAT) were inserted at soil depths of 10 and 20 cm, and free draining water was collected at the base of the columns. Samples were analyzed monthly for pH, EC, Ca, Mg, and Na, and bicarbonates. Additionally, 4 columns without lysimeters, treated with the same amount of irrigation water were used for measuring infiltration rate at the beginning and at the end of the research period using a double ring infiltrometer (Turf-Tec International, Tallahassee, FL). At the end of the study, soil samples were taken from all 3 depths to be analyzed for salinity relevant parameters including bicarbonates. During the shipping process bags containing the soil were torn open and damaged. Unfortunately there was not enough remaining material in most of the bags to run a complete analysis that included bicarbonates.

Experimental Design and Statistical Analyses

The experimental design was completely randomized with two SAR levels and two water treatments. Each water treatment consisted of a high (15) and low (2.4) SAR level. All water treatments with either high or low SAR were replicated 3 times. To test the effects of sulfuric acid on level of bicarbonates, EC, pH, and SAR, data were subjected to an analysis of variance (ANOVA) using SAS Proc Mixed followed by multiple comparisons of means using Fisher's LSD test at the 0.05 probability level.

RESULTS

Statistical analysis revealed that SAR and sampling depth affected all measured parameters. Consequently, data were reanalyzed (Table 2) and are presented separately for high and low SAR content in the irrigation water at each sampling depth. We found no depositions of carbonate in the soil at any depth at the end of the study.

BICARBONATES IN LEACHATE

Soil depth 10 cm

In alkaline soils (similar to the one used in this study), a buffer reaction involving sulfuric acid, carbonates, bicarbonates, carbonic acid, and water takes place. The concentration of bicarbonates did not change for sulfuric acid treatment for the first 2 sampling dates (Figure 2). This can be explained by the dissolution of solid soil carbonates during the early stages of the study. However, after the first two sampling dates, the amount of bicarbonates in the leachate was consistently lower for both high and low SAR in the irrigation water when sulfuric acid was added.

Soil depth 20 cm

Sulfuric acid decreased the level of bicarbonates in the leachate for low SAR from September to December. Although at high SAR, sulfuric acid decreased the level of bicarbonates numerically, statistically it was lower only for one sampling date (Figure 3).

Drainage

In the drainage water, for both low and high SAR level, the amount of bicarbonates did not differ between sulfuric acid treatment and untreated control (Figure 4).

PH IN LEACHATE

- Generally, as a result of soil buffering, sulfuric acid did not affect the pH of the leachate for either SAR level at a soil depths of 10 and 20 cm and in the drainage water (Figures 5, 6, and 7).

EC IN LEACHATE

- At a soil depth of 10 cm, sulfuric acid did not affect electrical conductivity. At the end of the study, EC ranged from 1.3 to 1.2 dS m^{-1} for low SAR and from 8.2 to 8.4 dS m^{-1} for high SAR irrigation water (Figure 8).
- At a soil depth of 20 cm, in columns irrigated with low SAR water, EC was higher in the leachate from the sulfuric acid treated columns compared to the control on three sampling dates but at the end of the study the measured values ranged only from 1.1 to 1.4 dS m^{-1}. For the high SAR irrigated columns, sulfuric acid did not affect electrical conductivity. Generally, the EC values increased from the beginning to the end of the research period and reached between 5.1 and 5.6 dS m^{-1} in November and December (Figure 9).
- In drainage water, sulfuric acid did not affect electrical conductivity for low SAR. For the high SAR irrigated columns, overall there was no clear trend whether sulfuric acid affected drainage water quality (Figure 10).

SAR IN LEACHATE

- SAR values (soil depth of 10 cm) were did not affected by sulfuric acid compared to the untreated control for both high and low SAR. At the end of the study, values ranged from 3.6 to 4.0 for low SAR and from 17.2 to 18.6 for high SAR treatments (Figure 11).
- At the depth of 20 cm, SAR values did not differ between sulfuric acid and untreated control. At the end of the study, values ranged from 2.9 to 3.2 for low SAR. For high SAR the values ranged from 13.5 to 13.9 (Figure 12).

- In drainage water, values of SAR were not different between sulfuric acid and untreated control for low SAR and at the end of the study they ranged from 7.2 to 9.3. For the high SAR level, SAR values at the end of the study ranged from 27.9 to 28.4 (Figure 13).

Soil

- Statistical analysis revealed that the SAR level in the irrigation water affected measured parameters. Consequently, data were reanalyzed (Table 3) and are presented separately for high and low SAR content (Table 4).

INFILTRATION RATE

Infiltration rates were determined on one column only and treatments were not replicated. Generally, infiltration rates were lower for each treatment at the end compared to the beginning of the study (Table 5).

CONCLUSIONS

- Acidification of irrigation water by neutralizing bicarbonates with sulfuric acid until pH of 6.5 is reached appears to be an effective means to lower bicarbonates in the leachate in the top 10 cm of the rootzone for low and high SAR levels in the irrigation water. Unfortunately, there are no values for bicarbonates in the soil available.
- After 6 months of the experiment, the infiltration rate was numerically lower for all treatments compared to the rates measured at the beginning of the study.

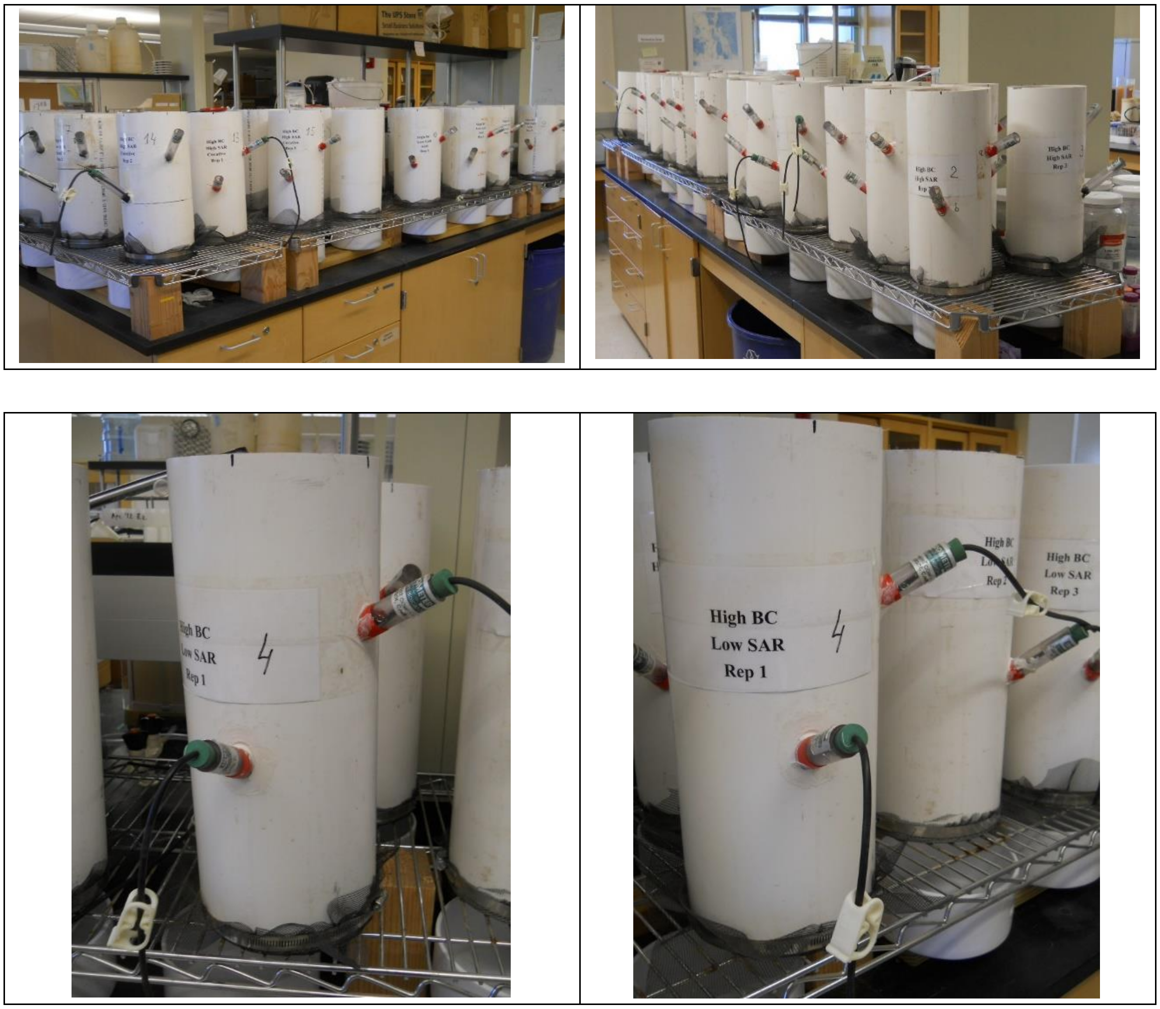

Figure 1. Set up of the soil columns in the laboratory.

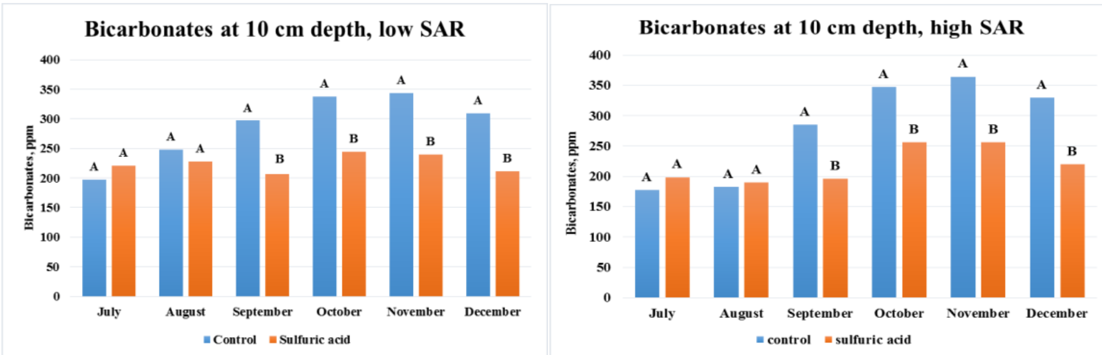

Figure 2. Bicarbonates in leachate (collected at a depth of 10 cm) of soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

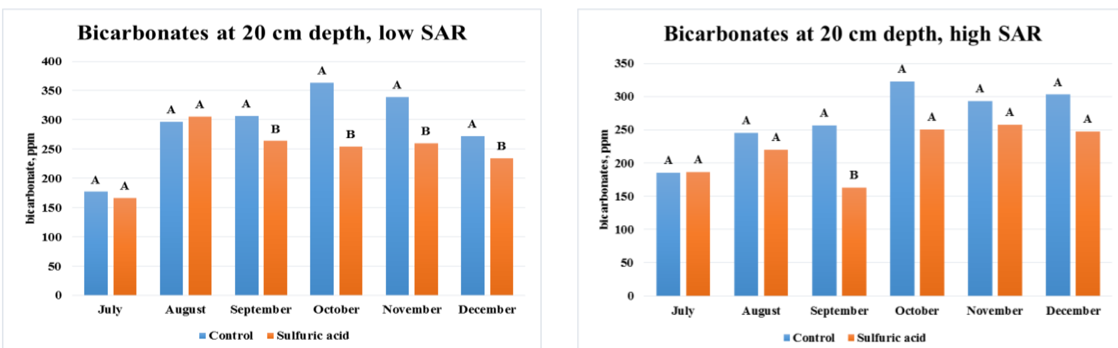

Figure 3. Bicarbonates in leachate (collected at a depth of 20 cm) collected in soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

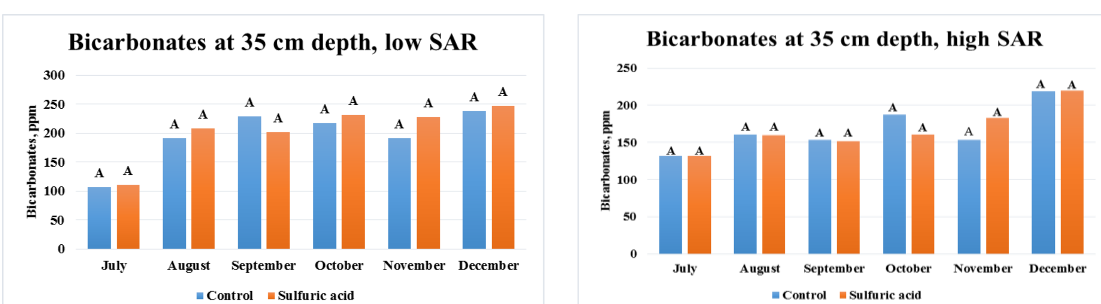

Figure 4. Bicarbonates in drainage water collected under soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

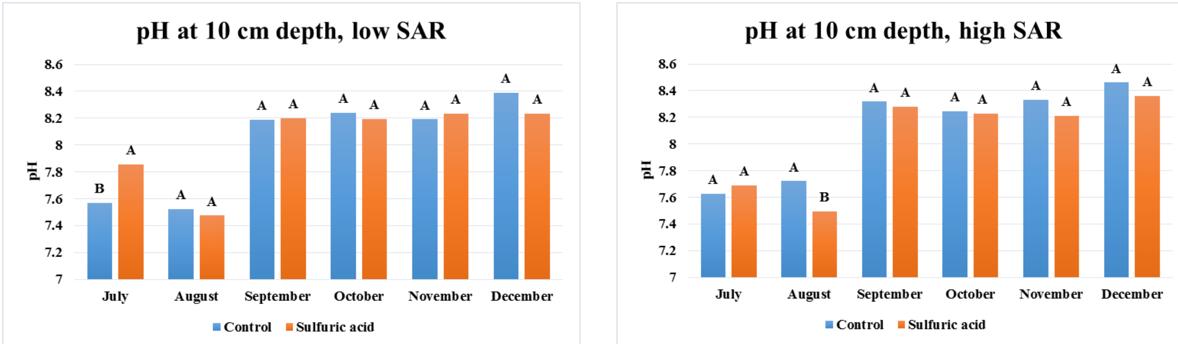

Figure 5. pH in leachate (collected at a depth of 10 cm) collected in soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

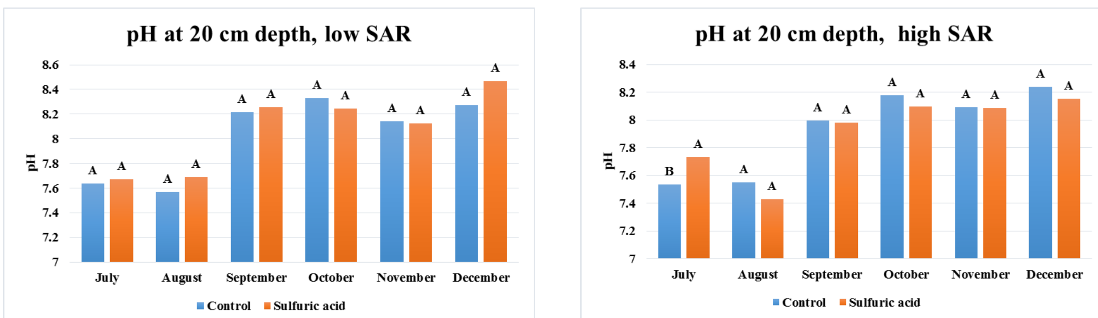

Figure 6. pH in leachate (collected at a depth of 20 cm) collected in soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

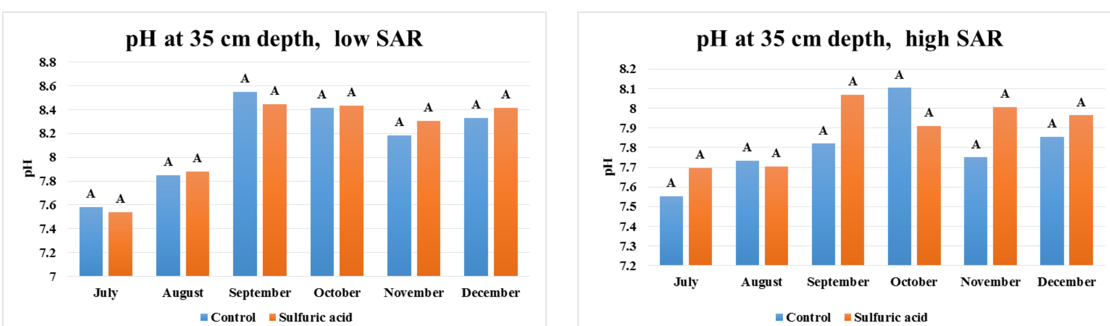

Figure 7. pH in drainage water collected under soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

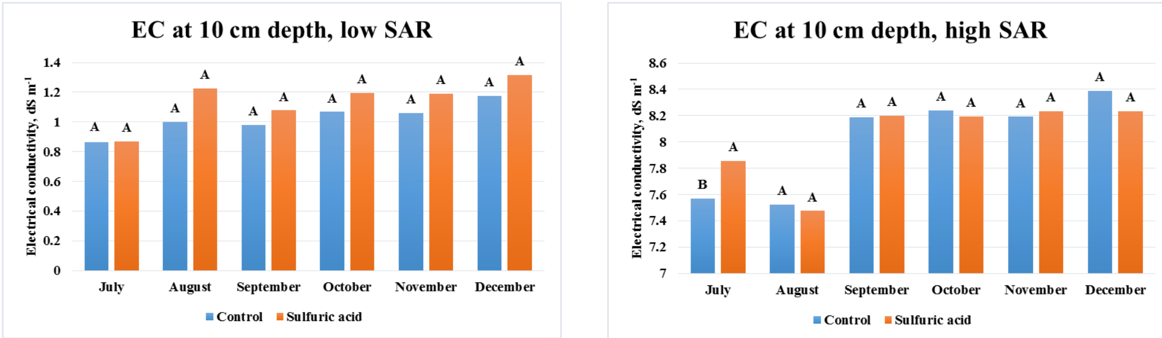

Figure 8. EC in leachate in leachate (collected at a depth of 10 cm) collected in soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

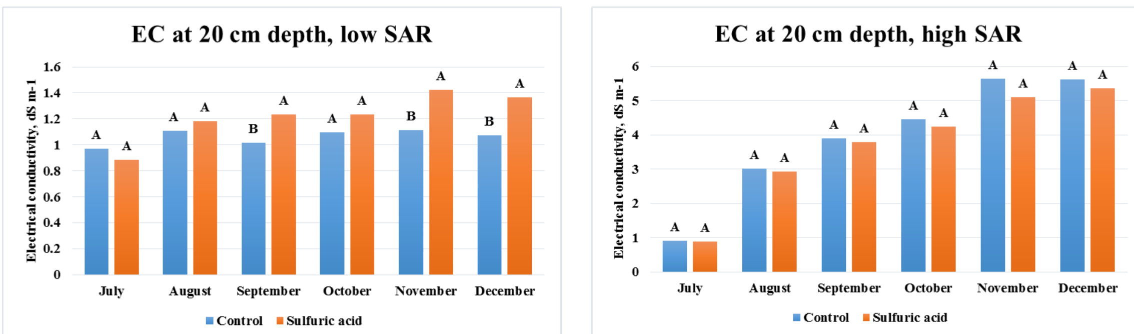

Figure 9. EC in leachate in leachate (collected at a depth of 20 cm) collected in soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

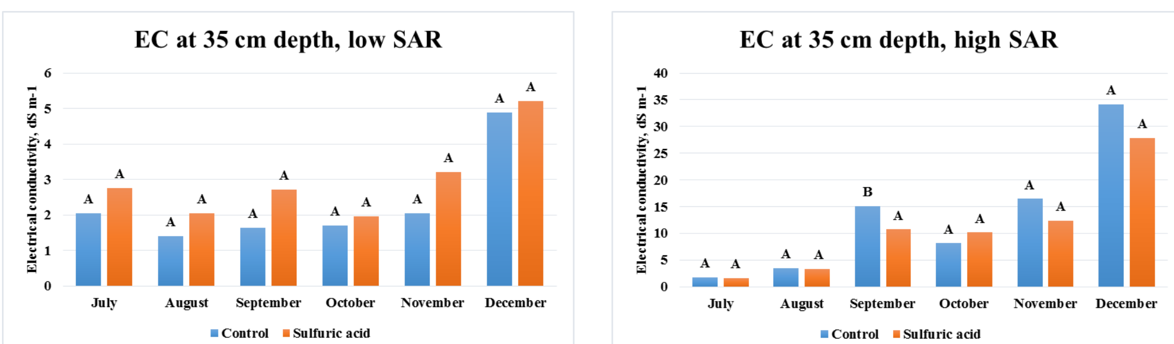

Figure 10. Electrical conductivity in drainage water collected under soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

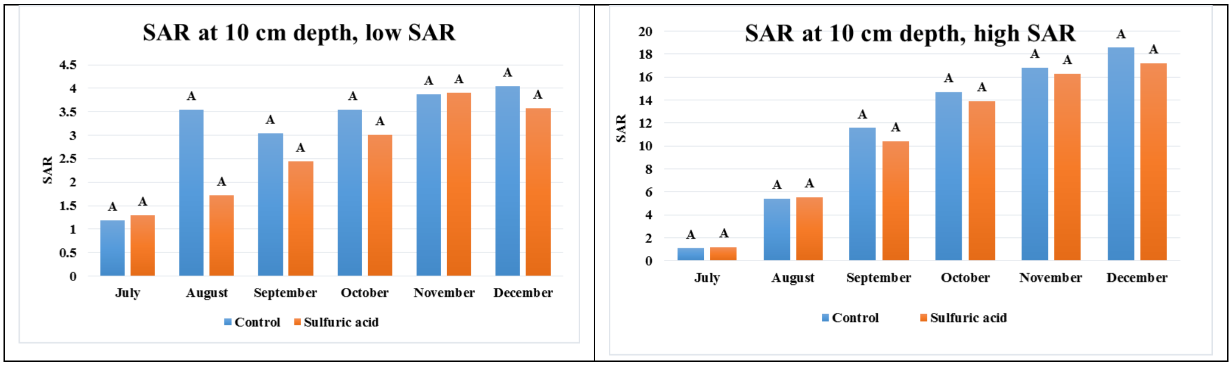

Figure 11. SAR in leachate (collected at a depth of 10 cm) collected in soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

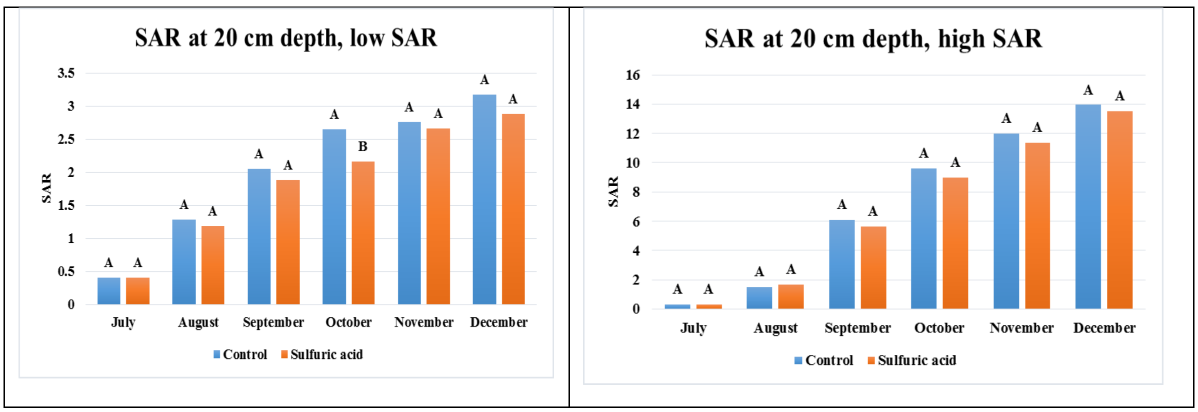

Figure 12. SAR in leachate (collected at a depth of 20 cm) collected in soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

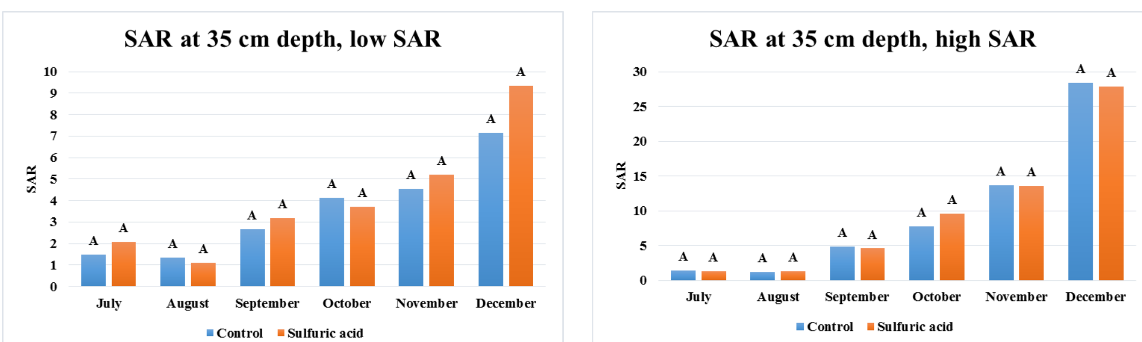

Figure 13. SAR in drainage water collected under soil columns to which irrigation water was applied with either a low (left) or a high (right) SAR.

Table 1: Main chemical constituents of the irrigation water.

Treatment	Bicarbonate, ppm	pH	EC	SAR
Control, high SAR	280-285	8.2	2.7	15
Control, low SAR	285	8.3	0.6	2.6
Acid, high SAR	205	6.5	2.65	14.7
Acid, low SAR	275	6.5	0.82	2.6

Table 2: ANOVA results for leachates.

	EC	**SAR**	**Bicarbonates**	**pH**
SAR High				
Trt	0.8217	0.327	0.088	0.8644
depth	<.0001	<.0001	<.0001	<.0001
Trt*depth	0.5603	<.0001	<.0001	0.1357
Date	<.0001	<.0001	<.0001	<.0001
Trt*Date	0.371	0.4145	0.0001	0.6086
depth*Date	<.0001	<.0001	<.0001	0.0027
Trt*depth*Date	0.4562	0.0035	0.0005	0.8862
SAR Low				
Trt	0.0816	0.0017	0.0034	0.3323
depth	<.0001	<.0001	<.0001	0.5361
Trt*depth	<.0001	0.0005	<.0001	<.0001
Date	<.0001	<.0001	<.0001	<.0001
Trt*Date	0.0303	0.0066	<.0001	0.2915
depth*Date	<.0001	<.0001	<.0001	<.0001
Trt*depth*Date	0.038	0.1385	<.0001	0.5552

Table 3: ANOVA results for salinity parameters in the soil (after the 6 months research period).

	SAR high			**SAR low**		
	EC	SAR	pH	EC	SAR	pH
Trt	0.0557	0.3556	0.0138	0.607	0.4689	0.0016
depth	0.0214	0.0002	<.0001	0.4231	0.4237	<.0001
Trt*depth	0.6252	0.4247	0.017	0.6707	0.5407	0.1706

Table 4: Electrical conductivity, SAR, and pH in soil. Values are averaged over all soil depths.

	SAR high			**SAR low**		
	EC	SAR	pH	EC	SAR	pH
Control	2.85†A	15.09A	9.03A	1.42A	5.75A	8.8A
Sulfuric Acid	3.28A	15.03A	8.93A	1.20A	3.33A	8.7B

†Values in the columns followed by the same letter are not significantly different from one another (Fisher's protected LSD, $P \leq 0.05$).

Table 5. The infiltration rate for each treatment before the first treatments application and after 6 months of treatments.

Treatment	Before treatment, mm $15min^{-1}$	After 6 months of treatment, mm $15min^{-1}$
Control, high SAR	38	22
Control, low SAR	67	53
Acid, high SAR	71	29
Acid, low SAR	64	35

2016-32-602

Dealing with Salinity Issues and More on Fairways by Topdressing and Aeration

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ADDITIONAL INDEX WORDS. Organic matter, recycled water, salt, saline, topdressing, turfgrass.

SUMMARY. Based on a national survey, golf course management in the United States used 2.3 million acre-foot of irritation water per year during 2004 to 2005, with 12% of all golf facilities using recycled water as one of the water sources (Throssell et al., 2009). Recycled water usage increased from the 14.7% in 2005 to about 25% in 2013 of all water used on golf course (Gelernter et al., 2015). Most of the recycled water has elevated amounts of salts (Marcum, 2006; Harivandi, 2007). Golf courses that are developed on saline soils, or where the major water sources contain high levels of salts also experience salinity problems. The objective of this study was to investigate if using humus on golf fairways by topdressing or spray can alleviate soil salinity problems and improve turfgrass quality. The study was conducted from 2015 to 2016 on Valley Country Club, Aurora, CO, and from 2016 to 2017 on Bully Pulpit Golf Course, Medora, ND. Treatments included an untreated control, topdressing (sand, sand/peat), and spray of humic acid. Treatments were applied in the first week of May, July, and September each year. Topdressing was applied at 1/8 inch depth. Humus was sprayed at a spray volume of 30 gal/acr. The treatments were arranged in randomized complete block design with 3 replications. Our results showed that application of humus increased the soil microbial biomass and improved turf quality on fairways either with inherent soil salinity problem or irrigated with recycled water with elevated salt content. The effects on turfgrass health and turf quality were dependent on the rates of humus. Humic acid at 3 gal/acr was equivalent to topdressing sand/peat (80/20), and consistently showed improved turf quality over the untreated control. Soil properties also were affected by the application of humus and the effects on soil pH, EC, bulk density, water infiltration, and soil microbial biomass may have contributed to the ultimate turfgrass quality.

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Throssell, C.S., G.T. Lyman, M.E. Johnson, G.A. Stacey, and C.D. Brown. 2009. Golf course environmental profile measures water use, source, cost, quality, and management and conservation strategies. Appl. Turfgrass Sci. doi:10.1094/ATS-2009-0129-01-RS.

Figure 1. Golf courses that are developed on saline soils, or where the major water sources contain high levels of salts experience salinity problems.

Table 1. Soil and water analysis at two fairways in 2015 and 2016 prior to the initiation of study.

	EC	pH	OM	Carbonate	Bicarbonate	Available P	Available K	Na	Ca	Mg	S	Cu	Mn	Zn	Fe	B
	dS m^{-1}		%	ppm												
17th fairway of Valley Country Club (VCC), Aurora, CO																
Soil	0.93	7.8	6.3	2.2	/	9	212	148	2816	274	60	0.75	2.7	11.46	31.3	2.69
Water	1.08	7.8	/	3.0	277.4	/	14.1	89	100	13.5	154.2	<0.02	0.026	0.07	0.01	0.16
1st fairway of Bully Pulpit Golf Course (BPGC), Medora, ND																
Soil	3.37	7.6	4.2	2.0	/	10	287	660	3686	405	271	2.7	7.1	8.3	40.4	1.1
Water	2.47	8.3	/	2.4	209.6	0.007	11.4	409	52.2	63.1	372.4	/	0.01	/	0.09	0.46

Table 2. Turfgrass quality on the 17th fairway of Valley Country Club, Aurora, CO during 2015 to 2016; and the 1st fairway of Bully Pulpit Golf Course, Medora, ND during 2016 to 2017.

	VCC					BPGC				
Treatment	May	June	July	August	September	May	June	July	August	September
Control	5.5b	6.0c	5.9d	5.9c	6.0d	0.50c	0.54c	0.65b	0.68c	0.70c
Sand	5.5b	6.2bc	6.0d	6.0c	6.5c	0.52c	0.56c	0.68b	0.72c	0.79b
Sand/Peat (90/10)	5.7ab	6.5b	6.5c	7.0b	7.2b	0.56b	0.66b	0.76a	0.79b	0.80b
Sand/Peat (80/20)	5.7ab	6.7b	7.0b	7.2ab	8.2a	0.61a	0.72a	0.78a	0.83a	0.84a
Humic acid (1 gal/acr)	5.7ab	6.7b	7.0b	6.8b	7.0b	0.59ab	0.68ab	0.77a	0.78b	0.77b
Humic acid (3 gal/acr)	6.0a	7.2a	7.5a	7.6a	8.1a	0.62a	0.70ab	0.79a	0.84a	0.85a

2016-31-601

Earthworm Casting Activity as Affected by Sand Topdressing in Turf Systems

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As earthworms feed, they can egest soil and nutrient-rich aggregates (casts) on the soil surface (Photo 1). In low-cut turfgrass systems, such as golf course greens, tees, and fairways, surface casting can result in mowing issues, muddy playing surface, ball roll issues, weed and pest invasion, reduced aesthetics, surface softening, and reduced photosynthesis. As the use of pesticides for earthworm control is illegal in the U.S., earthworms must be managed through cultural practices. Sand topdressing is one method of earthworm control studied for use on golf courses, with the supposition being that the abrasive sand particles will deter the soft-bodied earthworms from remaining in the system; however, effects have been varied.

Objectives:

- Test the effect of heavy (2.54 cm yr^{-1}) or light (0.64 cm yr^{-1}) sand topdressing treatments and the effect of native soil and sand-capped rootzones on earthworm casting activity in ‘Patriot’ bermudagrass (*Cynodon* spp.).
- Assess the relationships between soil moisture and soil temperature on earthworm casting activity.
- Determine earthworm species present on golf course turf in Arkansas and Oklahoma.

Materials and Methods:

This trial was conducted at the University of Arkansas Agricultural Research and Extension Center in Fayetteville, AR. The rootzone treatments included a native soil rootzone (Captina silt loam; fine-silty, siliceous, active, mesic Typic Fragiudults with an average pH of 6.2) and a sand-capped rootzone containing a 12.5 cm depth of a sub-rounded, medium size sand that meets the United States Golf Association particle size specifications for putting green construction. Topdressing treatments included light (0.64 cm yr^{-1}) and heavy (2.54 cm yr^{-1}) topdressing rates. The experimental design was a two-factor (rootzone and topdressing) randomized complete block with sixteen 1.5 x 4.9 m (7.4 m^2) plots comprised of four replications of each rootzone and topdressing treatment combination. Plots were established in 2010 to ‘Patriot’ bermudagrass. Cultivation, including topdressing treatments, has been consistent since establishment. Cast counts, soil moisture measurements, and soil temperature measurements were conducted at least twice per month and reported as monthly averages. Month was included as a factor in a repeated measures analysis of variance. Additionally, because efficacy of earthworm casting control methods are likely species-specific, earthworms were collected from five collection sites across Arkansas and Oklahoma (Table 1) for morphological and molecular identification.

Results:

- There was generally very little casting activity in the light topdressing soil rootzone treatment throughout the two years of this study and casting activity was significantly greater under heavy topdressing in the soil rootzone (Fig. 1).
- In the sand rootzone, there was no significant difference in casting activity between topdressing treatments in year one; however, in year two, light topdressing resulted in significantly greater casting activity compared to the heavy topdressing treatment (Fig. 1). In addition, casting

activity in the sand rootzone treatments was similar to casting observed in the soil rootzone with heavy topdressing (Fig. 1).

- Soil temperature varied over time between treatments (Fig. 2). The relationship between soil temperature and casting activity was significant and soil temperature explained 10-34% of the variation in casting activity within a rootzone/topdressing treatment combination (Fig. 3).
- Within both rootzones, the light topdressing treatment resulted in significantly greater soil moisture content across the two years of the study (Fig. 4). The relationship between soil moisture content and earthworm casting activity was not significant.
- Morphological identification indicated that the Lew Wentz adult specimens were comprised of *Aporrectodea* and *Amynthas* spp. Jimmie Austin Golf Course contained *Amynthas* spp. as well as some unidentified adult and juvenile specimens.
- Molecular identification indicated that specimens collected from the University of Arkansas, Meadowbrook Country Club, and Chenal Country Club grouped with the North-American native *Diplocardia* genus. Several individuals from UA and Meadowbrook grouped with *Amynthas* and *Metaphire* spp.

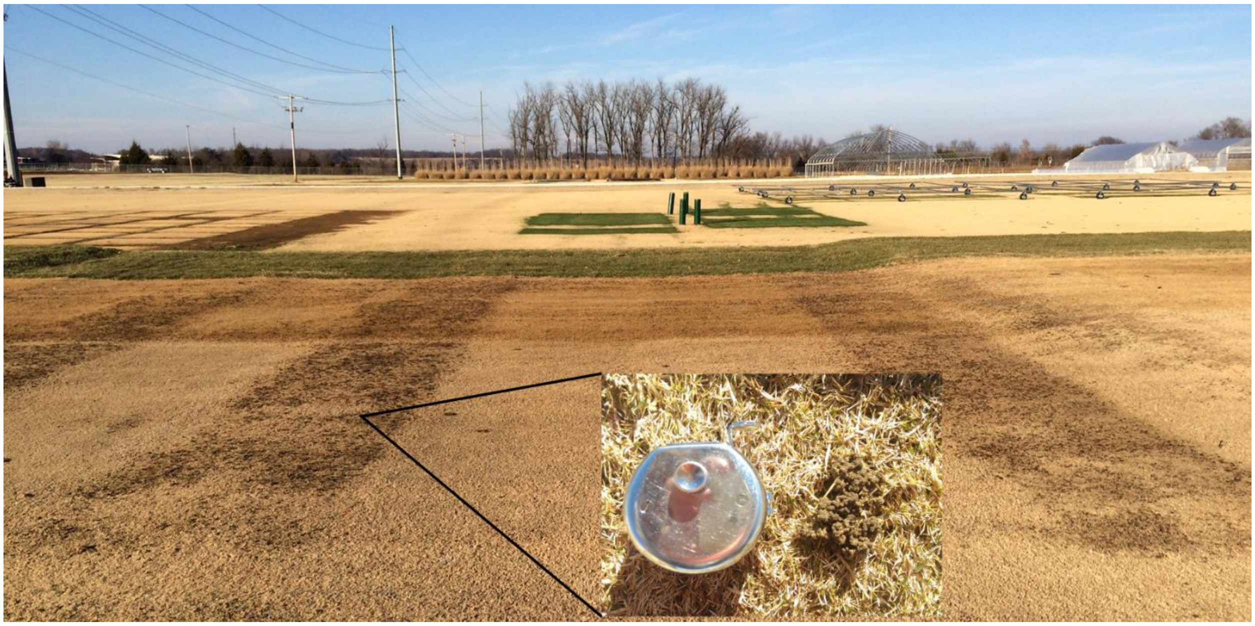

Photo 1. Casting on 'Patriot' bermudagrass (*Cynodon* spp.) tee boxes, Fayetteville, AR.

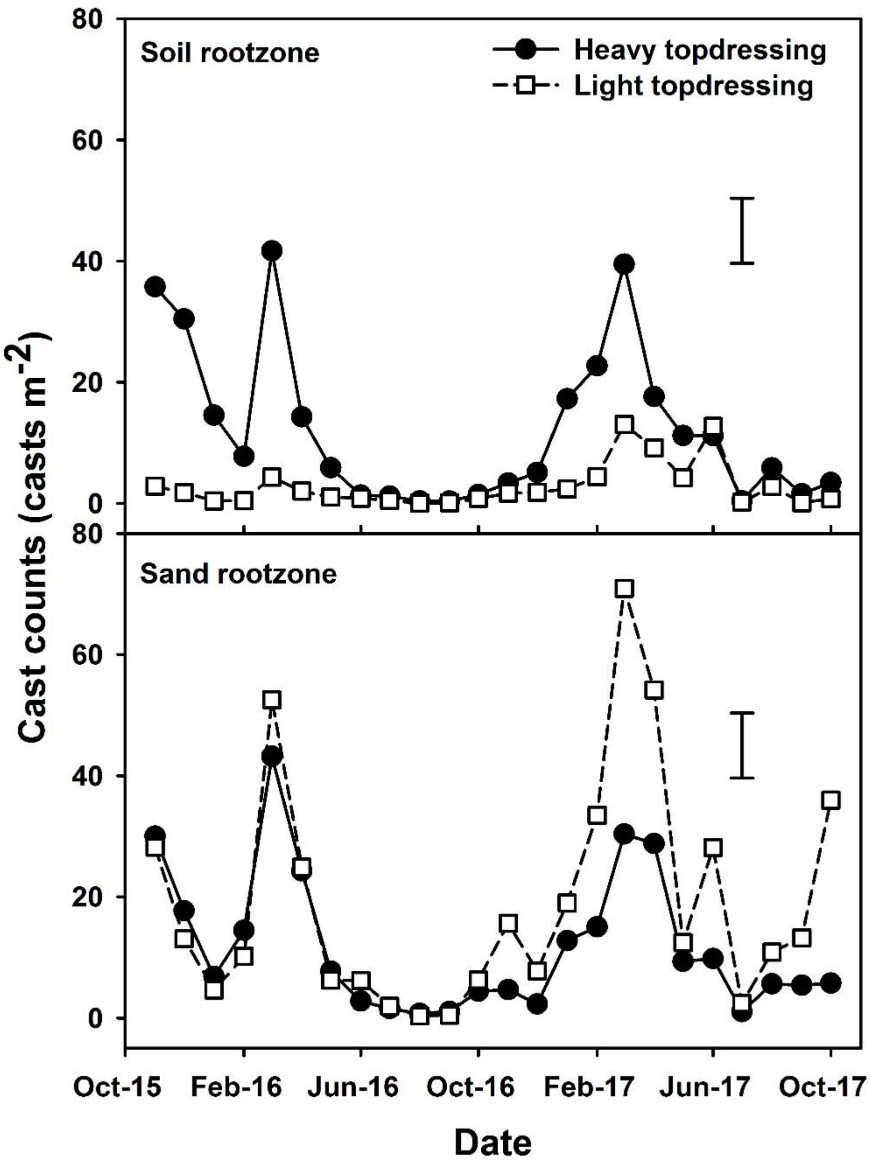

Figure 1. Effect of sand topdressing rate within rootzone on casting activity between November 2015 and October 2017 on ‘Patriot’ bermudagrass tee boxes in Fayetteville, Arkansas. Heavy topdressing = 2.54 cm per growing season and light topdressing = 0.64 cm per growing season. Bar represents the least significant difference for comparing means within a date.

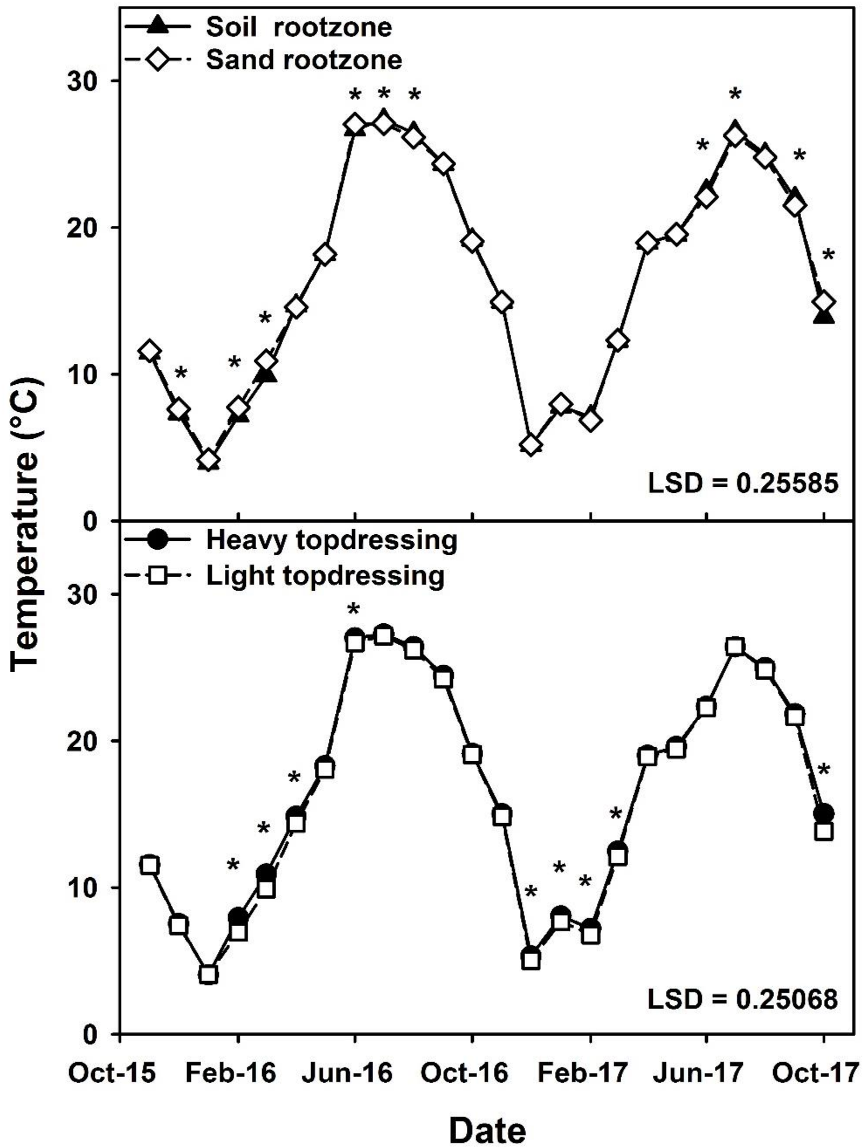

Figure 2. Interactions between rootzone and month (top) and sand topdressing rate (bottom) on soil temperature between November 2015 and October 2017 on 'Patriot' bermudagrass tee boxes in Fayetteville, Arkansas. Heavy topdressing = 2.54 cm per growing season and light topdressing = 0.64 cm per growing season. * indicates a significant difference within a date.

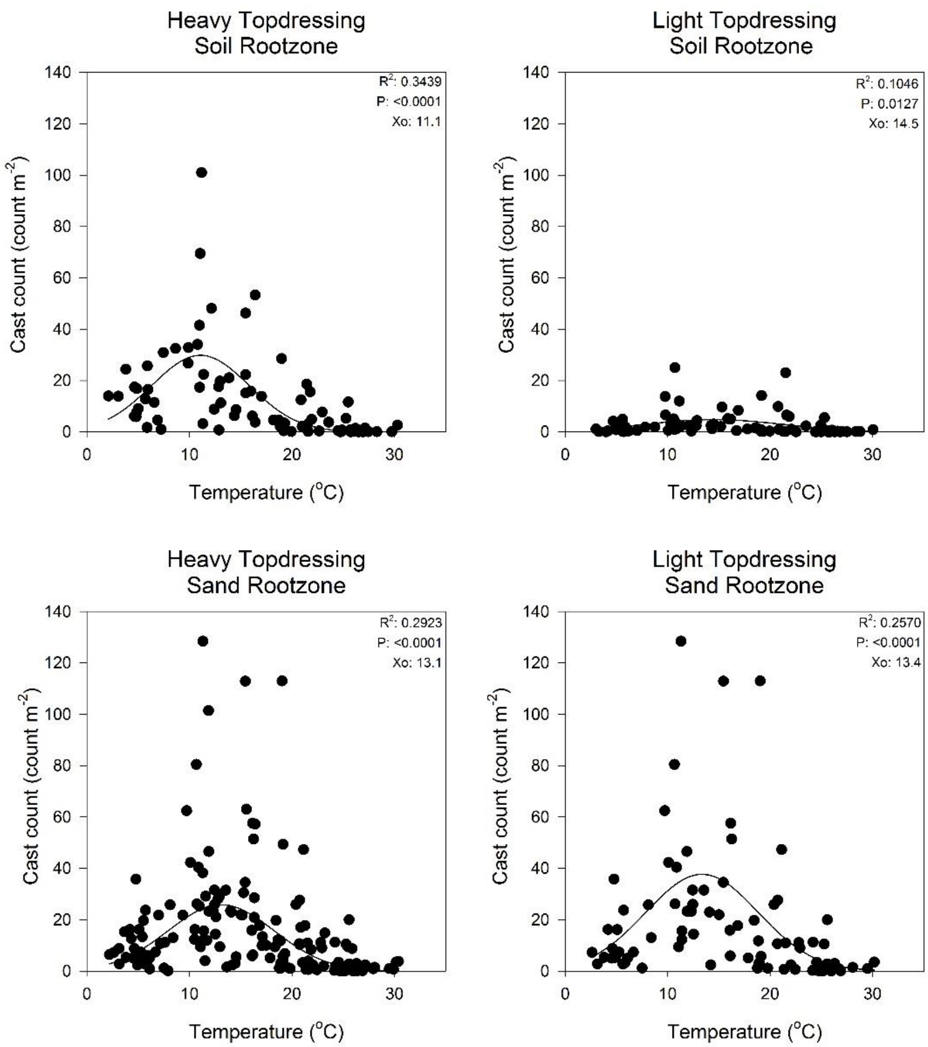

Figure 3. Gaussian regression showing the relationship between average soil temperature and casting activity on 'Patriot' bermudagrass tee boxes in Fayetteville, Arkansas. X_o indicates the critical temperature at which casting was maximized under each sand topdressing rate and rootzone combination. Heavy topdressing = 2.54 cm per growing season and light topdressing = 0.64 cm per growing season.

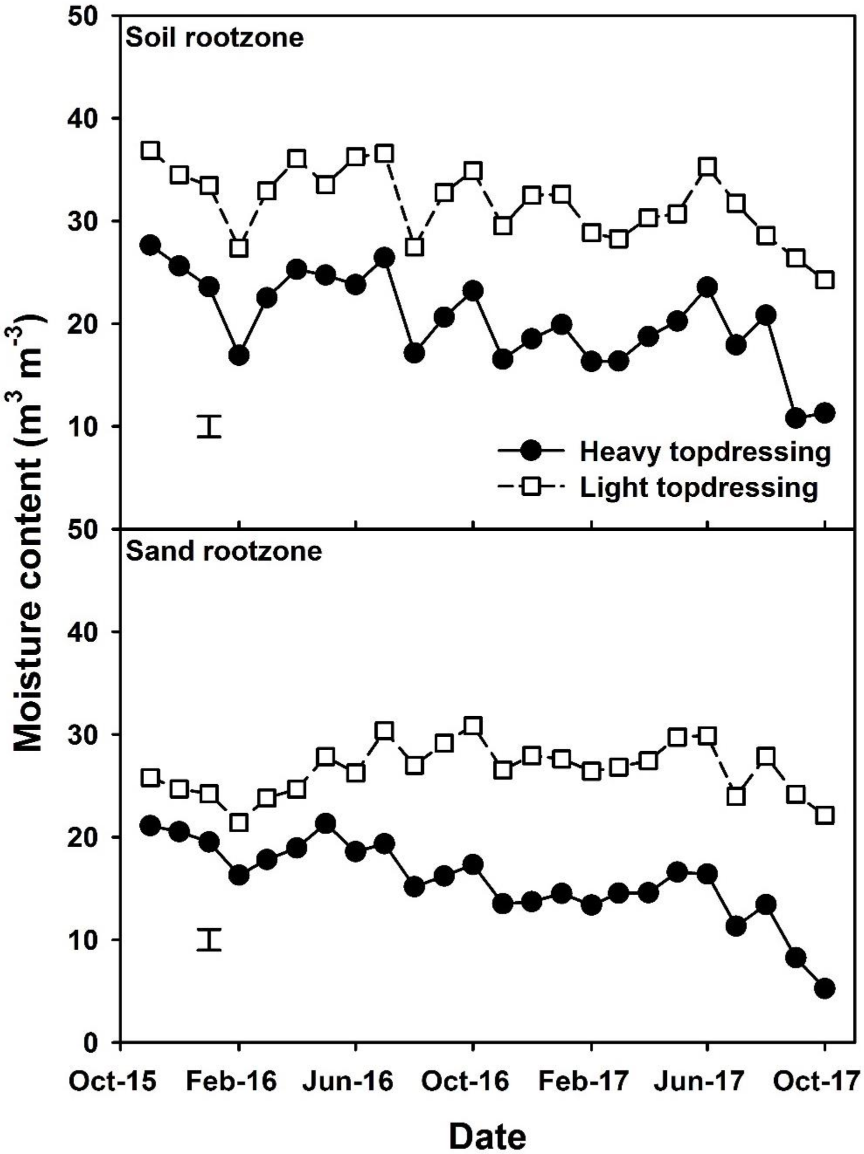

Figure 4. Effect of sand topdressing rate within rootzone on soil volumetric water content between November 2015 and October 2017 on 'Patriot' bermudagrass tee boxes in Fayetteville, Arkansas. Heavy topdressing = 2.54 cm per growing season and light topdressing = 0.64 cm per growing season. Bar represents the least significant difference for comparing means within a date.

Table 1. Collection sites in Arkansas and Oklahoma sampled for identification of earthworm species. Number in parentheses indicates the number of samples collected from each sampling location.

Collection site	City	Latitude / longitude	Date sampled	Turfgrass area sampled	Cultivar
Jimmie Austin Golf Club	Norman, OK	35.188541 N 97.427982 W	30 Nov 2015	No. 5 practice zoysiagrass tee (1) No. 12 zoysiagrass tee (1) No. 13 bermudagrass fairway (1)	Zeon Zeon Unknown
Lew Wentz Memorial Golf Course	Ponca City, OK	36.730351 N 97.024931 W	30 Nov 2015	No. 8 creeping bentgrass collar (3)	Unknown
Chenal Country Club	Little Rock, AR	34.778560 N 92.475937 W	26 Oct 2016	Founders no. 9 bentgrass green (1) Founders no. 9 zoysiagrass fairway (1) Bear Den no. 10 zoysiagrass tee (1)	A-1 Meyer Cavalier
University of Arkansas	Fayetteville, AR	36.100229N 94.168845W	20 Dec 2016	Simulated bermuadgrass tees (16)	Patriot
Meadowbrook Country Club	Tulsa, OK	36.042490 N 95.872778 W	12 Jun 2017	No. 14 bermudagrass rough (2) No. 15 bermudagrass rough (1)	Unknown

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2017-30-640

The Effect of Wetting Agents and Plant Growth Regulators on Microbial Growth in Culture Medium

Mussie Y. Habteselassie, University of Georgia

Introduction

This is a preliminary study that was done to assess the impact of selected wetting agents and plant growth regulators on bacterial growth in culture medium under laboratory conditions. Seven wetting agents and three plant growth regulators were mixed at four concentrations with the growth medium that was inoculated with microorganisms extracted from soil. The bacterial growth was monitored over time by measuring the turbidity of the medium as an indicator of growth. More information on details of the study is given below.

Materials & Methods

We used a generic growth medium for total heterotrophic bacteria called nutrient broth. The broth contained antifungal additive (nystatin) to prevent fungal interference on bacterial growth. The growth assay was prepared by mixing the various ingredients in a 24-well culture plate as shown in Figure 1. The total assay volume was 1 mL (1000 µL). Each product was added at four levels: 0 (positive control), 10, 20 and 50 µL. The concentrations corresponded to 0, 1, 2 and 5%. The positive control included everything but the product. The negative control, on the other hand, received everything but the microorganisms. After mixing all the ingredients, the plates were shaken in an incubator at 25°C at 150 rpm to facilitate aeration. Two separate plates were set up for the two sampling times, which were 24 and 48 hrs.

Measurements for turbidity were taken with a spectrophotometer at 600 nm. All treatments were set-up in duplicate. Sterile phosphate buffer was used to extract microorganisms from soil to be used as inoculants. Some of the products contain surfactants that turned the medium milky upon addition. This interfered with the measurement of turbidity initially. To correct for this, the medium was centrifuged at high speed to separate the bacteria that settled at the bottom. The surfactant was then removed, and the bacteria were subsequently resuspended in sterile phosphate buffer for measurement. The absorbance from the negative control was subtracted from the absorbance values of the rest. Analysis of variance was conducted in JMP Pro 13 to compare the mean absorbance values among treatments and concentrations.

Summary of Results & Recommendation

- Dispatch, Fleet, Oars, Prevade, Vivax, Proxy and Trimmit inhibited bacterial growth as compared to the positive control (Table 1; see below). Their impact was statistically significant ($P < 0.0001$).
- Similarly, Anuew, Proxy and Trimmit inhibited bacterial growth as compared to the positive control (Table 1). Their impact was also statistically significant ($P < 0.0001$).
- Sixteen 90 did not show any negative impact on bacterial growth whereas the impacts of Magnus and Anuew appeared to be only temporary.
- The effects of the wetting agents and plant growth regulators in a growth medium might not

be reflective of what will happen in soils where there are organic matter and soil particles that can minimize the impact.

- However, we recommend field based studies for the wettings agents and the plant growth regulators that completely inhibited microbial growth to further study their impacts not only on microbial growth but also their impact on microbial functions.

Table 1. Bacterial growth (as indicated by average absorbance reading) in response to wettings agents and plant growth regulators at four concentrations.

Product	**Time**	24 hr				48 hr			
		Concentration (parts per thousand-ppt)				Concentration (ppt)			
		0	10	20	50	0	10	20	50
		-----------Mean absorbance-----------							
Wetting agents	Dispatch	0.266	0.036	0.038	0.037	0.623	0.036	0.037	0.036
	Fleet	0.370	0.181	0.028	0.036	0.766	0.120	0.079	0.121
	Magnus	0.224	0.000	0.000	0.000	0.789	0.273	0.339	0.550
	Oars	0.399	0.036	0.043	0.037	0.680	0.078	0.039	0.037
	Prevade	0.442	0.038	0.043	0.044	0.768	0.032	0.039	0.060
	Sixteen 90	0.188	0.217	0.236	0.217	0.615	0.778	0.985	0.897
	Vivax	0.246	0.078	0.111	0.136	0.530	0.112	0.119	0.215
Plant growth regulators	Anuew	0.314	0.100	0.257	0.184	0.614	0.566	0.465	0.502
	Proxy	0.337	0.038	0.036	0.035	0.916	0.039	0.057	0.036
	Trimmit	0.388	0.017	0.039	0.000	0.598	0.018	0.150	0.006

2017-31-641

Title: Pythium Patch: Identification of the Causal Agent and Insights into the Biology of the Pathogen and the Epidemiology and Management of the Disease

Project Leaders: John Kaminski and Patrizia Rollo

Affiliation: Pennsylvania State University

Objectives:
1. Identify and confirm the causal agent(s) of this new disease.
2. Elucidate the biology of the pathogen(s) involved and epidemiology of the disease.
3. Determine cultural and chemical management options for turfgrass managers to more effectively prevent the disease from causing extensive damage.

Start Date: 2017
Project Duration: One year
Total Funding: $5,000

Summary Text:
First observed on a golf course in Connecticut in 2005, “Pythium patch” was a relatively unknown and minor disease in the Northeastern United States for nearly 10 years. During the summer of 2016, however, outbreaks of the disease were observed on 13 golf courses in 5 different states. Symptoms of the disease are unlike most traditional Pythium diseases. The disease is slow to progress, but most unique is its selective targeting of annual bluegrass within mixed populations of creeping bentgrass greens. Disease symptoms are similar to summer patch and therefore is often misdiagnosed. While control measures include traditional Pythium-based fungicides, management options are relatively unknown. Limited information on the causal agent(s) of Pythium patch are available.

There is currently no information on this disease in the scientific literature. Our lab received suspected Pythium patch samples from 20 golf courses in 6 different states in 2016. Of those samples, we were able to culture 14 isolates for further analysis. This represents the largest possible collection of isolates to identify the pathogen(s) responsible for causing Pythium patch. We are currently completing DNA isolations to identify the species involved and are preparing to perform Koch’s postulates. Based on the information obtained from these preliminary studies, we will be conducting various lab and field experiments to better understand the biology of the pathogen(s) and epidemiology of the disease. Future work will include management strategies for Pythium patch.

Without science-based information related to the causal agent and a better understanding of the pathogen’s biology and disease epidemiology, management options will be limited. A goal of this project is to investigate the factors that promote the spread of the disease on annual bluegrass. Through these studies, we will be able to provide information to golf course superintendents related to the best management practices in order to keep the turfgrass healthy and prevent a substantial economic loss.

2017-26-636

Project Title: Developing an IPM Program to Control Frit Fly, a Challenging Turfgrass Pest in Hawaii

Project Leader: Zhiqiang Cheng, Ph.D.

Affiliation: University of Hawaii at Manoa

Start Date: 2017

Project Duration: Two years

Summary Text:
Frit fly (*Oscinella frit*) is a relatively new and less studied turfgrass insect pest in Hawaii (Brennan, et al., 2002). This pest mainly develops on bermudagrass varieties in Hawaii. Larva stage is the life stage when frit fly causes actual damages to turfgrass. The larvae feed at the base of the succulent young leaves, causing the tips to yellow and wilt. The older leaves, however, usually remain green. As the larvae continue to feed, the stem is severely damaged, causing the tip to wither. The pest's small, white eggs are laid in leaf sheaths. They hatch in 3-4 days. Mature larvae are about 1/8 inch long. The adult fly is small, 3/16 inch long, and black with yellow on the legs. Three to four generations a year have been reported in temperate regions. The warmer conditions in Hawaii will likely produce more generations per year (Brennan, et al., 2002). Adults can be found in grass clippings, on freshly mowed grass, and on white objects such as golf balls and white shirts and towels. Therefore, frit fly is oftentimes considered as a nuisance pest in golf courses as well.

Since its introduction, frit fly continues to be a management challenge to many golf courses in Hawaii. The turf/golf industry in Hawaii has been using trial and error methods of treatment. This is inefficient and costly at best and possibly harmful to the environment at worst. To address this urgent need from local turf/golf industry, we started this project to develop an IPM program to control frit fly in turfgrass systems in Hawaii.

In October 2017, PI Z. Cheng visited two golf courses on Maui and located research trial sites on both courses. Figure 1 shows the trial site at one golf course. These two courses were chosen for this research because they have history of repeated frit fly infestation on their Bermudagrass putting greens and fairways. Our plan is to wait for frit fly activities and then apply the treatments in spring 2018. There will be 5 treatments and a control, with 4 replications for each, arranged into a Randomized Complete Block Design. Each plot will be 7 ft x 7 ft. Each treatment will be applied 3 times, with 21 days between consecutive applications. Data on % Control, Turf Color and Quality will be collected after each application.

Reference

Brennan, BM, SF Swift, and CM Nagamine. 2002. Turf and Ornamental Pest Control - A Guide for Commercial Pesticide Applicators. University of Hawaii at Manoa Cooperative Extension Service. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/PRRE-3_rev2016.pdf (link verified on January 25, 2018).

Figure 1. Trial site at one golf course on Maui.

2017-35-645

Title: Effects of Ethylene Inhibition on Creeping Bentgrass and Annual Bluegrass Survival of Ice Cover Stress

Project Leaders: Emily Merewitz and Kevin Frank

Affiliation: Michigan State University

Start Date: 2015
Project Duration: Two years
Total Funding: $5,000

Objectives:
1. Evaluate the effects of ethylene regulation on annual bluegrass fall performance and survival of ice cover

2. Determine whether respiration rates (metabolic activity), antifreeze proteins, antioxidants, carbohydrate content, and fatty acid profiles are affected by ethylene regulatory treatments

Summary Text:

Ice damage to annual bluegrass (*Poa annua;* ABG) and creeping bentgrass (*Agrostis stolonifera;* CBG) golf course putting greens is a significant problem in many parts of the world. ABG and CBG are both susceptible to ice cover, with ABG being more susceptible (killed at approximately 45 to 70 d) and CBG being more tolerant (killed after 100+ day). The primary cause of death to turfgrass under ice sheets is most likely from oxygen depletion and toxic gas accumulation. Ethylene, a gaseous hormone, is known to play a role in regulating metabolic activity rates during dormancy. CBG and ABG are known to produce different amounts of ethylene. Faster growing species of ABG produce more ethylene when compared to slower growing ABG species (Fioriani et al., 2002). Ethylene improves plant tolerance of freezing stress by increasing antifreeze protein expression in winter rye plants (Yu et al., 2001) but reduces freeze tolerance in other species (Shi et al., 2012). Ethephon (effective ethylene) treatment in the fall has been proposed as one alternative to mefluidide, which is being phased out in the turfgrass market, for controlling ABG flowers. To our knowledge, whether ethylene may be associated with the difference in tolerance to various winterkill stresses, particularly ice stress, of cool-season turfgrasses has yet to be investigated. Since ABG is less tolerant of ice stress, we hypothesize that high levels of ethylene production or ethylene treatment products may have negative effects on ice stress survival and treatments that inhibit ethylene production may improve survival under ice stress.

In the field, turf plots were treated with one of the following treatments throughout the late fall (weekly) starting on 10/3/16 and then naturally acclimated to cold temperatures. Treatments included 1) negative control 2) ethephon (Proxy) as an ethylene application (8 L ha^{-1}) 3) ethylene precursor aminocyclopropane- 1-carboxylic acid (100 µmol L^{-1}) as an ethylene application 4) aminoethoxyvinylglycine (AVG; 25 µM) to inhibit ethylene 5) ReTain (226 g ha^{-1}) to inhibit ethylene and 6) urea at 12.2 kg N ha^{-1}. Due to availability of AVG, it was only able to be applied twice during the acclimation period. Prior to freezing of the soil, plugs of ABG turf (10 cm diameter x 10 cm depth) were taken and placed in a low temperature growth chamber (-4°C) and subjected to either ice (1.27 cm thick) or no ice cover treatment. Plants were exposed to two ice treatments 1) no ice 2) ice cover (1.27 cm thick). Plants were sampled at 0, 10, 20, 40 and 80 days in the low temperature chamber. Half of the plugs went towards a regrowth assay in a greenhouse and percent regrowth will be documented weekly or on an as needed basis. The other half went towards antioxidant enzyme activity, antifreeze protein content, total nonstructural carbohydrate content (TNC), and fatty acid profiles.

Based on two years of field research and one year of growth chamber results, turfgrass managers that may be using ethephon for control of annual bluegrass flowering in the fall or for other purposes may see a slight decrease in turf performance and quality. More importantly, this research indicates that ethephon treatments could significantly reduce spring recovery following winter conditions either under no ice or ice-covered conditions. Primarily, ethephon research on annual bluegrass flowering control is being performed in southern states. Research done in these states are suggesting that ethephon application (in combination with other treatments) may be a viable alternative to mefluidide (Askew, 2016). Thus, turfgrass managers in northern climates need to be cautious of recommendations originating from southern research and should use caution with using ethephon during the fall, since a reduction in annual bluegrass survival over winter could occur. Thus far, our ethylene inhibition treatments showed some promise for not causing any major changes in turf physiology or performance in either creeping bentgrass or annual bluegrass, which is important if a mixed stand putting green is treated with any of these chemicals. Before making any claims about ethylene inhibition or urea application on winter survival we need to first complete our second year of growth chamber results.

Summary Points:

- Ethylene evolution from annual bluegrass plots was enhanced due to ACC and ethephon treatments. Ethylene levels were not significantly different than untreated controls for ethylene inhibition treatments.
- Ethephon treatments reduce some attributes associated with fall turf performance and reduced recovery of annual bluegrass following simulated low temperature and ice cover conditions.
- It is not yet clear how urea and ethylene inhibition treatments played a role in winter survival of annual bluegrass.

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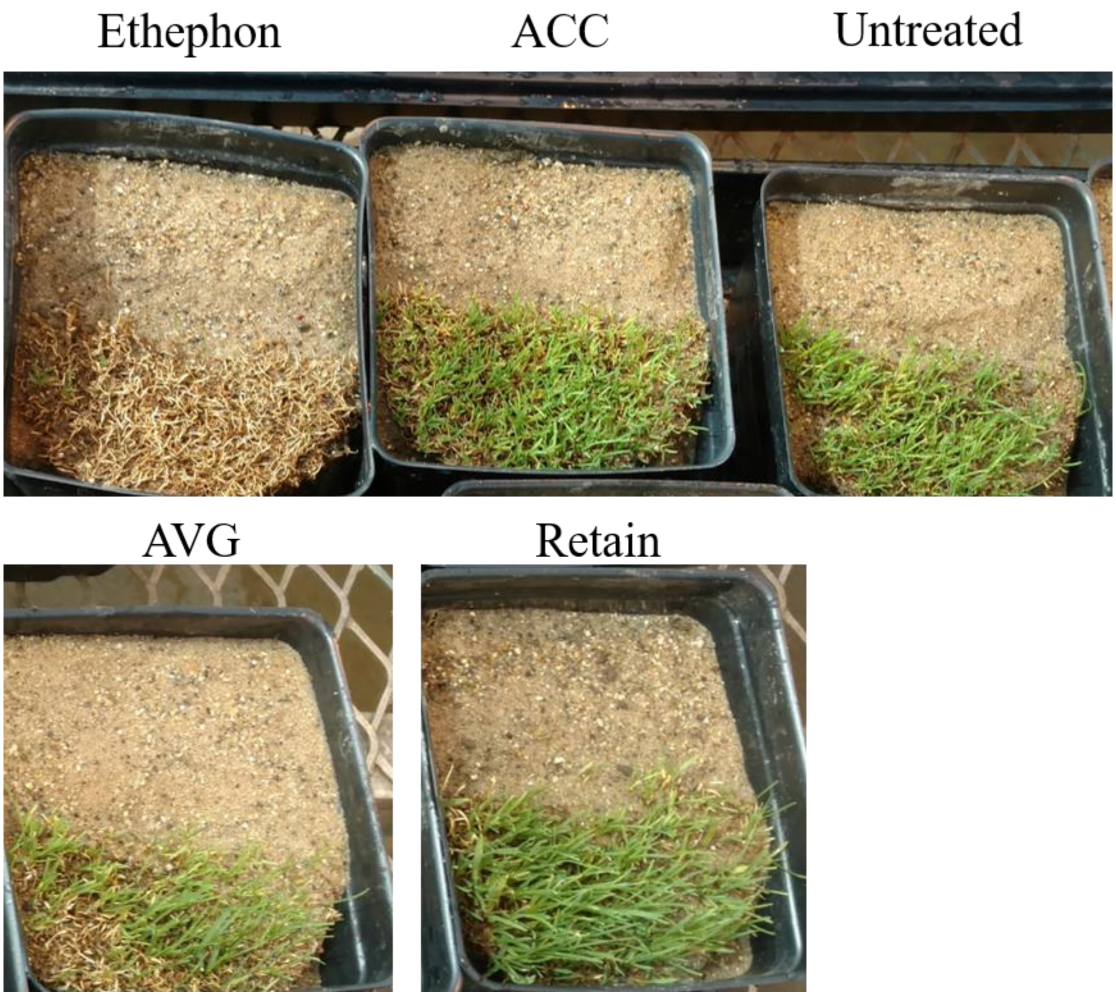

Figure 1. Annual bluegrass plants in the greenhouse recovery period following 80 days of low temperature treatment (no ice cover). Plants were untreated or treated in the field with ethephon, aminocyclopropane- 1-carboxylic acid (ACC), aminoethoxyvinylglycine (AVG), or Retain prior to simulated winter conditions in a low temperature growth chamber.

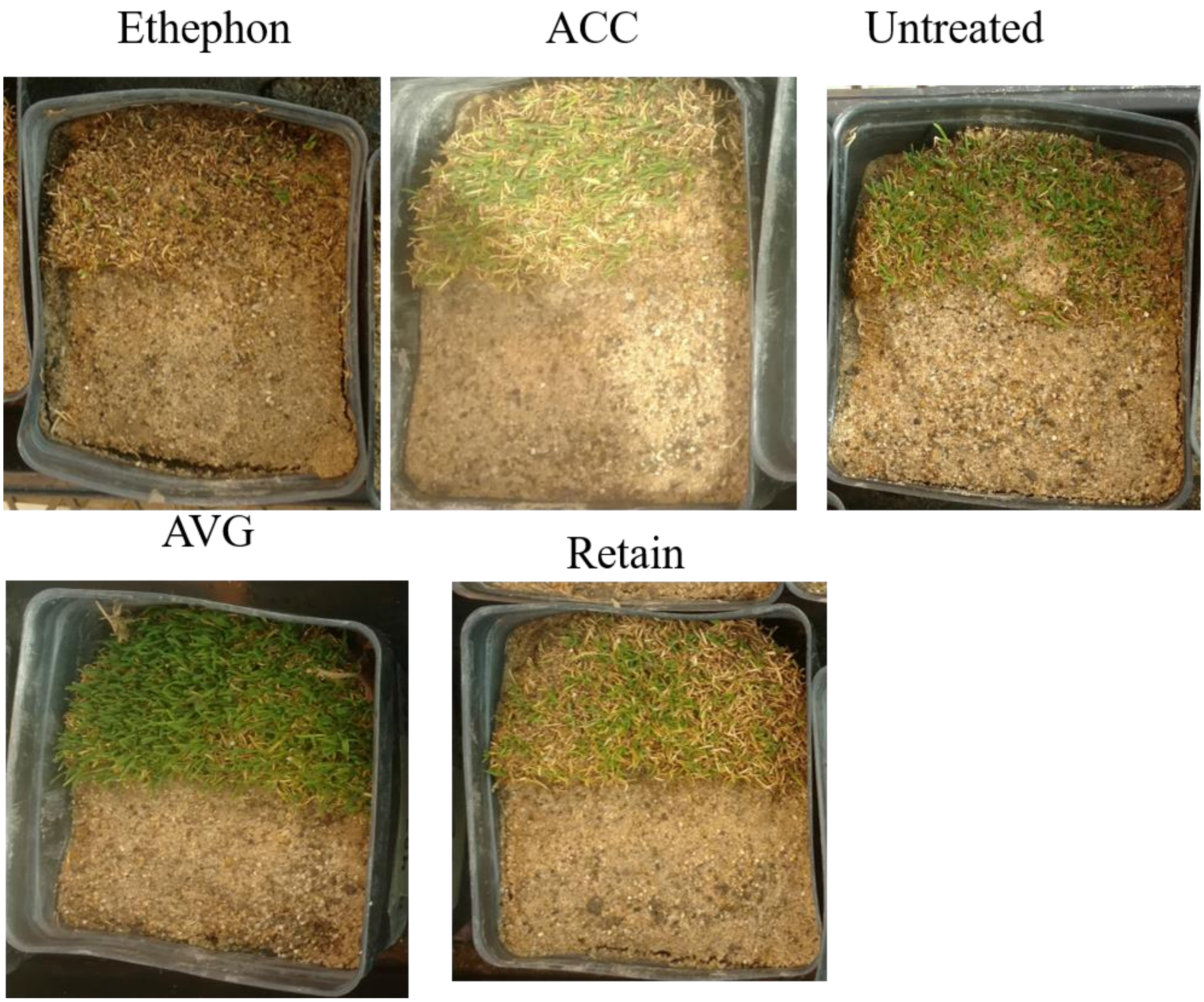

Figure 2. Annual bluegrass plants in the greenhouse recovery period following 80 days of low temperature and ice treatment. Plants were untreated or treated in the field with ethephon, aminocyclopropane- 1-carboxylic acid (ACC), aminoethoxyvinylglycine (AVG), or Retain prior to simulated winter conditions in a low temperature growth chamber.

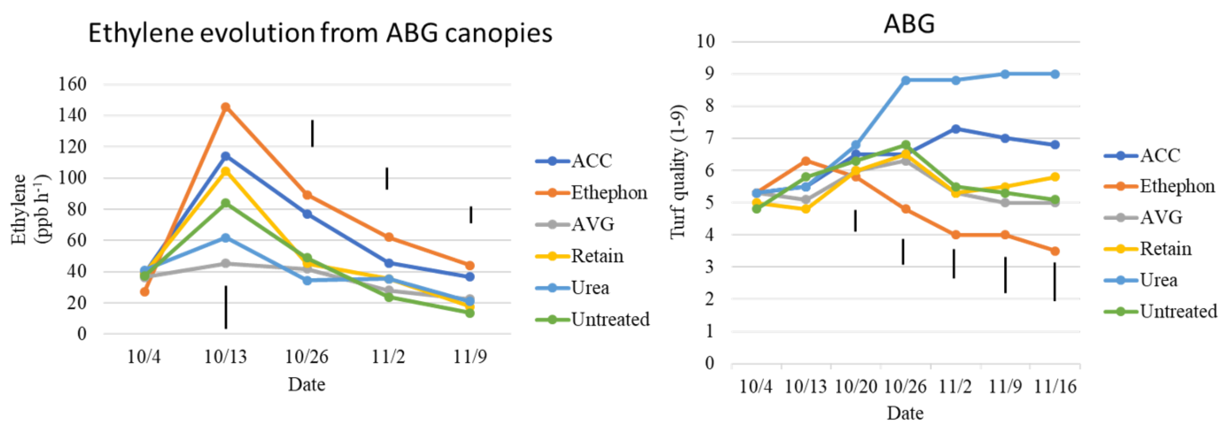

Figure 3. Ethylene evolution from annual bluegrass field plot canopies for each chemical treatment (left). Turf quality ratings for annual bluegrass field plots during the fall in response to chemical treatments. Chemical treatments included no treatment, ethephon, aminocyclopropane-1-carboxylic acid (ACC), aminoethoxyvinylglycine (AVG), or Retain.

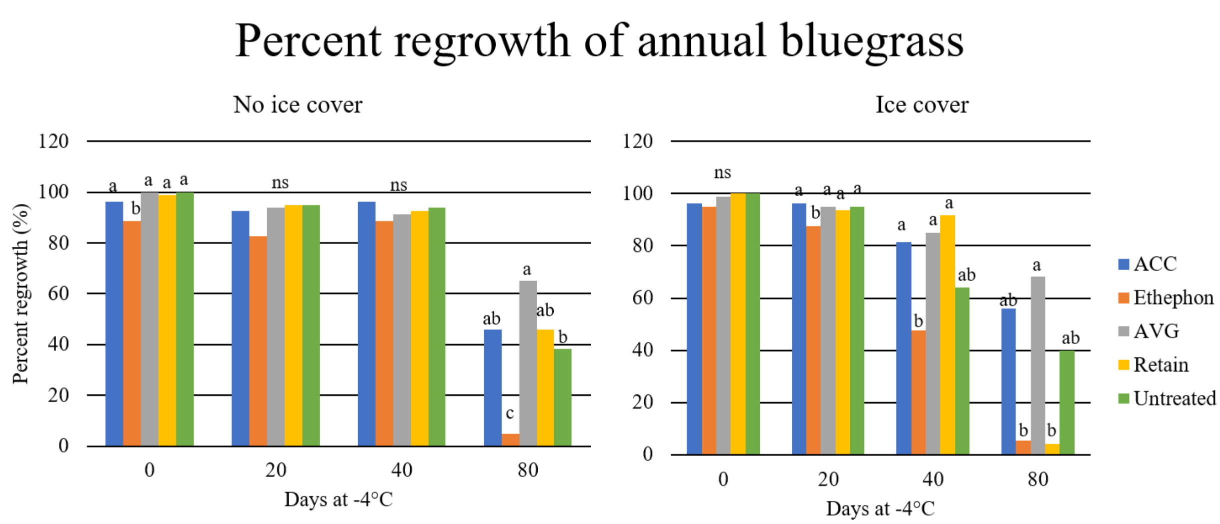

Figure 4. Greenhouse recovery ratings of annual bluegrass plugs following 0, 20, 40 or 80 d under no ice or ice conditions in a low temperature growth chamber. Chemical treatments included no treatment, ethephon, aminocyclopropane- 1-carboxylic acid (ACC), aminoethoxyvinylglycine (AVG), or Retain.

2017-24-634

Title: Impact of Cultural Practices on Putting Green Speed and Plant Health

Project Leader: John Kaminski

Affiliation: Pennsylvania State University

Objectives:

1. Determine the effect of mowing frequency and height of cut on ball roll distance and health of three turfgrass species.
2. Quantify the effect and consistency of various combinations of cultural practices used in tournament preparation programs on putting green performance.
3. Elucidate influences of weather variables on ball roll distance.
4. Survey various golf course tournament preparation programs used by golf course superintendents.

Start Date: 2017
Project Duration: One year
Total Funding: $5,000

Summary Text:
Rationale
Golf course putting greens are arguably the most intensely managed playing surface on golf courses. Ball roll distance, often referred to as "green speed", and trueness of the ball's roll across a green have a major impact on the playability of putting surfaces. Green speed is the most requested information on golf course conditions by players (Nikolai, 2005). Golf course managers, therefore, strive for consistently fast and smooth playing surfaces on putting greens while maintaining acceptable turfgrass quality.

Research involving green speed has mostly focused on quantifying the impact of individual cultural practices on ball roll distance. The goal of most research on ball roll distance has been to identify cultural practices that maintain a reasonable ball roll distance during day to day operations while lowering the stress caused to turfgrass through standard cultural practices such as mowing frequency and height of cut (Gilhuly, 2006; Soller, 2013). Beyond daily play, turfgrass managers are routinely charged with preparing for tournaments which often require the production of abnormally fast green speeds. In preparing putting greens for a tournament, managers are faced with integrating several cultural practices into a program to develop the best possible playing surface for a short period of time.

While faster green speed is a primary goal for golf course tournaments, turfgrass managers must balance the use of cultural practices to achieve desired putting green speeds while not overly compromising the health of the turfgrass (Zontek, 1997). Some components of a greens tournament preparation program are not limited to but may include: lowering the height of cut, increasing the frequency of mowing events, lightweight rolling, topdressing, grooming or vertical mowing, as well as adjustments in fertility and irrigation regimens (Nikolai, 2005; Zontek, 1997). Integrating all or some of these potential cultural practices into a program that produces the required greens conditions for a short time period is the goal of a tournament preparation program.

While there have been many studies elucidating the influence of individual or even limited combinations of factors on ball roll distances, there has been little research into the synergistic effects of a programmatic approach to increasing ball roll distances and their influence on plant health. The influence of environmental conditions also must be taken into consideration. Ultimately, the ability to predict ball roll distance based on multiple inputs under various conditions would be a valuable tool for golf course superintendents.

Methods

Mowing height and frequency

Field studies are being conducted on various research putting greens at the Valentine Turfgrass Research Facility located in University Park, PA. All studies are being conducted on three sand-based putting greens consisting of either: 1) 100% annual bluegrass (Poa annua L.). 2) 98% “Penn A-4” creeping bentgrass (Agrostis stolonifera L.) with 2% annual bluegrass and 3) 90% “Bridgeport II” fine fescue (Festuca rubra L.) and 10% “Alister” colonial bentgrass (Agrostris capillaris L.). All studies will be repeated in subsequent years.

All studies are designed as a 3 x 3 factorial arranged in a randomized complete block design with 3 replications. Main effects will consist of mowing height and mowing frequency. For experiments conducted on annual bluegrass and creeping bentgrass, mowing heights will be set to a bench height of 2.1 mm, 2.5 mm, and 2.9 mm. For the fine fescue putting green, heights will be 4.0 mm, 4.5 mm, and 5.0 mm. For the main effect of mowing frequency, individual plots will be mowed either once, twice, or four times per day. Single cut (SC) treatments involved one single pass through each plot with the mower in the morning. Double cut (DC) treatments will consist of two passes of the mower down and back along the same line in the morning. Double-double cut (DD) treatments will consist of a DC in the morning and again in the afternoon.

Playability data will be collected two times per day for the 14-day duration of each experiment. Data collected included: ball roll distance (BRD) using a USGA Stimpmeter, surface firmness (TF) using a Fieldscout TruFirm True Firmness Meter, ball roll physics (BRP) characteristics using the Sphero Turf Research App and putting green trueness (PGT) using a Greenstester.

Plant health data will be collected daily for the 14-day duration of each experiment. Data collected includes: normalized difference vegetative index (NDVI) using a Fieldscout TCM 500 meter, chlorophyll content (CM) using a Fieldscout CM 1000 Meter, and surface temperature/stress using a FLIR-ONE Thermal imaging device. Visual ratings will also be used to assess turfgrass quality and color.

Environmental data will also be collected for the duration of each experiment. Data collected includes: soil moisture (SM) at 3.8 cm and 7.6 cm using a Fieldscout TDR 300 meter, air temperature (AT) and relative humidity (RH) using a Kestrel 3000 Weather Meter. Additional weather data will be obtained from an on-site weather station at the Valentine Turfgrass Research Facility.

Thermal images will be analyzed using Flir Tools software (FLIR Systems, North Billerica, MA) to determine and average infrared signature for each plot. All data will be subjected to analysis of variance using PROC MIXED and means were separated at $P \leq 0.05$ according to Fisher’s Protected least significant difference test. Preplanned contrasts will be determined for select comparisons and assessed using SAS MIXED procedure (SAS, Inc., Cary, NC).

Mowing patterns, fertility and plant growth regulators

Based on preliminary results from a previous study which indicated that mowing patterns influenced ball roll distances, a field study will be conducted on a research putting green at the Valentine Turfgrass Research Facility located in University Park, PA. The experiment will be initiated in 2017 and repeated in

2018. The site consists of a stand of 98% “Penn A-4” creeping bentgrass with 2% annual bluegrass. The study is designed as a 3 x 4 factorial arranged in a randomized complete block design with 3 replications. Main effects will consist of mowing patterns and various cultural practices.

For the main effect of mowing pattern, individual plots will be mowed by: 1) a single cut (SC) treatment involving one single pass through each plot with the mower in the morning; 2) a double cut (DC) treatment involving two passes of the mower down and back along the same line in the morning; or 3) a cross cut (CC) involving two mower passes in perpendicular directions two each other. All plots will be mowed to a height of 2.5 mm. For the main effect of cultural practices, plots will receive: 1) 6 kg N/ha; 2) 0.4 L Trinexapac-ethyl/ha; 3) N + Trinexapac-ethyl; and 4) and non-treated control. Nitrogen and plant growth regulator treatments will be applied every two weeks for the duration of the 6 week study.

Playability, plant health, turfgrass quality and environmental conditions mentioned previously will be periodically collected throughout the study. All data will be subjected to analysis of variance using PROC MIXED and means were separated at $P \leq 0.05$ according to Fisher’s Protected least significant difference test. Preplanned contrasts will be determined for select comparisons and assessed using SAS MIXED procedure (SAS, Inc., Cary, NC).

Vertical mowing and brushing
A field study will be conducted on a research putting green at the Valentine Turfgrass Research Facility located in University Park, PA. The experiment will be conducted on a stand of 98% ‘Penn A-4’ creeping bentgrass with 2% annual bluegrass and a stand of 100% annual bluegrass. The study will be arranged in a randomized complete block design with 4 replications. Treatments will include various cultural practices around vertical mowing and brushing. The influence of vertical mowing depths and frequencies as well as various brush types and stiffness on turfgrass quality and ball roll distances will be assessed. The exact number of treatments will depend upon equipment and space limitations.

Playability, plant health, turfgrass quality and environmental conditions mentioned previously will be periodically collected throughout the study. All data will be subjected to analysis of variance using PROC MIXED and means were separated at $P \leq 0.05$ according to Fisher’s Protected least significant difference test.

Preplanned contrasts will be determined for select comparisons and assessed using SAS MIXED procedure (SAS, Inc., Cary, NC).

Green speed as influenced by weather parameters
Data collected from the previously mentioned field studies as well as data collected specifically for this experiment will be used to elucidate the influence of weather variables on daily green speed. In addition to the aforementioned studies, an observational study will be conducted on a research putting green at the Valentine Turfgrass Research Facility located in University Park, PA. The experiment will be conducted on a stand of 98% ‘Penn A-4’ creeping bentgrass with 2% annual bluegrass. Height of cut will be set to a bench height of 2.5 mm.

Ball roll distance will be collected three times per day using a USGA Stimpmeter. Data will be collected throughout the growing season. Environmental conditions will be continually recorded for the duration of the experiment. Data collected included: soil moisture (SM) utilizing a Toro Turf Guard soil monitoring unit. Air temperature, RH, wind speed (WS), wind direction (WD, and leaf wetness (LW) using Stevens on site weather station. All data will be subjected to a multivariate and correlation analyses in an attempt to develop a mathematical model designed to predict maximum green speeds based on select cultural practices and environmental conditions.

Tournament preparation survey

A survey of golf course superintendents will be developed with the purpose of compiling information on common cultural practices believed to enhance golf course putting green playability. The survey will be made available to all turfgrass managers, but also directed towards golf courses hosting professional golf events.

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