2018 Research Summaries

TURFGRASS AND ENVIRONMENTAL RESEARCH PROGRAM

Green Section Research, 1910 Pacific Avenue, Suite 8030, Dallas, TX 75201 | cthompson@usga.org

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2018 Turfgrass and Environmental Research Program Summaries

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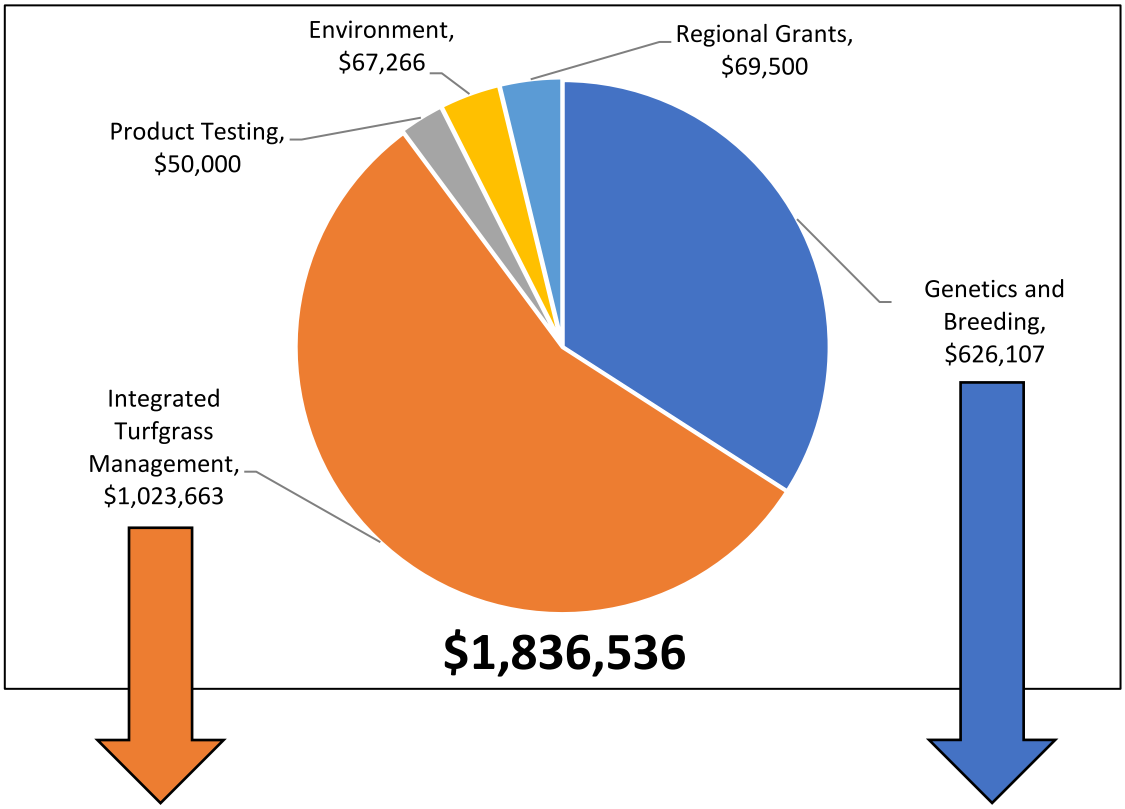

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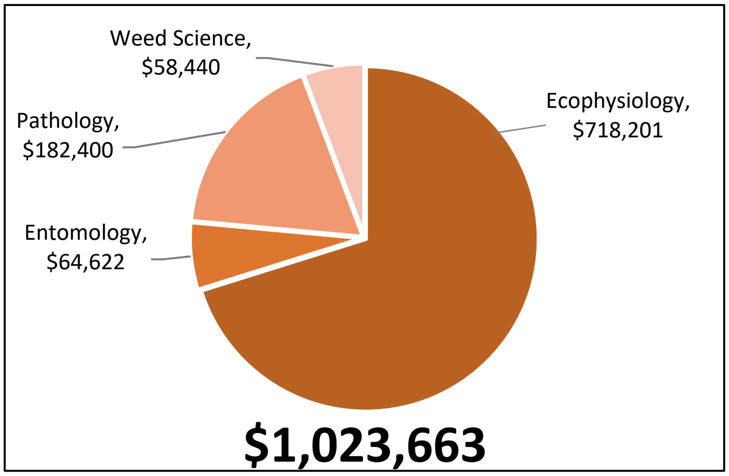
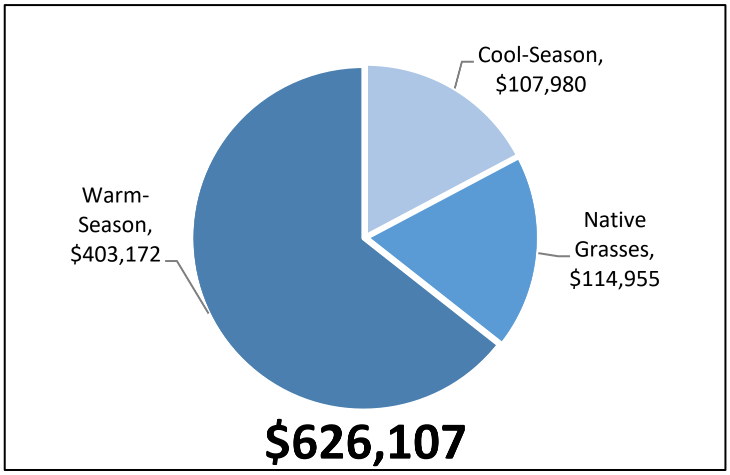


Genetics and Breeding



1. 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 are directed toward the development of turf cultivars that conserve natural resources by requiring less water, and fewer pesticides and fertilizers. Among the characteristics most desirable in the new turfgrasses are:

- 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.

USGA ID#: 1983-01-001

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

Summary Points:

- Continued progress was made in obtaining new sources of turfgrass germplasm. These sources are being used to enhance the Rutgers breeding program.
- Modified population backcrossing and continued cycles of phenotypic and genotypic selection combined with increasing sources of genetic diversity in turfgrass germplasm. This has resulted in the continued development and release of top performing varieties in the NTEP.
- Three perennial ryegrasses, 5 new tall fescues, 5 fine fescues, and 2 creeping bentgrasses in 2018.
- Published or have in press over 7 referred journal articles in 2018.
- 9 Plant variety certificates issued and 12 PVP's applied for in 2018.

Summary Text:

As of October 30, 2017 over 1659 promising turfgrasses and associated endophytes were collected in Slovenia, Poland, Croatia, Italy, Hungary, Ireland, No. Ireland, Mallorca, Menorca and Romania. These were planted in the Netherlands and evaluated in the spring of 2018. Seed was produced in the Netherlands in the summer of 2018 for the 515 that were selected and will be evaluated in New Jersey starting in fall 2018. In the spring and summer of 2018, 1400 collections were made in Albania, Poland, Slovania, Bulgaria, Croatia, Hungary, Italy and Romania. Over 9,675 new turf evaluation plots, 90,100 spaced-plant nurseries plants and 14,000 mowed single-clone selections were established in 2018.

Over 200,000 seedlings from intra- and inter-specific crosses of Kentucky bluegrass were screened for promising hybrids under winter greenhouse conditions and the superior plants were put into spaced-plant nurseries in the spring. Over 20,266 tall fescues, 14,000 Chewings fescues, 6,000 hard fescues, 26,952 perennial ryegrasses and 11,440 bentgrasses were also screened during the winter in greenhouses and superior plants were put in spaced-plant nurseries. Over 20 new inter- and intra-specific Kentucky bluegrasses were harvested in 2018.

The following crossing blocks were moved in the spring of 20 I8: 5 hard fescues (148 plants), 7 Chewings fescues (166 plants), 5 Strong Creeping red fescue (131plants), 19 perennial ryegrasses (846 plants), 10 tall fescues (372 plants), 9 creeping bentgrasses (180 plants) ,4 velvet bentgrasses (158 plants) and 6 colonial bentgrasses (203 plants).

The breeding program continues to make progress breeding for disease resistance and improved turf performance. New promising varieties named and released in 2018 were Shield, Signet, and Ruckus perennial ryegrasses, new tall fescues were Amity, Paramount, 4th Millennium., Rambler 2 SRP, Traverse 2SRP. There were also three Chewings fescue named Woodall, Leeward and Compas I, one hard fescue named Minimus, and one creeping red fescue named Cardinal II. There was two new creeping bentgrasses named 777 and Tour Pro. The new Kentucky bluegrasses were Martha, Bolt, Heidi, SR 2150 and Bluebank.

Figure 1. Gray leaf spot on seedling tall fescue in Freehold, NJ in fall 2018.

Figure 2. Gray leaf spot on hard fescue in Freehold, NJ.

USGA ID#: 2007-05-346

Title: Collection, Enhancement, and Preservation of Turfgrass Germplasm

Project Leaders: Kevin Morris, President
Affiliation: National Turfgrass Federation (NTF)

Start Date: 2017
Project Duration: 3 years
Total Funding: $30,000

Summary Points:

- Priority research needs identified at a Fall 2017 workshop include social and environmental research to document the inherent value of turfgrass, turf cultivars that are more persistent, using less water, fertilizer, pesticides and other inputs, quantification of the acreage, various uses, and economic value of the turfgrass industry in the U.S., identification, evaluation and development of native and/or non-traditional turf species, and investigation of the turfgrass phytobiome.
- As a result of the workshop, USDA-ARS is committing new funding for genome sequencing of turfgrass species.
- Language that recognizes the importance of the National Turfgrass Research Initiative and turfgrass research priorities is included in the final draft of the 2018 Farm Bill.
- EPA Water Sense, an important federal program that certifies low-water use products, was Congressionally authorized in 2018, with support from the National Turfgrass Federation. Water Sense is a potential partner with the turfgrass industry in certification of water-saving turfgrasses.

Summary Text:

Turfgrass is an estimated $60 billion, 60 million-acre industry in the U.S., making turfgrass the third largest agricultural crop in the U.S. by acreage. With tens of millions of home lawns, millions of miles of turf on roadsides, a million or more athletic fields, thousands of parks, golf courses, institutional grounds and other sites, turfgrass is an ubiquitous crop in the U.S., but often taken for granted as to its importance and value. To that end, federal government turfgrass research funding falls far below research funding for other comparably sized agricultural industries, averaging just over $1,000,000 annually. With the industry facing serious challenges such as water shortages, concerns about pesticide use, fertilizer restrictions and economic issues, research is needed to help the turfgrass industry overcome these challenges and thrive over the next 25-30 years.

To better address industry challenges, in September 2017 about 40 attendees participated in a professionally facilitated workshop, hosted by the National Turfgrass Federation and the U.S. National Arboretum, to discuss turfgrass research needs, priorities and funding strategies. Attendees included representatives from golf, parks, seed and sod, lawn and landscape, irrigation, equipment and the plant protection/enhancement industries; as well as university research, non-profits and the federal government.

The historical context and development of the 2004 National Turfgrass Research Initiative (NTRI) was presented, as well as presentations outlining federal government, non-profit organization and commercial turf industry research accomplishments. Two days of discussions within small groups, and one large group resulted in twenty-eight research needs that were consolidated considering overlap of ideas, resulting in eighteen broader research topics.

Voting by all participants on their priorities resulted in the following research needs list:

Topics – Ideas	Tally - # of votes
• Social research to identify gaps between green industry benefits and societal values. • What will connect millennials to turf? What is the driver?	24
• Evaluate cultivars or alternative species for longer periods. • A need for more real-world research to capture if/how people interact with improved cultivars. • Persistent turf – development of these types.	22
• Characterize turfgrass phytobiomes.	20
• Quantify amount of turfgrass in U.S. using big data. • Quantify turfgrass usage with big data.	16
• Research comparing turfgrass to alternative landscape species. • Evaluate alternative turf species. • Identify alternate turf species. • Related: What is out there for different kinds of environments?	14
• How does turfgrass breeding lead to efficient operations. • Develop turf germplasm with improved tolerance to biotic stress. • Develop turf germplasm tolerance to abiotic stress.	14
• Genome sequencing, RNA sequencing, POP development and Proteome. • Sequence of genome of turfgrass species. • Related: What is out there for different kinds of environments?	13
• Interactions of BMPs for each cultivar. • BMPs for fertilization, mowing, water, herbicides, etc.	12
• Quantify cooling benefits, carbon sequestration, water savings, etc.	10
• Modify soils for urban and suburban use (soil health, macro organisms).	10

Results to Date

Currently, USDA is funding genome sequencing of many crop plants, farm animals, poultry and even pests such as diseases and ticks. As a result of this workshop and the interest shown by participants in increasing research funding, USDA-ARS is committing new resources to genome sequencing of turfgrasses at several locations. Much like the potential of genome sequencing to develop new treatment strategies for human health issues, this funding will contribute foundational information to aid the development of better heat, cold, drought, disease and insect resistant grasses.

The National Turfgrass Federation (NTF) worked to develop and include in the 2018 U.S. Farm Bill language that outlines not only the importance of turfgrass research (through the National Turfgrass Research Initiative), but also broad national turfgrass research needs. To date, this language is included in both Senate and House Farm Bill versions, and we are waiting for development and passage of a consensus bill by Congress. Farm Bill language is critical to the justification of turf research needs and subsequent federal and non-profit turfgrass research funding.

EPA Water Sense is a volunteer program that certifies water-saving products, akin to the energy-saving program Energy Star. To give increased credibility, visibility and branding to new drought tolerant grasses, we have an interest in developing Water Sense certified turfgrasses. However, Water Sense has languished in funding due to its lack of federal authorization. NTF helped Water Sense by supporting Congressional authorization of Water Sense within the new law, *America's Water Infrastructure Act of 2018*. Turfgrass was the only crop industry that supported Water Sense authorization and could emerge as a leader in the development and marketing of drought tolerant plants to the general public.

Future Plans

A priority need identified at the workshop is the gathering and publishing data on the U.S. turfgrass industry: acreage, scope, usage and economic value. NTF has consulted with and selected a firm to conduct a national turfgrass survey. The next step is to obtain a federal grant to fund the survey. Turfgrass acreage, use and economic value is another essential piece is demonstrating the need to turfgrass research needs nationally, and in our states and communities.

A lot has changed within, and outside of the turfgrass industry since NTRI was first developed and published in 2004. Research needs identified at the workshop will be incorporated in an updated version of NTRI that should be available in 2019. This 'new' NTRI will be the ultimate foundation and guiding document for future turfgrass research direction.

Figure 1. Workshop participants selecting turfgrass research priorities in September 2017.

Figure 2. A USDA scientist sequencing the cacao genome (credit: USDA-ARS).

USGA ID#: 2016-25-575

Title: Genetic Engineering of Turfgrass for Enhanced Multi-Stress Resistance

Project leader: Hong Luo
Affiliation: Department of Genetics and Biochemistry, Clemson University

Objectives:

The main objective of this project is to genetically engineer enhanced tolerance to multiple adverse environmental conditions, such as drought, salt, heat and nutrient deficiency in turfgrass using agricultural biotechnology approaches. 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 a vacuolar H^+-pyrophosphatase, *AVP1* from Arabidopsis, a SUMOylation E3 ligase, *OsSIZ1* from rice, and a flavodoxin, *Fld* from cyanobacterium. Specifically,

1. We will prepare a chimeric gene construct, p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/ p35S-*bar* containing CaMV35S promoter-driven *AVP1*, corn ubiquitin promoter-driven *OsSIZ1* and *Fld* genes together with a CaMV35S promoter-driven 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* construct and overexpressing *AVP1*, *OsSIZ1* and *Fld* genes.
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 abiotic stress 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

Summary Points:

- Three representative transgenic lines harboring the chimeric gene construct, p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/p35S-*bar*, and expressing high level of the three stress-related genes, *AVP1*, *OsSIZ1* and *Fld* were grown in greenhouse and asexually multiplied for performance evaluation.
- Conducted drought and heat stress tolerance test with the three transgenic lines in comparison with wild type control plants and transgenic plants outperformed wild type controls, exhibiting enhanced tolerance to the stress conditions tested (examples shown in **Fig. 1**).
- Evaluation of plant response to additional abiotic stresses including salt and oxidative stress as well as P and N starvation are currently being conducted. In addition, we are also preparing to simultaneously test plant response to a combination of several different stress conditions, including salt, drought, heat, oxidative stress, P and N starvation. This would reveal how transgenic plants tolerate various environmental adversities, potentially providing new turf cultivars or foundational breeding materials for products of wide environmental adaptation.

In the face of a global scarcity of water resources, the increased salinization of soil and water as well as elevating environmental pollution caused by fertilization, enhancing crop plant tolerance to various abiotic stresses 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 summaries presenting our research data obtained in 2016 and 2017, we reported the construction of a chimeric gene construct, p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/p35S-*bar* that contains expression cassettes for three genes, *AVP1*, *OsSIZ1* and *Fld* together with a selectable marker gene, *bar* for herbicide resistance, and its introduction into creeping bentgrass plants. Transgenic analysis confirmed foreign gene insertion and expression in the twenty primary T_0 transgenic lines using PCR and Northern hybridization. Three representative transgenic lines with high level of foreign expression were selected and asexually propagated for further analysis. We have been conducting greenhouse experiments evaluating transgenic plants in comparison with wild type controls for their performance under various abiotic stresses (examples shown in **Fig. 1**).

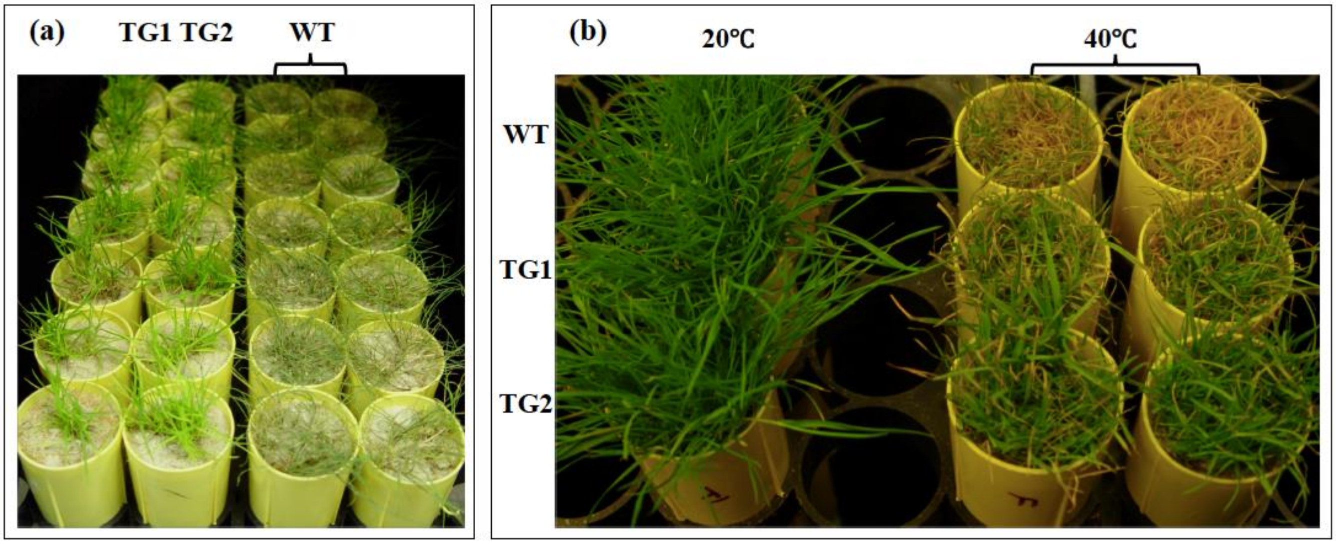


Figure 1. Transgenic (TG) creeping bentgrass plants harboring the chimeric gene construct p35S-*AVP1*/Ubi-*OsSIZ1*/Ubi-*FNR:Fld*/p35S-*bar* exhibited enhanced tolerance to multiple environmental stresses. Wild-type (WT) control plants and two TG lines (TG1 and TG2) were fully developed in cone-tainer for 8 weeks, under normal conditions in growth room.
(a). To evaluate plant performance under drought stress, both WT and TG plants were maintained in the growth room and subjected to a 7-day water withholding and photographed for documenting plant response to drought stress. As exemplified in the picture, the TG lines all survived drought treatment and continued their growth, whereas the WT controls became wilted and failed to recover upon resumed watering.
(b). To evaluate plant performance under heat stress, both WT and TG plants were transferred to the growth chamber and maintained for one week under the same conditions as in growth room prior to heat treatment. Heat stress was applied by heating the plants to 40 °C in the light and 35 °C in the dark with the relative humidity of 60%–80% for 10 days. Plants were moved back to growth room for 2 weeks of recovery and photographed for documentation. As exemplified in the picture, the TG lines exhibited much less heat damage than wild type control plants, which became largely wilted and could not recover.

USGA ID#: 2017-12-622

Title: Pre-Breeding for Bentgrass Germplasm Improvement

Project leader 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: 3 years
Total Funding: $51,040

Summary Points:
- Hybrid progeny derived from an open pollinated creeping bentgrass and colonial bentgrass crossing block were developed.
- Species specific genetic markers coupled with the FTA PlantSaver Card DNA extraction technique supported rapid hybrid detection.
- A recurrent breeding cycle was established to develop and evaluate new bentgrass hybrids in Beltsville, MD and Lincoln, NE.

Summary Text:
The bentgrasses (*Agrostis* spp.) are a complex genus within the BOP clade of Poaceae which represents the Bambusoideae, Oryzoideae, and Pooideae subfamilies. The bentgrasses use the C3 photosynthetic pathway and are adapted to cool, temperate climates. Creeping bentgrass (*A. stolonifera*) is an important species to the golf course industry because of its ability to thrive and form an exceptional turf when subjected to modern golf course putting green management. Colonial bentgrass (*A. capillaris*) and velvet bentgrass (*A. canina*) are also used on golf courses. In the central Great Plains, colonial bentgrass is most often found mixed with fine leaved fescues in fairways. Velvet bentgrass has very fine leaf texture and is found on many old golf course putting greens in the northeastern United States. While I have not observed highland bentgrass (*A. castellana*) or redtop bentgrass (*A. gigantea*) outside of research, they are also known for their success as a turf or forage.

The bentgrasses comprise a complex genus, posing several obstacles for research and breeding for improved cultivars. The bentgrasses represent a ploidy series and the range from diploids to hexaploids are common, although mixed ploidy and higher ploidy levels have been reported. Ploidy refers to the number of chromosome sets in the species and higher ploidy levels have more complex genomes, often complicating mendelian genetics and making it difficult to fix desirable traits through plant breeding. In nature, more complex genomes contribute to genetic diversity and species survival by increasing occurrence of rare alleles associated with stress tolerance, adaptation, or persistence. Ploidy differences in many species also attribute to species boundaries since balanced chromosome pairing cannot occur between mixed ploidy levels. The bentgrasses are highly outcrossing and promiscuous, blurring species boundaries.

The bentgrasses comprise more than 150 species and many of the species serve as reservoirs for genes contributing to stress tolerance and turf function. A common breeding strategy used to improve many cultivated species is to hybridize wild unimproved material with elite germplasm to move new traits into elite material and reduce the occurrence of genetic bottlenecks. Genetic bottlenecks occur when the genetic base for plants is narrowed resulting from recurrent selection without a conscious effort to maintain genetic diversity. A major hurdle for implementing a plant breeding strategy that utilizes wild material for bentgrass improvement is the concerted introgression of other traits that negatively impact turf function. A backcross breeding strategy is often used to recurrently backcross to elite lines and remove undesirable traits while testing for and maintaining the target trait of interest. Bentgrass breeders have made significant improvements in stress tolerance, visual and functional quality, and shoot densities through plant breeding and the introduction of wild material would set back breeding efforts for several generations.

Our research project is designed to evaluate bentgrass germplasm and develop new breeding lines of sufficient quality and that harbor desirable traits to make the use of wild germplasm more practical for bentgrass breeders. In Lincoln, NE, a collection of 69 bentgrasses representing nine different species was obtained from the National Plant Germplasm system. The plants were evaluated in the field and subjected to low-input management and different mowing heights. The lines that persisted were allowed to intermate and seed was harvested in 2017. The plants will be established in the greenhouse and planted in the field in 2019.

In 2018, we focused our efforts on the development of hybrids formed between creeping bentgrass and colonial bentgrass at the USDA-ARS in Beltsville, MD. A crossing block was established to creeping bentgrass and colonial bentgrass in a pot-in-pot system and the plants were allowed to intermate (Figure 1). Seed was harvested and progeny plants were established in the greenhouse. Leaf tissue was collected from each putative hybrid and DNA was extracted using the previously described FTA PlantSaver Card technique. Finally the putative hybrids were tested using colonial bentgrass and creeping bentgrass specific DNA markers. Of 2,200 progeny plants tested, 524 were confirmed hybrids. Based on the maternal plants, interspecific hybridization ranged from 1% to 85%. There was significant phenotypic variability observed in field grown plants including differences in genetic color, canopy density, leaf texture, and lateral spread (Figure 2). A materials transfer agreement is being finalized to transfer the 524 hybrid progeny to Lincoln, NE to test field performance in the central Midwest region of the United States (Figure 3). Plants will be established in the field in May, 2019 and evaluated for early establishment characteristics in 2019 and field performance in 2020. Top performing individuals will be transferred back to Beltsville, MD to support germplasm improvement breeding efforts and starting a cyclical process to develop and evaluate material in Beltsville, MD and Lincoln, NE. Results from these breeding efforts should produce broadly adapted germplasm valuable to bentgrass breeders and the golf course industry.

Figure 1. Bentgrass growing in a pot-in-pot system in Beltsville, MD.

Figure 2. Genetic color, canopy density, leaf texture, and lateral spread varied for field grown bentgrass plants in Beltsville, MD.

Figure 3. A population of 524 creeping bentgrass and colonial bentgrass interspecific hybrids.

USGA ID#: 2018-11-661

Title: Evaluation of activity of a fungal endophyte antifungal protein against dollar spot infected creeping bentgrass

Project Leaders: Faith C. Belanger and Bruce Clarke
Affiliation: Rutgers University

Objectives: The goal of this project is to produce the *Epichloë festucae* antifungal protein in bacteria and test its activity in dollar spot infected creeping bentgrass and fine fescue. If the purified protein is effective, this could represent an additional method to control dollar spot and reduce fungicide inputs.

Start Date: 2018
Project Duration: 3 years
Total Funding: $120,000

Summary Points:

- 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.
- We have expressed and purified modified forms of the antifungal protein in the bacterium *E. coli*
- The modified forms of the antifungal protein had activity against the model test fungus *Neurospora crassa*.
- We successfully carried out a gene knockout of the *E. festucae* antifungal protein gene using the CRISPR-Cas9 gene editing technology.
- Isolates with the knockout will be reintroduced into strong creeping red fescue to evaluate susceptibility to dollar spot disease.

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 sequences are 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.

The antifungal protein was previously expressed in the yeast *Pichia pastoris* and the recombinant protein has been shown to inhibit growth of the important fungal pathogen of strong creeping red fescue, *Clarireedia jacksonii* (formerly *Sclerotinia homoeocarpa*), the causal agent of dollar spot disease (Salgado-Salazar et al., 2018; Tian et al., 2017). Treatment of the dollar spot fungus with the antifungal protein resulted in uptake of the viability stains SYTOX Green and Evans blue indicating that observed growth inhibition of the pathogen was due to damage of plasma membrane (Tian et al., 2017). These results support the hypothesis that the *E. festucae* antifungal protein is a component of the disease resistance seen in strong creeping red fescue.

The yeast system was valuable for the initial demonstration that the purified *E. festucae* antifungal protein was active, but it would be cumbersome to scale up for large-scale production of the protein. Unlike similar proteins from *Penicillium* and *Aspergillus*, where their antifungal proteins either expressed in *P. pastoris* or found in the culture filtrate could be readily purified by cation exchange chromatography, the *E. festucae* antifungal protein did not bind to either cation or anion exchange columns. Also, it was not found in the *E. festucae* culture filtrate, although it was highly expressed in the infected host grass (Ambrose and Belanger, 2012). Therefore a simpler method of producing large amounts of the protein was sought.

Expression of proteins in bacteria is a commonly used method to purify and characterize a protein of interest because it is relatively easy and can often yield large amounts of the desired protein. However, expression of antifungal proteins from other fungal species has not previously been successful in bacteria. Recently, we have succeeded in expressing modified forms of the *E. festucae* antifungal protein in *Escherichia coli* and confirmed the activity of the recombinant proteins. The proteins were modified to take into account some of the previous problems with expression of antifungal proteins in bacteria. Figure 1 shows the purification of a representative modified form of the *E. festucae* antifungal protein. The antifungal activity of the modified proteins was quantitatively assessed against *Neurospora crassa* in a microtiter plate assay. *N. crassa* has been established as a sensitive model system for testing the antifungal activity of the antifungal protein from *Penicillium chrysogenum*. All of the modified forms of the *E. festucae* antifungal protein had activity at 10 ug mL^{-1} with one modified form having the highest inhibition at all concentrations from 10 ug mL^{-1} to 100 ug mL^{-1} (Fig. 2). At 100 ug mL^{-1}, the inhibition of *N. crassa* growth was similar with all modified forms, ranging from 74-78%.

Now that we have established a method for purification of the modified *E. festucae* antifungal protein expressed in *E. coli*, we will scale up production to test its activity on creeping bentgrass and endophyte-free strong creeping red fescue inoculated with the dollar spot fungus. If direct application of the antifungal protein is effective in protecting creeping bentgrass from dollar spot, then it could be developed as an alternative method to control this disease and reduce synthetic fungicide use.

To further study the role of the antifungal protein in the endophyte-mediated disease tolerance *in planta*, we carried out a gene knockout of the *E. festucae* antifungal protein gene. The conventional fungal gene knockout approach that relies on homologous recombination was unsuccessful, likely because this gene is flanked by repeated sequences. However, we successfully applied the new CRISPR-Cas9 technology to the non-model fungus *E. festucae*. The Cas9 endonuclease generated a double-strand break at the target site of the antifungal protein gene, and a mutation was introduced when repairing the break. To date, we have identified one mutant with a single base pair insertion at the Cas9 target site, which introduced an early stop codon, and two mutants with large insertions from the fragments of the transformation vector. Next, the knockout isolates will be reintroduced into strong creeping red fescue as a proof of concept to evaluate disease susceptibility of the host plant to dollar spot disease using an established greenhouse inoculation assay.

References

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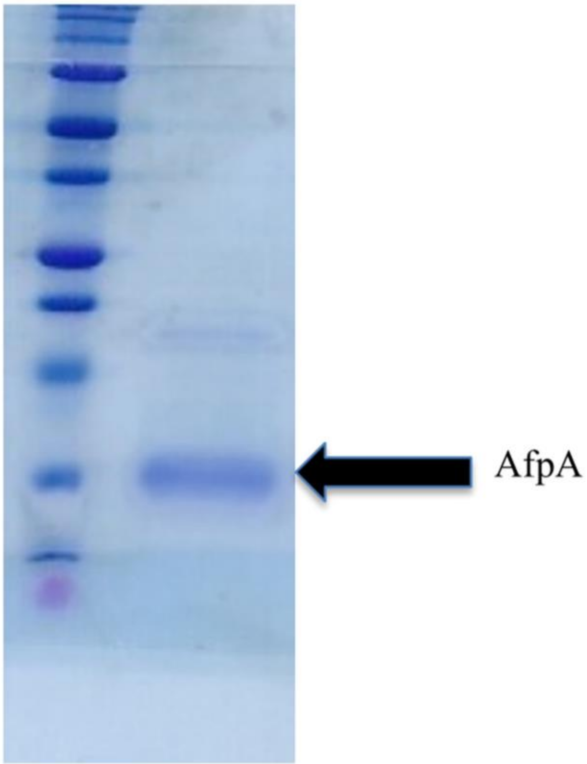

Figure 1. SDS-polyacrylamide gel of a representative purified modified form of the *E. festucae* antifungal protein (AfpA) expressed in *E. coli*. Protein size markers are in the left lane and the purified the antifungal protein is indicated by an arrow.

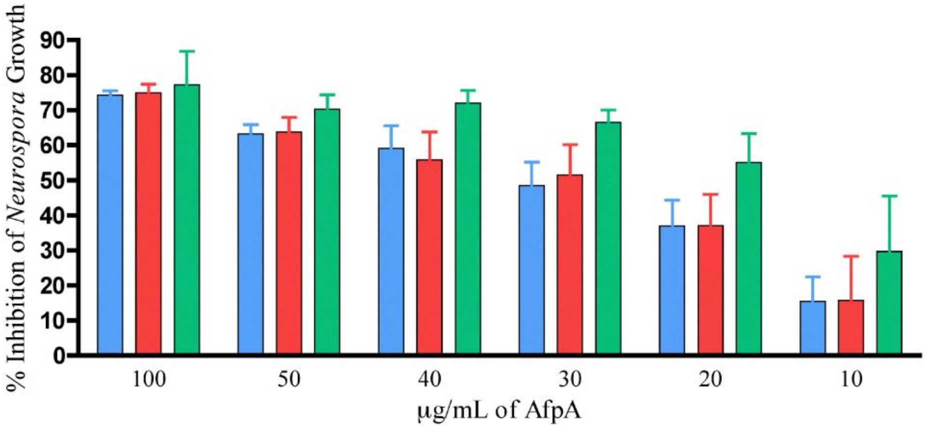

Figure 2. Percent inhibition of *Neurospora* growth by 3 modified forms of the *E. festucae* antifungal protein. Increasing concentrations of modified antifungal proteins were assayed in triplicate against *Neurospora* conidia and growth was measured after 24 hours. Each color is representative of a different antifungal protein modification. Standard deviation is represented by the error bars.

USGA ID#: 2016-01-551

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

Project Leaders: Yanqi Wu, Dennis Martin, Justin Quetone Moss, and Nathan Walker
Affiliation: 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: 6 years
Total Funding: $300,000

Summary Points:

- 'OKC 1131' was named 'Tahoma 31' by and licensed to Sod Production Services for commercial production in the USA. 'Tahoma 31' bermudagrass performed well when mowed at 3.2 mm (0.125 inches) in a greens mowing trial.
- Several OSU experimental bermudagrass genotypes performed as comparable to 'Champion,' 'TifEagle,' 'Mini Verde,' and 'Sunday' in field trials when mowed at 3.2 mm. Four superior experimental entries have been selected for the 2019 NTEP Warm-season Greens Test.
- Two seeded synthetics and four clonal experimental genotypes from the OSU breeding program have been selected for the 2019 NTEP National Bermudagrass Test.

Summary Text:

As a major warm-season turfgrass, bermudagrass [*Cynodon dactylon* and *C. dactylon* x *C. transvaalensis*] has been extensively used in the southern region and increasingly used in the transition zone in the USA. The Oklahoma State University (OSU) turfgrass breeding program 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, and 'OKC 1131' in 2017 for commercial use in the turf industry. The long-term goal of the OSU program is to develop new cultivars with high turf quality and improved resistance to abiotic and biotic stresses.

'OKC 1131' is an F1 interspecific hybrid between common bermudagrass and African bermudagrass. The new cultivar was tested in the 2013-18 National Turfgrass Evaluation Program (NTEP) National Bermudagrass Test (http://www.ntep.org/bg.htm), exhibiting exceptional winter survivability, improved spring greenup and traffic tolerance and drought resistance, and excellent turf quality. In 2018, OKC 1131 was named 'Tahoma 31' by and licensed to Sod Production Services, a company in Charles City, Virginia for commercialization in the USA.

Developing greens-type bermudagrass cultivars is an important component of the current research funded by the US Golf Association and Oklahoma Center for the advancement of Science and

Technology. Sixteen OSU experimental selections and four commercial cultivars (‘Champion,’ ‘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. In 2016, we established second field trial including 11 OSU experimental selections and four standard cultivars (‘Champion’, ‘Mini Verde’, ‘Sunday’, and ‘TifEagle’). In the summer of 2017, we established third green-type mowing trial of 17 OSU experimental selections and four commercial cultivars trial. In the summer 2018, we established a new green-type mowing trial of 19 OSU experimental selections and four commercial cultivars trial. Data collected in the trials included establishment rate, spring greenup, disease response (if present), as well as turf quality and its components under different mowing heights. In the summer of 2018, the 2016 and 2017 trials were mowed down to 3.2 mm (0.125 inches) height of cut from the beginning of June to the end of August. Several experimental selections along with four commercial ultradwarf cultivars performed very well (Figure 1). Interestingly, ‘Tahoma 31’ bermudagrass performed also very well under the low mowing height (Figure 2). The result indicated the potential of ‘Tahoma 31’ for use on putting greens on public golf courses. Four OSU experimental selections have been selected for the 2019 NTEP Warm-season Greens Test.

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. We collected data for spring greenup, turf quality, disease response, and drought resistance in 2018. Another replicated trial was established at Oklahoma Panhandle Research and Extension Center, Goodwell, OK in the summer of 2017. As part of graduate student Mr. Shuhao Yu’s thesis research, this test included 80 OSU experimental selections and 6 commercial cultivars (‘Latitude 36,’ ‘NorthBridge,’ ‘TifTuf,’ ‘Tifway,’ ‘Astro’ and ‘U3’) (Figure 3). We collected data for establishment rate, spring green up, turf quality, seedhead prolificacy, drought resistance, and fall color retention. Based on the two field-based trials and some other trials sponsored by the USDA Specialty Crop Research Initiative, two seeded entries and four clonal selections have been selected for the 2019 NTEP Bermudagrass National Test.

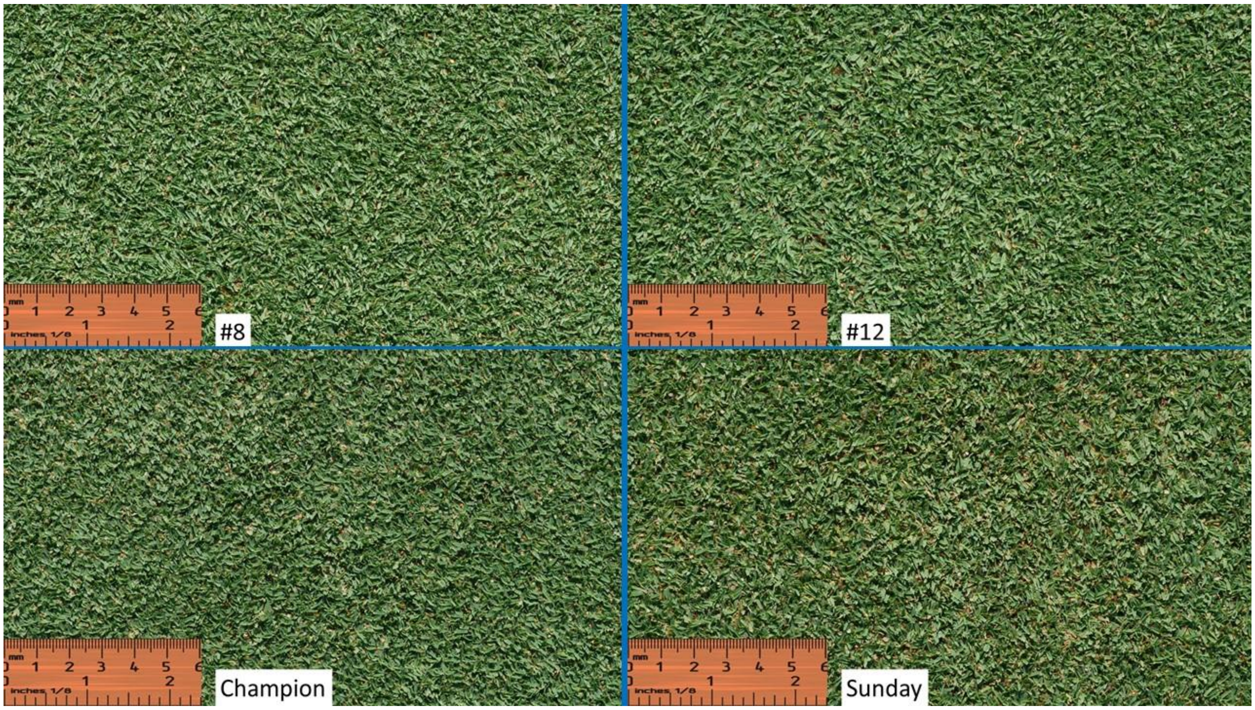

Figure 1. Turf coverage images of two OSU bermudagrass experimental selections (#8 and #12) and two ultradwarf cultivars (Champion and Sunday) at the mowing height of 3.2 mm in the summer of 2018.

Figure 2. Turf coverage of Tahoma 31 bermudagrass at the mowing height of 3.2 mm in the summer of 2018.

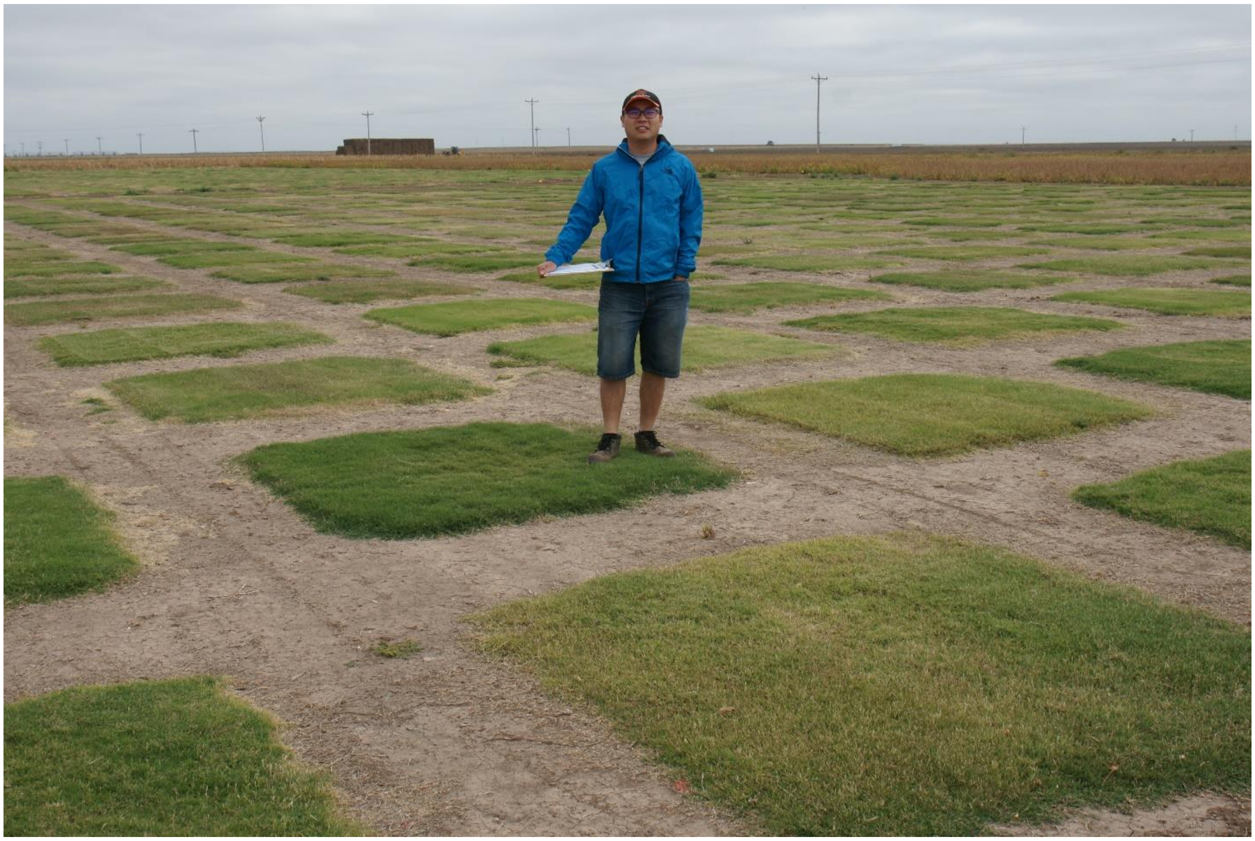

Figure 3. A replicated field trial established at Oklahoma Panhandle Research and Extension Center, Goodwell, OK as part of Mr. Shuhao Yu's thesis research. Some experimental entries showed improved drought resistance.

USGA ID#: 2016-34-604

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

Project Leaders: Joseph G. Robins and B. Shaun Bushman
Affiliation: USDA ARS Forage and Range Research, Logan, UT 84322

Objectives:

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

Summary Text:

Warm-season turfgrasses provide many benefits to managers in hot, desert regions. The benefits include growth during hot summer months under limited irrigation. On the flip side, warm-season grasses enter dormancy, or quiescence, during cool winter months. This dormancy results in turf with poor aesthetics and quality, and frequently requires managers to overseed with a cool-season species, such as perennial ryegrass, for winter growth. This allows for high winter turfgrass quality, but requires higher levels of inputs, including irrigation during the winter months. The identification of genetic variation for cool temperature green color retention in warm-season grasses would ameliorate the need for cool-season grass overseeding.

The subject of this research is the characterization of a collection of bermudagrass and zoysiagrass germplasms sources under constantly decreasing temperature in growth chambers. The University of Florida (Gainesville), Oklahoma State University (Stillwater), and Texas A&M University (Dallas) provided the germplasm resources for the study.

In spring/summer 2018, we completed the first growth chamber screening of the bermudagrass germplasm cool temperature color retention. We considered the first run a pilot study as we worked out the details of growth conditions and growth chamber settings. We cloned all germplasm sources and will begin the next round of screening in December 2018. We hope to complete three rounds of screening for both the bermudagrass and zoysiagrass. Each round takes eight weeks to step temperatures down from 20 °C to 5 °C. We hope to conclude the growth chamber evaluations in summer 2019. We will then choose a subset of germplasm from each species to transplant to a field site in the northern Mojave Desert (Washington County, UT). These plants will be monitored for green color retention under natural conditions. The objective being to validate the growth chamber study and to collect plant tissue for gene expression studies.

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.

USGA ID#: 2017-07-617

Title: Physiological Mechanisms for Developing Improved Drought Tolerance in New Bermudagrasses

Project leader: David Jespersen, Brian Schwartz
Affiliation: 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
Project Duration: 2 years
Total Funding: $9,800

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', While 'TifTuf' and 'UGB-70' were top performers in the 2018 field trial.
- Growth chamber studies have been completed and analysis which will provide a greater understanding in osmotic adjustment mechanisms is ongoing.
- 'TifTuf' had high performance in all measured traits, while some experimental lines also demonstrated their performance was less consistent across all measurements, indicating that multiple stress defense pathways are likely used by 'TifTuf' resulting in high levels of stress tolerance.

Summary Text:

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 and tolerance traits such as rooting and water usage, 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 to 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 bermudagrasses 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 (UGB-208, UGB-70, UGB-42) have been studied under both field and growth chamber studies. Field studies were performed under automatic rain-out shelters to prevent rainfall from reaching plots during the drought period when irrigation is withheld. During field trails plants were assessed using normalized difference vegetation index (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 have been performed to further characterize drought tolerance mechanisms by measuring shoot and root characteristics including anti-oxidative capacity, and the accumulation of important compatible solutes such as proline 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. Field trials performed with automated rain-out shelters in 2017 and 2018 lasted for 7 weeks each year. Significant declines due to drought were found in all lines, however the degree of drought induced damages were significantly different between lines. In the 2017 field trial, 'TifTuf' was the top performing genotype, and 'Tifway' one of the worst performing genotypes. 'TifTuf' maintained significantly higher NDVI (56.3 vs 45.5), leaf water content (77.9 vs 64.8%), and higher photosynthetic rates (19.3 vs 10.8 µmol CO_2 $m^{2\ -1}$ s^{-1}) as drought progressed compared to 'Tifway' (Fig. 1). Among experimental genotypes UGB-42 performed well in the 2017 field trial, frequently being placed in the top statistical group for multiple physiological measures. Similar trends were seen in the 2018 field trial, with 'TifTuf' again performing the best under drought conditions (Fig. 1). However, drought stress damages were less severe in the 2018 trial. Among the experimental lines, UGB-70 had the best performance in 2018, and UGB-42 did not repeat the previous years success. This highlights the importance of environmental and genotypic factors in assessing drought tolerance. Additionally the maturity of plants in the second year is likely to have had an important influence on results as plants may develop more mature rhizomes and root systems.

Growth chamber experiments also demonstrated significant differences between tested bermudagrasses, with 'TifTuf' and UGB-70 performing well in controlled environment studies. However, 'Tifway' performed relatively better in growth chamber studies, while 'Celebration' and UGB-208 accumulated greater drought related damages. These differences are likely due to the inherent limitations of pot sizes in controlled environment studies. Evapotranspiration measurements indicated that top performing lines did not use less total water avoiding drought conditions but were able to maintain water uptake further into drought conditions. Also of note UGB-70 had higher specific root lengths (m/g) compared to other genotypes which may aid in extracting additional water during drought conditions. Another physiological mechanism which was consistently associated with drought performance in both field and growth chamber experiments was osmotic adjustment, or the accumulation of compatible solutes to alter leaf osmotic potentials. The accumulation of compatible solutes for osmotic adjustment can help maintain the cells water potential, drawing water into the cell, and many of these compatible solutes can also help stabilize cellular structures.

Data collected from the trials is currently being further analyzed and the remaining samples from growth chamber experiments are being processed for anti-oxidant and compatible solute analysis. The aim is for analysis to be completed by the end of 2018, and results prepared for publication in a refereed journal. While valuable information related to the physiological responses to drought in different bermudagrass genotypes has been gathered, more research is needed to further understand drought defense mechanisms, their underlying regulation, and how to best use this information to further improve drought tolerance in turfgrasses.

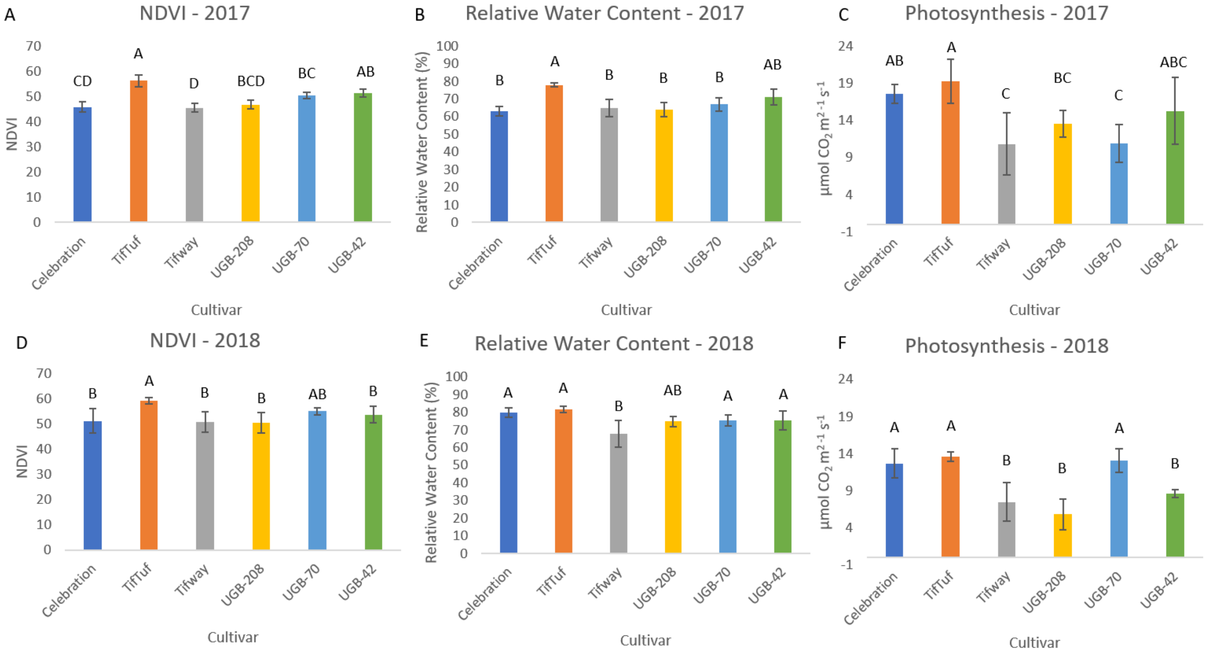

Figure 1. Comparison of genotypes at 5 weeks of drought stress for (A, D) NDVI, (B, E) leaf hydration levels determined by relative water content, and (C, F) photosynthesis rates during the 2017, and 2018 field trials. Bars represent standard error, and letters represent LSD groupings at $p<0.05$ with cultivars containing the same letter being in the same statistical group.

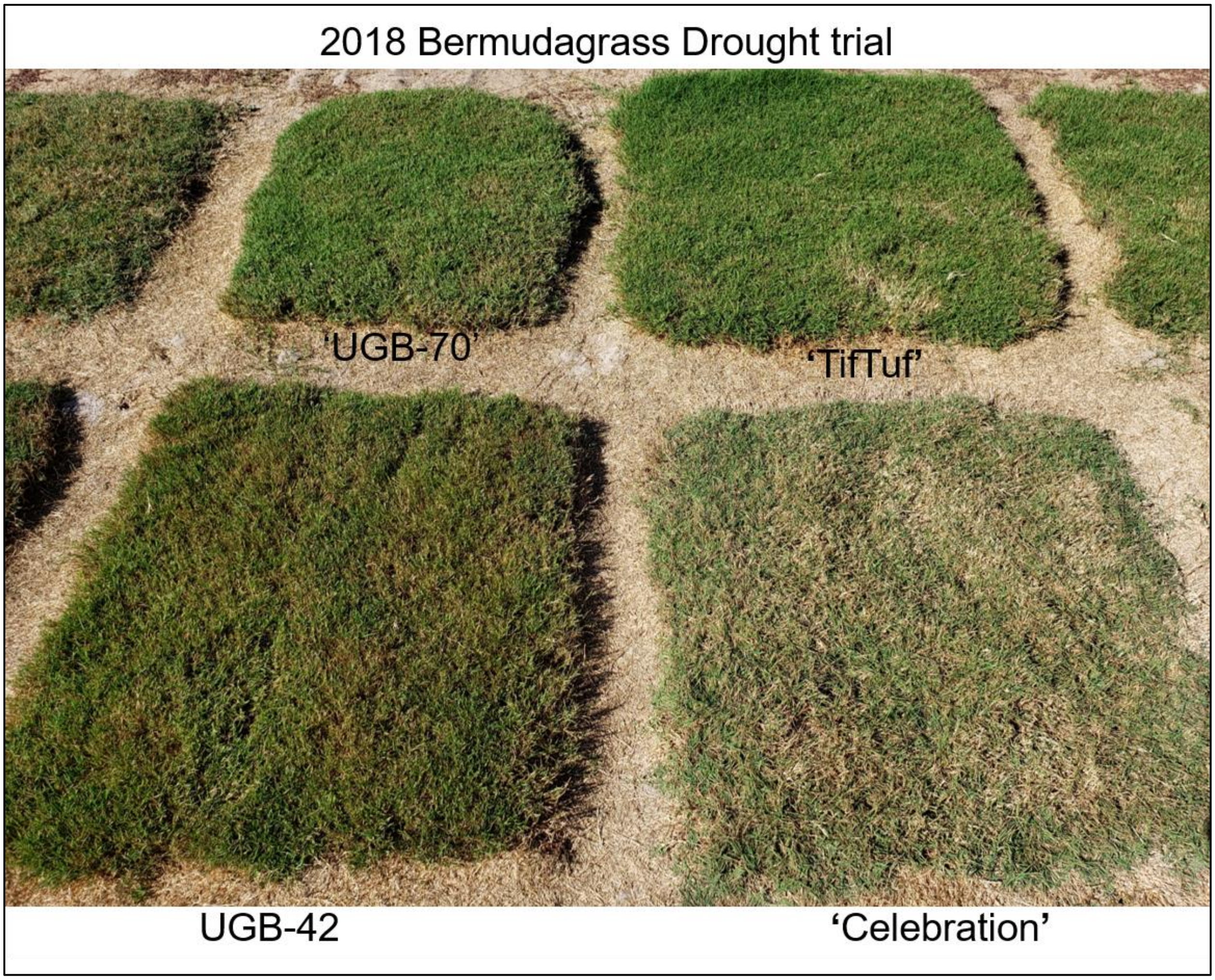

Figure 2. Comparisons of drought performance among genotypes during the 2018 drought field trial. Plots included in the image show examples of 'TifTuf', 'Celebration', UGB-42, and UGB-70 (clockwise, from the upper right corner).

USGA ID#: 2017-14-624

Project Title: Development of a shade-tolerant bermudagrass cultivar(s) suitable for fine turf use

Project 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

Summary Points:

- 75 bermudagrass genotypes have been screened for shade tolerance under greenhouse conditions.
- The top 20 genotypes and industry checks from the greenhouse trial were planted in the field in spring 2018 for validation of greenhouse screening methods.
- An additional 30 genotypes are being screened under greenhouse conditions.

Summary Text:

Background and Rationale

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.

Methods

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 diameter conetainers 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. The entire trial was repeated in Spring 2018 using only the heavy shade and non-shaded treatments as there was little value gained from the intermediate shade level. Data from greenhouse trials were subjected to a factor analysis to identify entries that performed well across all metrics.
In June 29, 2018, the top 20 performing genotypes were then planted as 2.5-inch plugs in a field study alongside industry standard cultivars (Patriot, Celebration, TifGrand, Latitude36) and five seeded populations from the OSU breeding program. Plots measured 3-ft by 3-ft and each treatment combination was replicated 3 times. The study site was split into two environments: heavily shaded versus non-shaded. The heavily shaded site was characterized by evergreen trees along the western edge and deciduous trees along the southern and eastern edge of the space. Plots were mowed weekly at 1.5-inches using a rotary mower, and fertilizer was applied monthly at 1lb N per 1000 square feet

An additional set of 30 plants from the OSU breeding program were selected and planted in conetainers using sprigs. The plants will be evaluated in the greenhouse for a rapid screening of shade tolerance similar to the one conducted previously. Top performers from this second greenhouse trial will be planted in summer 2019 within the existing shade field trials.

Early Results

Data from the greenhouse trial were reported on in 2017. The industry standard 'TifGrand' demonstrated a mean turf quality score of 4.7, while 18 of OSU's experimental cultivars exceeded this value. Similar to a 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. Results of the second experimental run were similar and thus the method was considered to be reproducible.

Surprisingly, there was poor correlation between any of the greenhouse trial measurements suggesting varying types of response to shade among entries. Alternatively, we speculate that canopy morphology (not characterized in this study) may be more important for shade tolerance than overall biomass and leaf extension rates.

Regarding the field study, data collection will begin in 2019. Preliminary visual observations suggest substantial variation in establishment rate between shaded and sun plots (Fig 1).

Future Expectations

Tree shade in the heavily shaded treatment will be supplemented with artificial shade from neutral density fabric beginning in May 2019. Ratings of percent cover, normalized difference vegetation index, and turf quality will be collected monthly using digital images, a spectral reflectance meter, and visual ratings. The top 10 to 20 entries from the ongoing greenhouse screening trials will be planted in summer 2019 on an adjacent plot area and subjected to shade using a large polywoven fabric as early as fall 2019.

Findings from the greenhouse trials will be compared to those from the field trial in order to validate the screening method and further work towards development of a new cultivar.

Figure 1. Establishment of bermudagrass genotypes under non-shaded (left) and shaded (right) conditions (9 Nov. 2018).

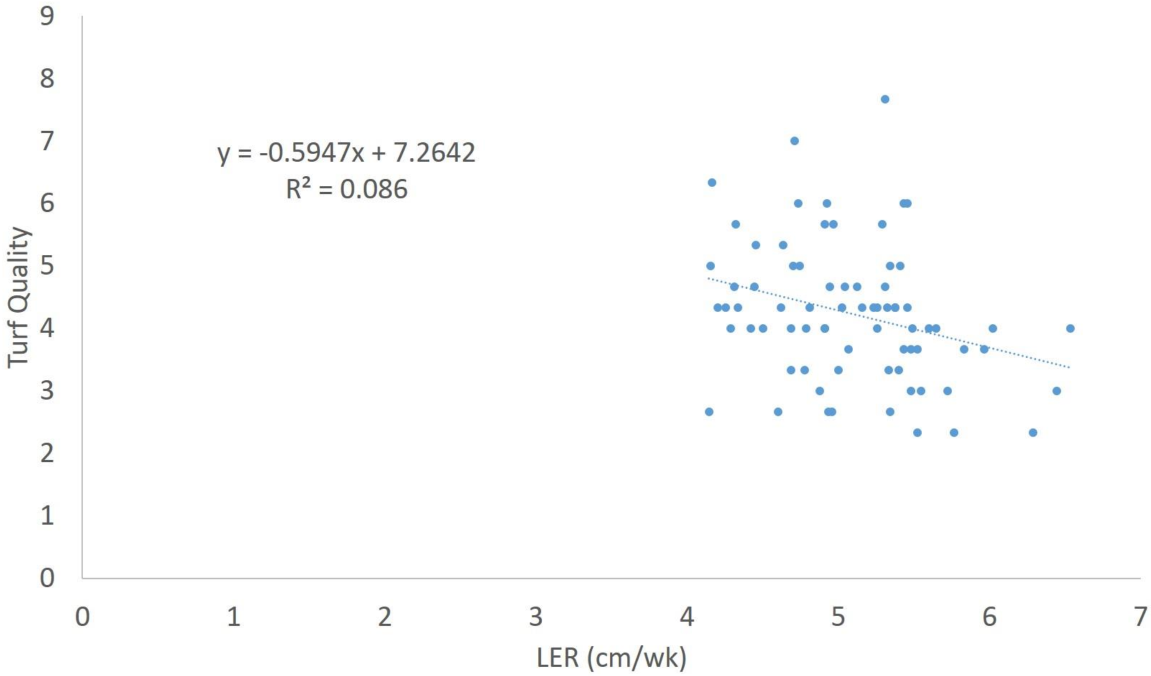

Figure 2. Poor linear relationship between leaf elongation rate (LER) and turf quality ratings for plants evaluated in greenhouse conditions under heavy shade.

USGA ID#: 2016-38-608

Title: Breeding for Resistance to Winter Dormancy in Bermudagrass and Zoysiagrass

Project Leader: Kevin Kenworthy, John Erickson, Kenneth Quesenberry
Affiliation: 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

Summary Points:

- Variation has been observed for winter performance among both zoysiagrass and bermudagrass.
- Selections have been made in both species to plant new fairway and putting green (zoysiagrass) trials in 2019.
- Crosses of elite lines exhibiting reduced dormancy characteristics will be made in 2019.
- There is overlap of several accessions that exhibit improved winter turf quality in Florida and California.

Summary Text:
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). To aid golf course superintendents and ensure the continued growth of golf in Florida, better turfgrass cultivars are needed. The majority of golf in Florida is played through the winter months when turfgrass growth, density and turf quality have declined. 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 2017 and data collection began in late 2017 to focus on identifying entries that grow and maintain quality through winter. Table 1 shows the top 10 ranked entries plus commercial cultivars for a turf quality selection index (TQSI) and winter density. The selection index was developed to emphasize turf quality during the winter months while maintaining good quality through the year. The highlighted entries in Table 1 are those that ranked in the top 10 in both TQSI and winter density. All commercial cultivars were included among the highlighted entries except ‘Latitude 36’. Eleven experimental lines were among the highlighted entries. ‘FB1628’, ‘FB1633’, ‘Celebration’, and ‘Bimini’ were ranked among the top 5 entries for both TQSI and winter density. The highlighted entries will be advanced for fairway evaluations and consideration for entry in NTEP.

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. Based on data collected in 2017 and 2018, 45 lines have been selected for expansion and further testing. The best lines will be replanted in a replicated study with larger plots.

Bermudagrass seed collected from crossing blocks in 2018 will be germinated and new populations planted in 2019. New crossing blocks will be established from the above selections. Crossing blocks will also be planted in Jay, FL under the direction of Dr. Bryan Unruh with a goal of improved flowering of African bermudagrass due to the occurrence of colder temperatures in Jay, FL compared to Gainesville, FL.

Advanced lines of zoysiagrass were planted in 2016 in replicated nurseries. These grasses have not received supplemental irrigation since February 2017. Twenty-seven zoysiagrasses are being advanced that have shown both acceptable turf quality and spring greenup in Gainesville, FL. In 2019, a new fairway trial of zoysiagrass will be planted to further evaluate these grasses for their use on golf courses.

Among our very fine zoysiagrass population we have identified five lines that show good persistence under heavy disease and insect pressure. These lines will be propagated and planted into a new putting green trial in 2019.

In 2017 and 2018 new space plant nurseries of zoysiagrass were planted. Additional controlled crosses will be made this fall among elite lines with improved winter performance.

Many of our germplasm lines of bermudagrass and zoysiagrass have been evaluated in a collaborative effort with the University of California, Riverside, CA. The primary emphasis for evaluation is winter performance to maintain year-round green color in California. Many of the lines identified in Florida overlap with good performance in California through the winter months. We have also identified lines that appear to be more specific to the conditions in southern California.

Table 1. Top ten entries plus cultivars for a turf quality selection index and winter density. Highlighted entries were ranked among the top 10 for both the selection index and winter density.

Entry	Rank	Turf Quality Selection index[$]	Entry	Rank	Winter Density[δ]
FB1628	1	6.9	FB1628	1	8.1
CELEBRATION	2	6.1	FB1633	2	7.1
FB1633	3	6.0	CELEBRATION	3	6.9
FB1632	4	5.7	BIMINI	4	6.4
BIMINI	5	5.4	FB1634	4	6.4
19-12	6	5.3	FB1629	5	6.3
13-2	6	5.3	13-2	6	6.1
TIFTUF	7	5.2	19-14	6	6.1
FB1634	8	5.1	TIFWAY	7	6.0
FB1630	8	5.1	13-7	7	6.0
TIFWAY	8	5.1	FB1632	8	5.9
18-14	8	5.1	TIFTUF	8	5.9
13-8	9	5.0	15-7	8	5.9
25-16	9	5.0	25-10	8	5.9
15-7	10	4.9	7-13	8	5.9
FB1629	10	4.9	9-6	8	5.9
FB1635	10	4.9	9-12	8	5.9
LATITUDE	13	4.6	19-9	8	5.9
			18-14	9	5.8
			13-8	9	5.8
			25-16	9	5.8
			18-8	9	5.8
			5-9	9	5.8
			9-11	9	5.8
			FB1630	10	5.6
			3-16	10	5.6
			7-7	10	5.6
			LATITUDE	16	4.9

[$] Turf quality rated using a 1 to 9 scale, where 1 = a dead plot and 9 = ideal turf conditions. The selection index was based on performance through the year and winter turf quality using the formula: ((Average of all TQ dates*0.50)(Average of winter TQ dates*0.5)).

[δ] Density rated using a 1 to 9 scale, where 1 = very poor density and 9 = highly dense turf.

USGA ID#: 2017-21-631

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

Project Leaders: Adam J. Lukaszewski and James H. Baird
Affiliation: 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 Points:

- Extensive genotyping of bermudagrass using DArT showed four distinct clusters formed by accessions of seven bermudagrass species; none of them was homogenous, suggesting serious misidentification in collections.
- Hybridization of existing UCR bermudagrass accessions continued, with emphasis on genotypes with desirable winter color retention, early spring green-up, and drought tolerance. A large amount of hybrid seed was produced and germinated, 770 new hybrids were planted.
- Evaluation continues of 12 our most promising bermudagrass hybrids in replicated trials across several climatic zones in California comparison to cvs. Tifway, TifTuf, and Bandera. Four best performing hybrids were chosen for tests at golf courses.
- The range of genetic variation of kikuyugrass has been expanded by addition of new accessions and expansion of the existing collection.
- The mode of pollination and hybridization in kikuyugrass is being studied with good indications of high tendency toward self-pollination.
- Selection among kikuyugrass was initiated for less aggressive growth, finer texture and good drought tolerance.
- Evaluation of winter color retention continues among entries of bermudas, kikuyus and zoysias.

Summary Text:

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.

Starting in spring 2017 the person responsible for the general advancement and day-to-day operations of this project is Dr. Marta Pudzianowska.

Bermudagrass

In addition to the existing collection of seven *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 and 2018. 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 UCR accessions, genotypes from crossing blocks were again intercrossed in 2018 (detached tiller crosses and open pollination). These seeds will be germinated and planted in the spring of 2019. Seeds from 2017 crosses were germinated, and 770 seedlings of bermudagrass hybrids were planted. Over the next few years these new hybrids will be evaluated for winter color retention and overall quality. Best performing genotypes will be planted in newly establish dry-down area and tested for drought tolerance. Accessions with the latest onset of dormancy and the earliest green-up will be intercrossed, on the assumption that the next generation hybrids may show reduced dormancy period. A new approach to selection has been introduced. All hybrids evaluated and selected for fairways are now being re-screened, this time for suitability for roughs or homeowners use (2” mowing height).

To support traditional selection of bermudagrass accessions and establish the parentage of the existing hybrids, marker-assisted selection using the Diversity Arrays Technology (DArT) was introduced. A total of 181 accessions were genotyping and after curating and cleaning the data, 15962 reliably performing markers were selected. Using these markers a dendrogram of relatedness was created using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean). The accessions formed four relatedness clusters. Only one cluster, consisting of only two accessions of *Cynodon dactylon*, was uniform. The remaining three clusters were not uniform and contained accessions from different species. The first group included most of the *Cynodon barberi* accessions (13 accessions out of 15), the second group contained most of *Cynodon transvaalensis* accessions (12 out of 18). *Cynodon dactylon* entries were scattered among all three clusters, but 21 out of 41 of these clustered in the third group, along with all commercial cultivars included in the analysis. None of the remaining species formed separate clusters but grouped together with other species in one or more of the three groups. This suggests a contamination or misidentification of the genotypes in the collections and re-classification of collection entries is clearly required. Moreover, the collections carry redundant entries; 19 % of the accessions tested were genetically identical when screened with over 15,000 DNA markers. Such redundancy increases the cost of maintenance and can be misleading to breeders.

Twelve of our most promising hybrids and accessions selected for detailed evaluation were planted in 2017 and evaluated during 2017 and 2018 seasons in replicated trials 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 three widely used or new cultivars: Bandera, TifTuf and Tifway. Fourth cultivar, Santa Ana, had to be replanted due to contamination and wasn’t included in the trial this year. In 2018, plots in Riverside and Coachella Valley were split in two to test different mowing heights (0.5”, fairway height, and 2”). Plots in Fairfax were not yet fully established at the time new mowing regimes were applied, and so they are still mowed in only in the fairway height. Visual quality, visual color, Normalized Difference Vegetation Index (NDVI), Dark Green Color Index (DGCI), flowering and scalping injury are being evaluated. In the ranking of hybrids mowed for fairways, 17-8, TP 6-3 and BF1, took the highest positions, with better performance than commercial cultivars. In plots mowed at 2.0”, 17-8, TP 6-3 and BF2 had the highest rankings, but only 17-8 was as good as Tifway 419, the best performing commercial cultivar. 17-8, TP6-3, BF2 and 10-9 (the latter having good color retention and quality in Northern California) were selected for further trials at golf courses, to test their performance under normal traffic. They were sprigged in September 2018 at the West Coast Turf fields in the Coachella Valley, to produce sod for next year planting.

Kikuyugrass

Accessions of kikuyugrass from California show relatively little morphological variation, therefore our work in two last years was focused on increasing genetic variability of our collection. Seeds of kikuyugrass of unclear origin were germinated and well over 2500 seedlings were individually evaluated for darker color, slower growth rate, finer texture and winter color retention. Best 105 selections were planted in 2018 as an addition to the existing collection of 103 accessions.

Observations of the pollination mode in kikuyugrass have started in October 2017 and were continued in 2018. This was done to better understand the pollination mechanisms and to help in breeding efforts. For this purpose, flowers are being self- and cross-pollinated, and observations of seeds development are being performed. After pollinating single flowers with their own pollen 4 out of 10 accessions developed seeds, suggesting that temporal and spatial separation between stigma and anthers does not prevent self-pollination; kikuyugrass is self-compatible. Seeds obtained from self- and cross-pollinations will be germinated and planted next year.

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 and 2018. Collection was supplemented with 14 UCR hybrids obtained from the breeding program conducted by Dr. V. B. Youngner and V. A. Gibeault, which resulted in releasing cultivars ‘El Toro’, ‘De Anza’ and ‘Victoria’. During the winter season 2017/2018 color retention and the overall quality of these genotypes were evaluated visually. Considerable variation in color retention and quality was observed among Zoysiagrass genotypes with the average color values being higher than those of bermudagrass.

Figure 1. UCR bermudagrass hybrids and commercial cultivars fall color retention at Meadow Club in Fairfax (Northern California).

Figure 2. New UCR bermudagrass hybrids planted in 2018.

Figure 3. The mode of pollination and hybridization in kikyuygrass study.

USGA ID#: 2016-35-605

Title: Developing phenotypic and genomic tools to study salt-tolerance in seashore paspalum

Project Leaders: Elizabeth Kellogg, Kenneth Olsen, Ivan Baxter
Affiliation: Donald Danforth Plant Science Center

Objectives: Increase diversity in available seashore paspalum germplasm, generate genome-wide SNP markers for seashore paspalum germplasm, identify phenotypic and genetic basis for variation in salt tolerance between lines.

Start Date: 2016
Project Duration: 2 years
Total Funding: $69,997

Summary Points:

- Generated genome-wide SNP markers for over 200 accessions.
- Determined that the "coarse" ecotype of seashore paspalum is a hybrid between the "turf" ecotype and a so-far unidentified paspalum species.
- High-molecular weight DNA was extracted and used to dramatically improve the quality of the reference genome assembly with long PacBio reads.
- Collected tissue samples from varying salinity samples for ionomics analysis.
- Generated over 140,000 images of paspalum accessions under varying salinity levels.

Summary Text:

Seashore paspalum (*Paspalum vaginatum*) is an extremely salt tolerant grass that has found an economic niche as a turfgrass in coastal regions, particularly on golf courses. Additionally, it has recently seen increased interest from the broader plant science community as a potential model system for the study of salt tolerance in plants. Both groups will undoubtedly benefit from any advancements made in understanding the biology of the species. Here we seek to provide some of the first steps toward making seashore paspalum a scientific model system by improving the quality of the reference genome, increasing the available germplasm, and quantifying genetic and phenotypic diversity in the species. These results will provide scientific tools to the turfgrass community previously only available in the most well-studied crop species and will serve as a springboard for future work in the system by breeders and basic scientists alike.

To increase the pool of available germplasm, we collected 200 wild seashore paspalum and the closely related species *Paspalum distichum* from a diverse range of freshwater and saline environments along the US Gulf and Atlantic Coasts. We intentionally included the "coarse" ecotype of seashore paspalum, which has previously been mostly ignored, in our collections because we believed it may contain useful physiological traits for breeding despite its undesirable morphology. We genotyped all of our samples along with the USDA GRIN collection using a Genotyping-by-Sequencing approach to generate genome-wide SNP markers. Population genetics analyses revealed that the "coarse" ecotype of seashore paspalum is actually a hybrid of the "turf" ecotype and another so-far unidentified *Paspalum* species. This conclusion is supported by the lack of genetic clustering of the coarse type with either *Paspalum distichum* or the turf ecotype of seashore paspalum (Fig. 1). The coarse type also shows increased genome-wide heterozygosity, which appears to be a reflection of its hybrid origin. These hybrids vary in ploidy with 2x, 3x and 4x individuals represented in our collection, while the "turf" ecotype is entirely diploid (2x). The hybrid should likely be considered its own species and we are pursuing documenting it as such. Despite the hybrid's lack of favorable turf qualities, it has been used as a dune stabilizer, particularly the cultivar "Brazoria".

In addition to genotyping our samples, we also performed two high throughput phenotyping assays on all accessions. The first method used automated flood trays to submerge pots in a nutrient solution with varying salinity levels twice daily (mimicking tidal inflows) (Fig. 2). We collected the total above-ground tissue from each genotype at each salinity level to measure biomass and the tissue concentration of twenty different ions using the Baxter lab's ionomics pipeline. Processing of these 6000 samples is ongoing but will be completed by the end of 2018 with computational analyses to follow. We expect to be able to identify ion concentration signatures that can be used to cheaply assay salt tolerance. The second phenotyping project used the Danforth Center's *Lemnatec* automated phenotyper. Plants were automatically watered to a set weight and subjected to one of five treatments: no salt, gradual daily salt application at a high or low concentration, and a large salt application applied at the beginning of the experiment at a high or low concentration. Color and infrared images were taken daily of each plant from three different angles to measure growth rate, color, and other morphological changes induced by exposure to the salt solution (Fig. 3). Over 140,000 images were taken. Computational analysis of these images with the *PlantCV* pipeline is pending. We expect to identify subtle changes in morphology associated with increased resistance that are invisible or difficult to measure with the naked eye. By comparing the ionomic results to the image analysis we should be able to develop a clear picture of both the morphological and physiologic responses to salinity in seashore paspalum.

A second goal of the *Lemnatec* experiment was to collect root and shoot tissue for an RNA-seq project to identify genes that are more highly expressed under saline conditions and therefore likely to be involved in salt tolerance. The saline treatments include tissue collected shortly after first exposure to a high salt concentration to measure the salt "shock" response due to a sudden change in osmotic pressure as well as after two weeks of gradual salt build-up to investigate genes involved in long term stress tolerance due to the toxicity of sodium ions. All tissue has been collected and is ready for RNA extraction and sequencing.

In addition to the main goals described above, we also extracted high molecular weight DNA for PacBio sequencing in collaboration with the Joint Genome Institute of the Department of Energy. We generated 74.03x coverage of long reads and used them along with a linkage map produced by the Devos lab at the University of Georgia to produce a highly contiguous genome assembly. Seventy-five percent of the genome can now confidently be assigned to its location on a chromosome. This new reference assembly represents a dramatic improvement over the previous draft and will form the backbone of future genetic studies in the system.

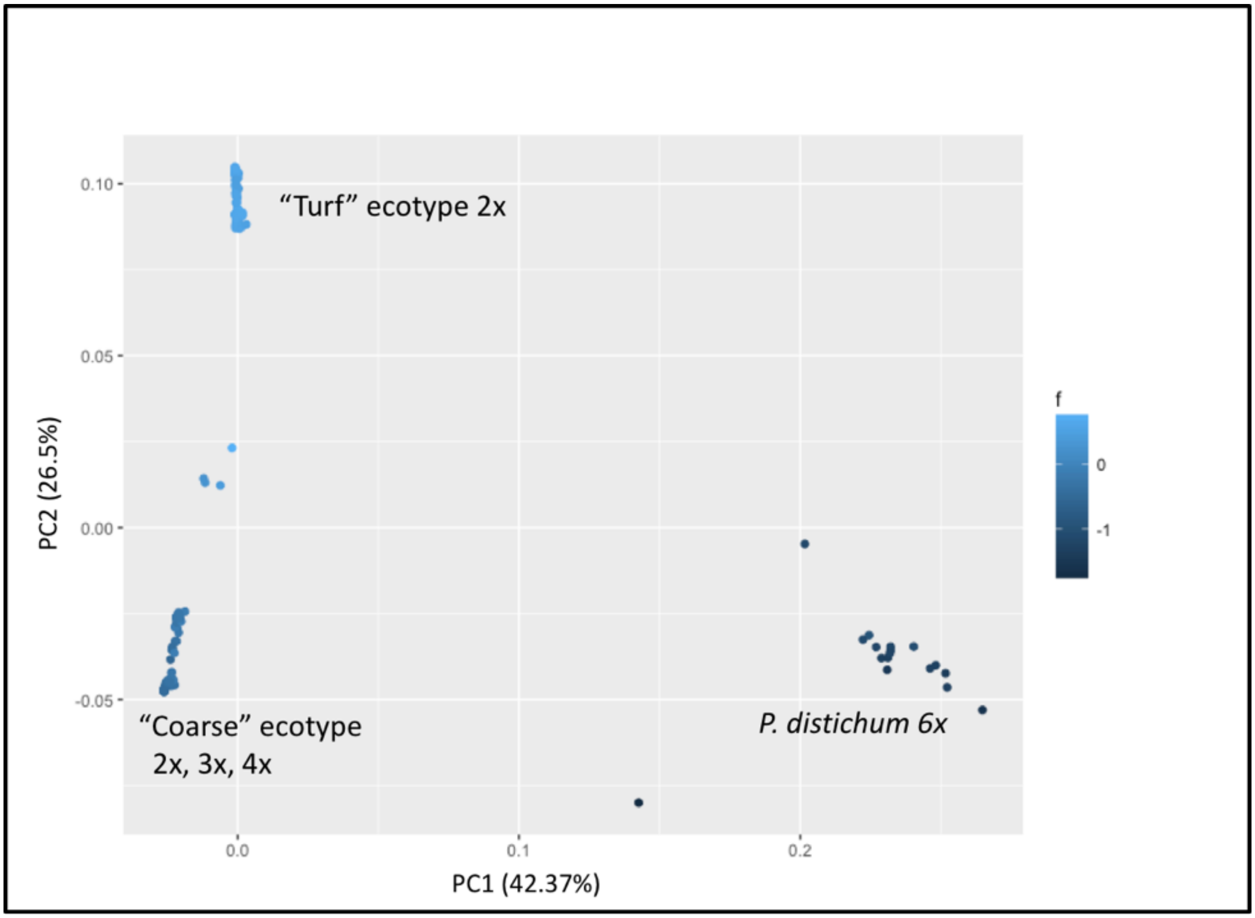

Figure 1. PCA of all *P. vaginatum* and *P. distichum* samples based on genome-wide SNP markers. Three clearly distinct clusters correspond to the "turf" ecotype, "coarse" ecotype, and *P. distichum.* Values next to group name represent inferred ploidy based on flow cytometry genome size estimates. Darker shades of blue represent higher genome-wide heterozygosity as measured by the individual inbreeding coefficient (f).

Figure 2. Paspalum accessions being watered by a pump system controlled by a Raspberry Pi. Three of the six trays were irrigated with a saline solution which increased in concentration every two weeks.

Figure 3. Side-view image of seashore paspalum taken on the *Lemnatec* automated phenotyper.

USGA ID#: 2012-24-458

Title: Development of Large Patch Tolerant and Cold Hardy Zoysiagrass Cultivarsfor 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.

Start Date: 2012
Project Duration: 5 years
Total Funding: $144,140

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 Points:

- Sixty zoysiagrass hybrids, each arising from a cross between a large-patch tolerant parent and cold-hardy parent, were evaluated after initially screening 2,858 progeny for quality and cold hardiness.
- Progeny were 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.
- Ten zoysiagrasses were selected in 2018 as the top performers and will continue to be evaluated in 2019 for turf quality characteristics and large patch tolerance in Manhattan, KS, Dallas, TX, and West Lafayette, IN.
- Discussions are currently underway for on-site evaluation of these top 10 hybrids at several golf courses in the transition zone.
- Discussion are also currently underway to potentially submit the top three hybrids showing cold hardiness and large patch tolerance in the 2019 zoysiagrass NTEP trial.

Summary Text:
This was the fourth year of field evaluation for 60 zoysiagrass experimental hybrids 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 non replicated 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

Data was collected for 60 advanced zoysiagrass progeny and standard cultivars at all ten study sites in 2018. In spring 2018, rainfall was limited, little large patch occurred in the spring. Based upon statistical analyses and a thorough evaluation of large patch tolerance in Kansas and Arkansas, and turf performance characteristics from all study sites in the transition zone, 10 progeny out of the original 60 have been selected for advancement and more intensive evaluation. The 10 zoysiagrasses were selected based upon their turfgrass performance index which is calculated as the total number of times an entry is placed in the top statistical group for a trait under evaluation at each study site (Table 1). Data in Table 1 represents a summary of spring green up, winter injury, monthly turfgrass quality, large patch tolerance, and percentage cover across all locations in the transition zone.

Figure 1. Zoysiagrass plots in Manhattan, KS on May 29, 2018. Note in the overview of the study area (bottom left) that some zoysiagrasses were slow to green up following cold winter temperatures. Although some large patch was observed on plots in spring 2018 (bottom right), the disease was not widespread due to dry conditions. The same grasses were evaluated in Arkansas, Illinois, Indiana, Oklahoma, Missouri, North Carolina, Tennessee, Virginia, and Texas.

Table 1. Turf performance index (based upon results from nine transition zone states and Texas) and large patch infection (observed in Arkansas and Kansas in 2017) of the ten zoysiagrass progeny selected for further research, including on-site evaluation at golf courses.

	TPI				Large patch (%)[§]					
EntryID	2016 TPI[†]	2017 TPI	Sum TPI (2016 + 2017)	RANK[‡]	AR		KS			
	(54 in total)	(57 in total)	(111 in total)	2016 + 2017	4/19/17	5/15/17	5/24/17	9/24/17	9/30/17	10/20/17
6099-145	28	50	78	1	8.0	0.0	15.7	0.0	0.0	3.3
6119-179	39	38	77	2	0.7	2.3	10.0	0.0	0.0	0.0
6095-83	31	45	76	3	2.0	4.0	18.3	0.0	0.0	0.0
6100-13	30	29	59	10	15.0	1.3	21.7	0.0	0.0	11.0
6095-101	21	35	56	12	4.0	0.7	21.7	1.0	0.0	1.0
6102-62	25	31	56	12	4.0	0.0	15.0	9.3	0.0	0.0
6099-359	29	27	56	12	6.7	3.3	18.3	0.0	0.0	5.7
6095-117	28	24	52	16	5.0	1.7	35.0	0.0	0.0	6.7
6096-36	23	28	51	17	5.7	9.0	18.3	0.0	0.0	6.7
6102-307	21	25	46	21	2.0	3.3	7.0	0.0	0.0	0.0
Zeon	21	23	44	23	21.7	4.0	28.3	3.3	1.7	6.7
Meyer	16	29	31	30	30.0	23.3	33.3	1.7	0.0	8.3
LSD[¶]	NA	NA	NA	NA	12.0	16.1	27.9	19.3	20.8	22.9

[†] TPI, Turfgrass performance index, is a sum of the number of times a genotype appears in the top statistical group; a higher number is better). It is based upon spring green up, winter injury, monthly quality, large patch tolerance, and percentage cover of 60 zoysiagrass progeny and standard cultivars across 10 study sites (Kansas, Indiana, Arkansas, Missouri, North Carolina, Oklahoma, Illinois, Texas, Tennessee and Virginia).

[‡] Ranking is out of a total of 68 entries.

[§] Large patch was rated visually on a 0 to 100% scale on the entire plot in AR, and on the *R. solani*-inoculated half of each plot in KS.

[¶] To determine statistical differences among entries, subtract one entry's mean from another entry's mean.

USGA ID#: 2017-11-621

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

Project Leaders: A. Dennis Genovesi and Ambika Chandra
Affiliation: 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 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
Project Duration: 3 years
Total Funding: $89,559

Summary Points:

- Data was collected from the 2015 SPN (1,750 progeny) in 2018 with notes taken for turf quality, seed head color, density, and height of seedhead exertion. Another seven progeny were selected for testing in addition to the twenty-three entries advanced in 2017. Data was collected on the twenty-three that made up the three isolation blocks (Red #1, Red #2 and Yellow) during 2018 as we wait for them to become fully established and come into full flower in 2019.
- The 3 new 3-clone synthetic varieties (DALZ 1803, DALZ 1804 and DALZ 1805) were planted in 2017 and are still in the process of growing-in before seed yield parameters can be measured.
- Synthetic parental lines (13) were shared with Johnston Seeds on MTA for evaluation at Enid, OK. Another 620 medium-coarse textured progeny were planted in SPN at Johnston Seeds to identify parental lines suitable for 3 clone synthetics for that texture class.
- DALZ 1512 and DALZ 1513, experimental synthetic varieties, exhibited better fall color in 2018 with turfgrass quality and spring greenup similar to the seeded checks. Establishment rate of these synthetic varieties is better than the vegetative checks. A four-year data summary is presented.

Summary Text:

Zoysiagrass (*Zoysia* spp.) is a warm season, perennial grass that is being used on golf courses and home lawns due to their lower level of maintenance as compared to other turfgrasses (Murray and Morris, 1988). Most cultivars are vegetatively propagated since they offer a uniform, high quality turf stand, but an alternative, relatively inexpensive, way is to propagate zoysiagrass by seed (Patton et al 2006).

Availability of seeded varieties is limited to *Z. japonica* Steud. types such as ‘Zenith’ and ‘Compadre’. The focus of this research project is the development of multi-clone synthetic varieties that exhibit leaf textures finer than Zenith with seed yields that meet the production goals needed to make it profitable to produce. Since the inception of the project in 2010, our breeding strategy has been to utilize the classical plant breeding method known as phenotypic recurrent selection. Our approach has been to alternate between Spaced Plant Nurseries (SPN) for progeny selection, and isolation crossing blocks to promote outcrossing and recombination. This strategy should allow for the gradual accumulation, over multiple generations, of desirable alleles affecting both seed yields and finer leaf texture.

In 2015, we began our third cycle of recurrent selection with the germination of seed harvested from isolation crossing blocks where 32 entries were planted in 2013. 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 in potting mix then fifty of the strongest seedlings from each family were advanced to establish the 2015 SPN with a total of 1,750 progeny with Zenith and Compadre as checks.

In 2017, out of theses 1,750 progeny, 23 were identified for advancement to 2017 isolation crossing blocks based on seedhead color, seedhead density, height of inflorescence exertion and leaf texture. In 2018 the 2015 SPN was revisited to identify any late bloomers that were missed during 2017. Another three red seeded types and four yellow seeded types were selected for advancement on 8/24/18. While this project focuses on the development of new seeded type synthetics, we noticed that as we walked the nursery there were numerous vegetative types that appeared promising. Samples of 25 of the most promising vegetative types were also collected. Data was collected in 2018 on the 3 isolation blocks (Red #1, Red #2 and Yellow) planted in 2017 (see Table 1). The plots are still too juvenile for seed harvest so that will occur in 2019. A subset of these isolation crossing block entries were also identified for use as parental lines in synthetic variety development for possible future commercialization (Red #1 = DALZ 1803, Red #2 = DALZ 1804, and Yellow = DALZ 1805). Again, synthetics were not completely grown-in and seed harvest will need to be delayed until 2019.

In 2017-2018, 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 has been collected over a 4-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 checks, Palisades and Zorro. 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 (Table 3). In 2018, fall color and spring greenup for DALZ 1512, 1513 and TAES 6619 was similar to the seeded checks. Seedhead density was significantly higher for the experimental entries over that of the checks (Table 3). While this does impact turf quality, it could be viewed as beneficial for planting seed production fields.

A more comprehensive collaboration with Johnston Seed has been undertaken with the transfer of vegetative material from our most recent synthetic parents. On 31 July 2018, 18 cell trays of our most advanced synthetic parents (13) were shipped to Johnston Seed on MTA for evaluation. Initially each of the synthetic parental lines will be evaluated for cold hardiness. Once cold hardiness is confirmed then 3- clone synthetics will be planted for seed yield testing. Since most of our research has been slanted toward a finer textured seeded zoysia than that of ‘Zenith’, we have intentionally selected for types that are of intermediate texture. Johnston Seeds also expressed an interest in medium-coarse textured types. Stored seed from 16 medium-coarse textured type families were scarified and germinated for Johnston Seeds to plant in a Spaced Plant Nursery. A total of 620 medium-coarse seedlings were sent and planted in 2018 at Enid, OK in SPN.

References:

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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. Mean establishment and seedhead density ratings for the TAES genotypes in each of the Red #1, Red #2, and Yellow isolation blocks recorded on 8.16.2018.

Isolation Block	**TAES #**	**Establishment†**		**Seedhead Density‡**	
Red #1	6593-10	1.7	d	6.7	abc*
	6594-09	4.0	b	7.3	ab
	6595-18	3.0	bcd	6.0	bc
	6596-34	3.3	bc	3.3	d
	6600-23	2.3	cd	7.3	ab
	6609-24	7.3	a	8.0	a
	6617-36	3.3	bc	5.7	c
	LSD(0.05)§	1.5		1.4	
Red #2	6596-05	8.0	ab	6.3	bc
	6596-42	8.0	ab	7.7	ab
	6598-02	5.7	b	8.7	a
	6598-38	3.0	c	6.7	bc
	6599-05	8.7	a	5.7	cd
	6600-10	7.0	ab	6.7	bc
	6616-35	7.0	ab	4.7	d
	6617-17	5.7	b	6.3	bc
	6618-31	2.0	c	7.3	ab
	LSD(0.05)	2.5		1.4	
Yellow	6585-34	8.3	a	7.0	b
	6597-41	5.0	abc	7.3	b
	6603-12	5.0	abc	9.0	a
	6603-16	6.7	ab	9.0	a
	6610-36	4.0	bc	5.7	c
	6611-18	2.0	c	4.3	d
	6612-15	6.3	ab	7.7	b
	LSD(0.05)	3.6		0.8	

* Significant at the 0.05 probability level.

† Establishment was recorded on a 1-9 scale (1 = no spread; 9 = fully established).

‡ Seedhead density was recorded on a 1-9 scale (1 = very high density; 9 = no seedheads present).

§ Means are presented as the average of three replications; means were separated using fisher's protected LSD; means followed by the same letter are not significantly different at the 0.05 probability level.

Tables 2. A and B. Mean performance of advanced synthetic zoysia lines DALZ 1512, DALZ 1513, and TAES 6619 compared to seeded checks, Compadre and Zenith, and vegetative checks, Palisades and Zorro in 2018.

A.

	Turfgrass Quality†					**Fall**
Entry	**5/30/18**	**7/5/18**	**8/22/18**	**9/28/18**	**Avg.**	**10/26/18**
DALZ 1512	6.0 bc	5.7 b	7.0 bc	7.0 cd	6.4 b	6.0 c
DALZ 1513	5.0 c	6.0 b	6.3 c	7.0 cd	6.1 b	6.7 bc
TAES 6619	7.7 ab	8.3 a	7.0 bc	7.7 bc	7.7 a	7.0 b
Compadre¶	7.0 ab	6.0 b	6.3 c	6.7 d	6.5 b	6.0 c
Palisades#	8.7 a	8.3 a	7.7 ab	8.0 ab	8.2 a	7.0 b
Zenith¶	5.0 c	5.3 b	7.0 bc	7.7 bc	6.3 b	6.7 bc
Zorro#	6.7 bc	7.3 a	8.0 a	8.7 a	7.7 a	8.3 a
LSD (0.05)††	2.0	1.1	0.7	0.8	0.7	0.7
C.V. (%)‡‡	16.9	9.3	5.6	6.0	13.2	5.8

B.

	Greenup†	**Leaf Texture‡**	**Genetic Color†**	**Fall Color†**	**Seedheads (%)§**
Entry	**4/3/18**	**7/26/18**	**7/26/18**	**11/14/18**	**4/3/18**
DALZ 1512	4.0 bc	5.0 b	6.0 c	6.0 c	5.0 bc
DALZ 1513	2.7 c	4.0 c	5.7 c	6.0 c	8.3 bc
TAES 6619	6.0 ab*	4.7 b	7.0 b	6.0 c	18.3 ab
Compadre¶	7.7 a	3.0 d	5.0 d	4.0 e	30.0 a
Palisades#	7.7 a	3.0 d	6.0 c	7.0 b	0.0 c
Zenith¶	5.0 b	3.0 d	5.7 c	5.3 d	16.7 ab
Zorro#	4.7 bc	8.0 a	8.0 a	8.0 a	30.0 a
LSD (0.05)††	2.1	0.4	0.6	0.4	15.8
C.V. (%)‡‡	21.9	4.9	5.2	3.5	58.0

* Significant at the 0.05 probability level.

† Spring greenup, genetic color, turfgrass quality, and fall color were rated on a 1-9 scale (1 = brown/dormant; 9 = completely green/excellent; 5 = minimum acceptable green color).

‡ Leaf texture was rated on a 1-9 scale (1 = extremely coarse; 9 = superfine).

§ Seedheads were rated visually as an estimation of plot coverage.

¶ Compadre and Zenith were seeded checks sown at a rate of 2lbs/ 1,000 ft^2.

Palisades and Zorro were planted as vegetative plugs with four 10 cm plugs per plot.

†† Means were separated using Fisher's protected LSD at the 0.05 significance level.

‡‡ Coefficients of variation (C.V.) were calculated by dividing the root mean square error by the grand mean and multiplying by 100.

Tables 3. A and B. Four-year performance of advanced synthetic 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†				
Entry	**Spring Greenup†**	**Leaf Texture‡**	**Genetic Color†**	**Summer**	**Dry down**	**Recovery**	**Fall**	**Fall Color†**
DALZ 1512	4.3 bc	5.0 b	6.0 c	5.3 bc	4.3 b	5.0 d	5.5	3.5 c
DALZ 1513	3.3 c	4.0 c	5.7 c	4.9 c	3.3 bc	6.7 bc	6.0	3.7 bc
TAES 6619	5.0 ab*	4.7 b	7.0 b	5.4 bc	4.3 b	7.0 b	5.5	3.8 abc
Compadre¶	5.7 a	3.0 d	5.0 d	5.2 c	4.0 b	7.3 b	5.5	2.6 c
Palisades#	5.8 a	3.0 d	6.0 c	6.0 ab	8.0 a	8.7 a	6.2	4.9 ab
Zenith¶	5.0 ab	3.0 d	5.7 c	5.1 c	2.7 c	5.3 d	6.0	2.9 c
Zorro#	5.0 ab	8.0 a	8.0 a	6.2 a	3.7 bc	5.7 cd	7.0	5.0 a
LSD (0.05)††	1.2	0.4	0.6	0.7	1.3	1.3	NS	1.3
C.V. (%)‡‡	26.4	4.9	5.2	31.6	40.2	24.1	19.4	41.7

B.

	Establishment (%)§			**Seedheads (%)§**		
Entry	**11/23/15**	**04/13/16**	**08/01/16**	**Spring**	**Summer**	**Fall**
DALZ 1512	95.0 a	73.3 a	100.0 a	46.3 a	70.0 a	55.0 a
DALZ 1513	93.3 a	80.0 a	96.7 a	44.6 a	56.7 b	43.3 b
TAES 6619	71.7 b	63.3 a	95.0 a	47.9 a	40.0 c	41.7 b
Compadre¶	88.3 a	76.7 a	98.3 a	22.9 b	5.0 de	5.0 c
Palisades#	28.3 c	21.7 b	76.7 b	10.4 b	13.3 d	6.7 c
Zenith¶	91.7 a	68.3 a	95.0 a	21.7 b	0.7 e	1.7 c
Zorro#	21.7 c	25.6 b	76.7 b	7.5 b	0.0 e	0.0 c
LSD (0.05)††	10.9	18.0	7.8	18.5	10.4	7.9
C.V. (%)‡‡	8.7	16.8	4.8	79.2	22.1	20.4

* Significant at the 0.05 probability level.

† Spring greenup, genetic color, turfgrass quality, and fall color were rated on a 1-9 scale (1 = brown/dormant; 9 = completely green/excellent; 5 = minimum acceptable green color).

‡ Leaf texture was rated on a 1-9 scale (1 = extremely coarse; 9 = superfine).

§ Establishment and seedheads were rated visually as an estimation of plot coverage.

¶ Compadre and Zenith were seeded checks sown at a rate of 2lbs/ 1,000 ft^2.

Palisades and Zorro were planted as vegetative plugs with four 10 cm plugs per plot.

†† Means were separated using Fisher's protected LSD at the 0.05 significance level.

‡‡ Coefficients of variation (C.V.) were calculated by dividing the root mean square error by the grand mean and multiplying by 100.

USGA ID#: 2018-01-651

Title: Development of Cold Hardy Zoysiagrass Cultivars for Golf Courses in the Transition Zone

Project Leaders: A. Dennis Genovesi[1], Ambika Chandra[1], Jack Fry[2], Megan Kennelly[2], Aaron Patton[3]

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

Objectives:

1. Phase I (year 1): Perform pairwise crossing between cold hardy zoysiagrasses adapted to the transition zone and fine textured zoysia species that historically have poor cold hardiness.
2. Phase II (year 2 and 3): Evaluation process will focus on field testing in the form of non-replicated spaced plant nurseries (SPN) comprised of the newly generated progeny population that will be conducted concurrently at Manhattan, KS, West Lafayette, IN, and Dallas, TX. The objective of Phase II field testing is the identification of experimental hybrids that have superior cold tolerance as well as excellent turfgrass quality. A note will be taken of entries that exhibit no visible symptoms of large patch or billbugs as a result of the natural infestations, as well as any prevalent stress at test locations.
3. Phase III (year 4-6): A set of 75 hybrids will be selected based on their superior performance for field evaluation in the form of replicated field trials (RFT) at Dallas, Manhattan, and West Lafayette. RFT in Dallas will be conducted under shade (83% PAR reduction). Evaluation of these advanced hybrids to large patch diseases tolerance will be conducted in Manhattan, KS and tolerance to hunting billbug will be conducted in West Lafayette, IN. RFTs will also be conducted at five to eight additional locations in the transition zone in 2021, 2022 and 2023.

Start Date: 2018
Project Duration: 6 years
Total Funding: $300,000

Summary Points:

- Phase I (year 1 completed): Pairwise crosses were made between cold hardy intermediate-textured types as well as cold hardy *Z. japonicas* adapted to the transition zone to finer textured species (*Z. pacifica, Z. minima and Z. pauciflora*) resulting in the production of 2,926 progeny. It should be noted that in this project we are attempting to build on the progress made in earlier work where we crossed cold hardy Japonica types with Matrella types which lead to the release of the cold hardy intermediate texture type, Innovation. This work should allow us to take another step toward a range of texture types that are better suited for golf course fairways and putting greens.
- Phase II (year 2 and 3 begun): Spaced Plant Nurseries were planted at three locations: 1,370 progenies at Olathe, KS, 1,608 progenies at West Lafayette, IN, and 1,661 progenies at Dallas TX (Table 1). The objective of Phase II field testing is the selection of experimental lines that have comparable/superior cold tolerance to that of Meyer with tees to greens turfgrass quality for the golfing industry in the Transition Zone. Attention will be paid to the selection for entries that exhibit no visible symptoms of large patch disease, hunting billbug susceptibility and shade tolerance.

Summary Text:

Zoysiagrass is a warm season grass that provides an excellent playing surface for golf with the added benefits of low nutrient and pesticide requirements making it an ideal turfgrass for use in transition zone (Fry et al., 2008). In the transition zone, 'Meyer' (*Z. japonica*) has been the cultivar of choice since its release in 1951 (Grau and Radko, 1951), primarily because it has excellent freezing tolerance. However, Meyer is relatively slow to establish and recover from divots, and is more coarse textured and less dense than *Z. matrella* cultivars (Fry and Dernoeden, 1987; Patton, 2009).

Researchers at Texas A&M AgriLife Research-Dallas and Kansas State University have worked together since 2004 to develop and evaluate zoysiagrasses with better quality than Meyer but adapted to the transition zone. From this work, a number of advanced lines derived from paired crosses between *Z. matrella* and *Z. japonica*, were identified (e.g. – KSUZ 0802, KSUZ 0806 and KSUZ 1201) with a level of hardiness equivalent to Meyer (Okeyo et al., 2011), but with finer texture and better density than Meyer. Because of its superior performance, KSUZ 0802 ('Innovation') was recently co-released by TAM AgriLife and KSU as a new commercial variety (Chandra et al., 2017).

TAM-AgriLife, KSU and Purdue University have been working on a USGA-funded project since 2012 where the main objective is to incorporate large patch (*Rhizoctonia solani* AG 2-2LP) tolerance, along with cold hardiness and improved quality, into new transition zone zoysiagrasses. In 2018, top ten hybrids with intermediate leaf texture (out of over 2,800) exhibiting large patch tolerance and cold hardiness were selected for advanced evaluations by the three collaborating institutions.

For the current project, we have initiated new crosses between these intermediate texture types with cold hardiness available in the pipeline and under-utilized and finer textured *Zoysia* species (*Z. pacifica, Z. minima and Z. pauciflora*) available in our germplasm collection. **The focus of this new project will be to develop cold hardy zoysiagrasses with quality suitable for golf course fairways, tees, and putting greens**. In addition to cold hardiness and turfgrass quality, hybrids generated and selected in this new project will also be evaluated for large patch, hunting billbug and shade tolerance.

We are partnering with Dr. Jack Fry, Turfgrass Scientist with K-State, Dr. Aaron Patton, Extension Turfgrass Specialist with Purdue and Dr. Megan Kennelly, Plant Pathologist with K-State. These folks have extensive experience with testing turfgrasses adapted to the transition zone for cold hardiness and disease susceptibility.

Progeny populations were produced in TAM AgriLife - Dallas and shared with our collaborators across three locations: 1,370 progeny for Olathe, KS, 1,608 progeny for West Lafayette, IN and 1,661 progeny for Dallas, TX (Phase I completed) (see Table 1).

Phase II was begun when three spaced plant nurseries were planted: (1) summer 2018 in West Lafayette, IN by Aaron Patton, (2) in 2017 and 2018 in Olathe, KS by Jack Fry (Figure 1) and (3) in 2017 and 2018 in Dallas, TX by A.D. Genovesi and Ambika Chandra. Jack Fry reports that out of nearly 500 progeny planted in 2017 only 17 survived the harsh winter of 2017-2018. The survivors were transplanted to a location next to the 2018 nursery.

The plan of work for 2019 is to allow the spaced plant nurseries to grow in for two years while taking timely notes before making selections in 2020. Advanced lines will be tested at five to eight locations in 2021, 2022 and 2023.

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Patton, A.J. 2009. Selecting zoysiagrass cultivars: Turfgrass quality, growth, pest and environmental stress tolerance. Appl. Turfgrass Sci. doi:10.1094/ATS-2009-1019-01-MG.

Figure 1. Planting of Spaced Plant Nursery in Olathe, KS on July 30, 2018.

Table 1. Lineage of progeny populations developed and distributed across locations.

Lineage	Number of Progeny Tested		
	Purdue U.	**K-State U.**	**TAM AgriLife**
CH Intmd. x *Z. pacifica*	333	492	927
CH Intmd. x *Z. pauciflora* hybrid	62	30	57
CH Intmd. x *Z. minima* hybrid	148	101	86
CH Intmd. x CH Intmd.	374	225	237
Z. matrella x CH Intmd.	296	190	257
LPT x CH Intmd.	83	69	21
CH LPT x CH Intmd.	51	43	11
Seeded Type Intmd. x CH Intmd.	155	130	37
Z. minima hybrid x CH *Z. japonica*	25	21	3
Z. minima hybrid x CH-LPT	3	3	0
Z. matrella x CH *Z. japonica*	50	43	15
CH *Z. japonica* x *Z. pacifica*	12	10	3
Z. sinica x CH Intmd.	5	4	3
Z. matrella x CH-LPT	10	8	4
Seeded Type Intmd. x CH LPT	1	1	0
Total by location	**1,608**	**1,370**	**1,661**

CH – Cold Hardy
LPT – Large Patch Tolerant
CH Intmd. – Cold Hardy intermediate (*Z. japonica x Z. matrella*)
Z. pauciflora hybrid – *Z. pauciflora x Z. matrella*
Z. minima hybrid – *Z. minima x Z. matrella*
Seeded Type Intmd. – Seeded *Z. japonica x Z. matrella*

USGA ID#: 2018-16-666

Title: Exploring the Use of Coarse Zoysiagrass Phenotypes as a Low-Input Turf for Golf Course Roughs

Project Leaders: Aaron Patton[1], Susana Milla-Lewis[2], and Brian Schwartz[3]
Affiliation: [1]Purdue University, [2]North Carolina State University, [3]University of Georgia,

Collaborators: Evergreen Turf in both Escondido, CA and Chandler, AZ.

Objectives: Evaluate coarse zoysiagrass phenotypes for their performance and playability in multiple climates (warm-arid, warm-humid, transition zone) as a potential grass for golf course roughs and other low-maintenance areas.

Start date: 2018
Project duration: 3 years
Total funding: $61,846

Summary Points:

- Zoysiagrass germplasm was propagated during the winter of 2017-2018 and then distributed and planted at all five locations in summer of 2018.
- In 2018 (year 1), plots received pest control, fertilization (1.0 lb N/1000 ft^2), and irrigation to promote establishment.
- In 2019 (year 2), data collection will continue, and plants will undergo a low-maintenance regime, which will consist of being maintained without inputs (fertilization, irrigation, or pest control) and mown as needed at 3.0 inches to help identify entries that perform well under these conditions and assist in lowering golf course maintenance budgets.
- Golf course superintendents visiting the experimental locations in 2019 for university field days will provide feedback and ratings of plots via a survey instrument.

Summary Text:

Both the first and third chairmen of the USGA Green Section recognized that zoysiagrass (*Zoysia* spp.) was an important acquisition to the US golf market (Patton et al., 2017). One of the first observations about zoysiagrass by Monteith (1942) was its potential for use on low maintenance areas. However, zoysiagrass use for golf course roughs is sparse. Current breeding efforts are focused on “fairway” and “putting green” zoysiagrass and coarse zoysiagrass germplasm is often discarded by breeders as unacceptable when it may in fact be of tremendous value. Zoysiagrass roughs are amongst some of the most easily played (improving pace of play) and easily managed (few inputs required with excellent weed suppression) of all the species used in golf course roughs. Breeding programs have “coarse-textured” germplasm available that has excellent stress and pest tolerance and fast establishment when managed with no inputs. These coarse *Z. japonica* genotypes have the ability to offer a superior golf course rough surface with little to no inputs and fewer long-term maintenance costs. Our research team has existing collections of zoysiagrasses collected from unmanaged areas or as part of germplasm collections. These existing collections have not been explored for their potential use, but they offer great promise as a low-input zoysiagrass for golf course roughs. Additionally, this project examines the performance of genotypes in a warm-arid climate outside of the SE (warm-humid) and the transition zone.

Zoysiagrass germplasm was propagated in greenhouses during the winter of 2017-2018 at Purdue, NCSU, and Georgia and then the germplasm populations were shared with collaborators across all three locations and planted at the following five sites in summer of 2018 (Tables 1 and 2). Plot sizes are at least 1.5 x 1.5 m, with 0.5 m borders, with 3 replications arranged in a randomized, complete-block design at each site (Figs. 1 and 2).

Following establishment in year 1 (2018) with fertilization (1.0 lb N/1000 ft^2), watering to promote establishment, and pest control, plants will be maintained without inputs (fertilization, irrigation, or pest control) in years 2 or 3, and mown as needed at 3.0 inches. This low-maintenance regime will help to identify entries that perform well under these conditions and assist in lowering golf course maintenance budgets. Data collection began in 2018 and is similar to typical NTEP trials in order to identify those that are best suited to the for golf course roughs (Fig. 3). Golf course superintendents visiting the experimental locations in 2019 for university field days will provide feedback and ratings of plots via a survey instrument. Superintendents will be asked for feedback on turf quality, ball lie (acceptable and optimal), and other potential turf characteristics. Ball lie will be determined in spring, summer, and fall of 2019 for each entry using the method developed by Richardson et al. (2010).

The results from this study are expected to identify *Z. japonica* germplasm suitable for low-maintenance golf course roughs that can be used over a wide geographic region and gather new feedback from golf course superintendents on species choices for golf course roughs pertinent to their maintenance, performance, and playability.

References

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Figure 1. Planting of germplasm material in Chandler, AZ on 29 May 2018.

Figure 2. Up-close picture of planting the germplasm material in Chandler, AZ on 29 May 2018.

Figure 3. Data collection at the Chandler, AZ site on 15 Nov. 2018.

Table 1. Treatment list of the material used in this experiment.

Trts #	Designation/Cultivar	Source	NOTES:
1-5	PURZ1602, PURZ1603, PURZ1606, PURZ1701, PURZ1702	Purdue	Coarse textured *Z. japonica* collected from unmanaged golf course, roadsides, or campus grounds.
6-15	XZ14055, XZ14069, XZ14070, XZ14071, XZ14072, XZ14074, XZ14092, ZG09004, ZG09055, ZG09062	NCSU	Coarse textured *Z. japonica* breeding lines
16-24	09-TZ-54-9, 09-TZ-89-73, 10-TZ-994, 10-TZ-1254, 15-TZ-11766, 16-TZ-12036, 16-TZ-12783, 16-TZ-13463, 16-TZ-14114	UGA	Coarse textured *Z. japonica* breeding lines
25	Chisholm	Check	New medium-coarse *Z. japonica*
26	Meyer	Check	Medium-textured *Z. japonica* used widely in the transition zone
27	Empire	Check	Medium-coarse Z. japonica used widely in the SE
28	JaMur	Check	Medium-coarse *Z. japonica*
29	Zenith	Check	Medium-coarse *Z. japonica* available as seed
30	'Riviera' Bermudagrass	Comparison	Cold-hardy seeded bermudagrass variety
31	Fine fescue mixture	Comparison (Indiana)	Low-input standard rough mixture of 25% 'Navigator II' strong creeping red + 25% 'Radar' Chewings + 25% 'Beacon' hard + %25 'Seabreeze GT' slender creeping red fescue
32	Ky. bluegrass	Comparison (Indiana)	'Bluenote' Kentucky bluegrass
33	Tall fescue	Comparison (Indiana)	'Mustang 4' tall fescue

Table 2. Planting site information.

Site		Planting Date
Purdue University	W.H. Daniel Turfgrass Research Center, West Lafayette, IN	22 May 2018
North Carolina State University	Lake Wheeler Turfgrass Field Laboratory, Raleigh, NC	10 July 2018
University of Georgia	Coastal Plain Experiment Station, Tifton, GA	1 June 2018
Evergreen Turf	Chandler, AZ	29 May 2018
American Sod Farms	Escondido, CA	30 May 2018

USGA ID#: 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: 2018
Project Duration: Continuous
Total funding: $30,000 per year

Summary Points:

- New buffalograss accessions were identified with superior establishment rate, fall color, and early quality.
- Prior high throughput DNA sequence data was leveraged to develop buffalograss-specific genetic markers.
- Hybrid buffalograss production fields out-yield seeded production fields.

Summary Text:
Buffalograss [*Buchloë dactyloides* (Nutt.) Engelm. syn *Bouteloua dactyloides* (Nutt.) Columbus] is ideally suited for low-input golf course roughs. Buffalograss forms a quality turf because it is a highly stoloniferous, sod-forming warm-season species that survives winters in northern climates, and has little pest pressure in its natural adaptation range, the central Great Plains. Buffalograss is also dioecious and the inflorescence of female plants develop on relatively short culms and are hidden by the turf canopy while the inflorescence of male plants develop on longer culms, typically several inches above the turf canopy. Clonal female lines are generally used for vegetative production including sod and plugs, while the gender of seeded populations segregate, approaching a 1:1 ratio of males to females. Females have better visual quality than males due to the difference in flower morphology, but otherwise the genders are indistinguishable. Our primary research objective is to improve buffalograss visual and functional turf quality to make it more desirable for use in golf course tees, fairways, and roughs while exploiting the innate drought, heat, pest tolerance, and broad adaptation range of the species.

Our recent focus at the University of Nebraska-Lincoln has been on optimizing our breeding methods and expanding our germplasm collection to maximize genetic diversity. Due to the dioecious nature of buffalograss it is ideally suited for hybrid production, which is a breeding method we use for obtaining sterility (by mating buffalograss from different ploidy levels) and unisexually female plants for release as vegetative cultivars, that will be used for either sod or vegetative plug production. Hybrids can also be used to increase seed yield, as with many agronomic crops, which is also important for buffalograss. Buffalograss typically yields less than 500 lbs of seed per acre making it expensive to produce. By vegetatively planting production fields and biasing the female:male ratio to 4:1, we have observed a significant increase in seed yield with averages exceeding 1,000 lbs per acre. The production fields are expensive to establish and there is a higher risk of genetic drift if those fields remain in production for several years, which is typical for buffalograss. We are conducting long-term research to see how fields change over time, if the increase in yield can be maintained as the female:male ratio naturally returns to 1:1, and ultimately if it worth the initial expense for our producers to vegetatively establish production fields. While that research is ongoing, we are also expanding on traditional recurrent phenotypic selection breeding schemes by pre-breeding to fix desirable traits in breeding populations, then combining high performing individuals from those populations, and backcrossing to combine multiple traits in single populations.

Maintaining genetic diversity in our buffalograss collection and maximizing genetic diversity in early stages of the breeding pipeline support novel genetic combinations and increased chances of identifying buffalograss selections with desirable turf characteristics. Last year, we reported on a new buffalograss collection conducted by graduate research assistant, Collin Marshall. In addition to buffalograss, there were a few blue grama, curly mesquite, bermudagrass, and inland saltgrass plants collected. A subset of 119 plants including plants from the collection, elite breeding lines from the breeding program, and cultivars were established in the field in 2018 (Figure 1). The material was arranged in a randomized complete block design and evaluated for establishment rate, sex expression, fall color, stolon count, stolon width, and turfgrass quality. Establishment rate in inches, fall color, and early turfgrass quality are reported in Table 1. Establishment rate was measured as an average spread from two distinct measurements per plant, ~45 days post planting. Fall color, collected on November 2nd, 2018, is a measure of greenness on a 1 to 9 scale, with 1 representing straw brown and 9 representing dark green color. Turf quality data was collected ~25 days post planting and the low values were influenced by the establishment rate of the accessions. Interestingly, 609 was the only named cultivar among the top performing individuals, demonstrating the value added to our germplasm through plant collection. Long term persistence and performance of the lines will be important to evaluate.

A component of this study is to genetically characterize the germplasm collection. The information will help minimize redundancy, document the amount of genetic diversity and relatedness among individual lines, and direct breeding decisions of which lines to cross. There are few buffalograss-specific genetic resources available so our program has historically relied on non-specific genetic tools, like amplified fragment length polymorphism markers to characterize genetic diversity. In recent years, several high throughput sequencing studies have been done on buffalograss and we have leveraged the data to develop gene-based buffalograss-specific simple sequence repeat (SSR) markers (Figure 2). We are in the process of applying high resolution melt analysis, which detects melting temperatures of a DNA molecule and can be used to differentiate molecules with different nucleotide compositions, like an SSR copy number difference.

In the future, we have plans to conduct flow cytometry experiments to characterize the ploidy level of individual lines in the new buffalograss collection, estimate genetic diversity in our collection based on the new SSR genetic markers, and test persistence, turf quality, and combining ability of top performing individuals from the new collection. Ultimately the data will support development of new high-yielding buffalograss cultivars that are desirable for golf course superintendents.

Figure 1. Buffalograss accessions representing newly collected plants, advanced breeding lines, and named cultivars during establishment in 2018.

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Prestige   ACCGGT CATCATCATCATCATCATCAT GCCTGC
378        ACCGGT CATCATCATCATCATCAT--- GCCTGC
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Figure 2. Example CAT simple sequence repeat (SSR) genetic marker with seven copies in Prestige and six copies in 378.

Table 1. 2018 field evaluation of 119 buffalograss accessions. Analysis of variance was tested and means separated using Fisher's LSD (P=0.05) separately for each trait. Genotypes performing in the top two statistical groupings for establishment rate (lateral spread in inches), fall color, and turfgrass quality are reported.

Genotype	Establishment	Fall Color	Quality	Location
ID37	40.3	3.0	3.3	Harper, TX
ID48	38.3	2.7	4.0	Sutton County, TX
ID51	34.3	2.7	3.3	Fort Stockton, TX
ID52	35.7	2.7	3.3	Fort Stockton, TX
ID54	40.3	3.0	2.7	Van Horn, TX
ID55	34.3	3.3	2.7	Van Horn, TX
ID56	39.0	2.7	3.0	Van Horn, TX
ID32	34.0	2.7	3.3	Taylor County, TX
ID29	38.3	3.0	2.7	Buffalo Gap, TX
ID89	34.0	2.7	3.0	Dalhart, TX
ID7	38.3	3.0	2.7	Stillwater, OK
ID9	36.7	3.0	3.0	Stillwater, OK
ID17	35.0	2.7	2.7	Stillwater, OK
ID18	40.0	2.7	3.0	Stillwater, OK
ID116	38.0	3.0	3.3	Weskan, KS
ID94	39.3	2.7	3.7	Colorado Springs, CO
609	39.3	4.0	3.3	

USGA ID#: 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 mechanisms of buffalograss seed dormancy and develop alternative methods for breaking dormancy.

Start Date: 2016
Project Duration: 3 years
Total Funding: $60,710

Summary Points:

- Most seed treatments reduce seed dormancy, suggesting that soaking the seed may be the important step rather than the soaking solution.
- Harvest date influences buffalograss seed dormancy.
- Acetone can break buffalograss seed dormancy in the absence of a stratification treatment.

Summary Text:
Seed dormancy is common in buffalograss [*Buchloë dactyloides* (Nutt.) Engelm. syn *Bouteloua dactyloides* (Nutt.) Columbus] and other native grass species. Buffalograss has non-deep physiological seed dormancy where the dormancy is imposed by the seed coat and if the caryopsis is removed, it readily germinates. However, the removal of the seed coat is not practical in buffalograss since it adds to production costs and since the exposed caryopses have a relatively short shelf life compared to intact burs. The bur structure of buffalograss consists of three to five caryopses and is often sold as buffalograss seed. The standard method for breaking dormancy for commercial seed producers is to soak buffalograss burs in a 5% potassium nitrate solution for 48 hrs followed by a 5-week cold stratification period. Once treated, the burs are dyed green indicating they have been treated. Any inhibitory compounds contained in the seed coat are degraded, leached, or in some other way inactivated during the seed treatment process allowing germination. In the absence of a seed treatment, buffalograss seed typically has a <20% germination rate, but once treated, seed germination typically exceeds 85%.

Commercial seed producers are seeking alternative methods for breaking seed dormancy. One concern is with the 5-week chill period when the buffalograss seed occupies valuable space in coolers that could be used to condition other crop seeds. Another concern is with inconsistent results, where certain seed lots require a second potassium nitrate treatment to reach target germination rates. Yet another concern is with the occurrence of secondary dormancy which occurs when the germination benefits of the initial potassium nitrate treatment are lost, but the seed remains viable. Secondary dormancy most often occurs when seed is not stored properly after purchase. Our research is to understand mechanisms of seed dormancy and identify and/or develop improved methods for breaking seed dormancy.

One approach is to overcome seed dormancy through traditional plant breeding methods. There is variability in the expression of seed dormancy. Based on previous experiments, we observe an initial reduction in seed dormancy when plants are selected that germinate within 21 days in the absence of a seed treatment, but dormancy returns in subsequent generations. We believe the dormancy returns in later generations in part due to the multiple caryopses in buffalograss burs harboring some of the dormancy (if partial dormancy is caused by something more than inhibitory mechanisms in the bur coat). We repeated the above experiment, selecting plants that germinate within 14 days. After germination, the developing seedlings were excised from the burs to exclude non-germinating caryopses. The plants were propagated in the greenhouse and planted in the field in 2018. We anticipate harvesting seed in 2019 and testing if removal of the germinating caryopses reduces dormancy.

Another approach is to test if there are maternal effects influencing the level of dormancy expressed in the offspring. Maternal effects may be influenced by the environment which can be controlled, to a certain extent, by management during seed development. Buffalograss flowers throughout the growing season, so seeds may be on the mother plant for varying lengths of time. We tested whether harvest timing effects dormancy of untreated seed. Seed was harvested from a four-year-old breeder field on July 17th, August 2nd, August 16th, and September 5th, 2017. The untreated seed was germinated in germination boxes and germination counts were taken over four weeks. The results show that later harvest dates had less dormant burs (figure1). However, the variance was larger for the later date than the earlier dates. Since variability was observed in response to harvest date, more research is needed to test the environmental influence on dormancy.

We are continuing to test alternate seed treatments to eliminate the stratification period. Seed treatments that consisted of untreated, acetone (24 hour soak and no chill), water (48 hour soak and 5 week chill), and 5% potassium nitrate (48 hour soak and 5 week chill) were advanced to field trials and were consistent with previous lab tests (Figure 2). In this study, 100 burs were soaked in Dawn dish soap at two different concentrations (100% and 50%) and 10% liquid smoke for 48 hours. The seeds were also treated with ethanol at the following concentrations 25%, 50%, 75%, or 100% for 5 min, 15 min, 30 min, 60 min, 24 hr, or 48 hr which sterilized the seed. Following the seed treatments, the seed was dried for 24 hr before storing the seed for a 5-week chill period at 5°C prior to transferring them to a germination chamber. 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 3).

In the future we plan to conduct metabolomics, transcriptomics, and hormone profiling experiments at 0, 2, 4, 8, and 24 hr after treatment to identify which germination step is impacted by buffalograss dormancy mechanisms. Results should help us to resolve which treatments are likely to reduce seed dormancy and direct future studies and recommendations to native grass seed producers.

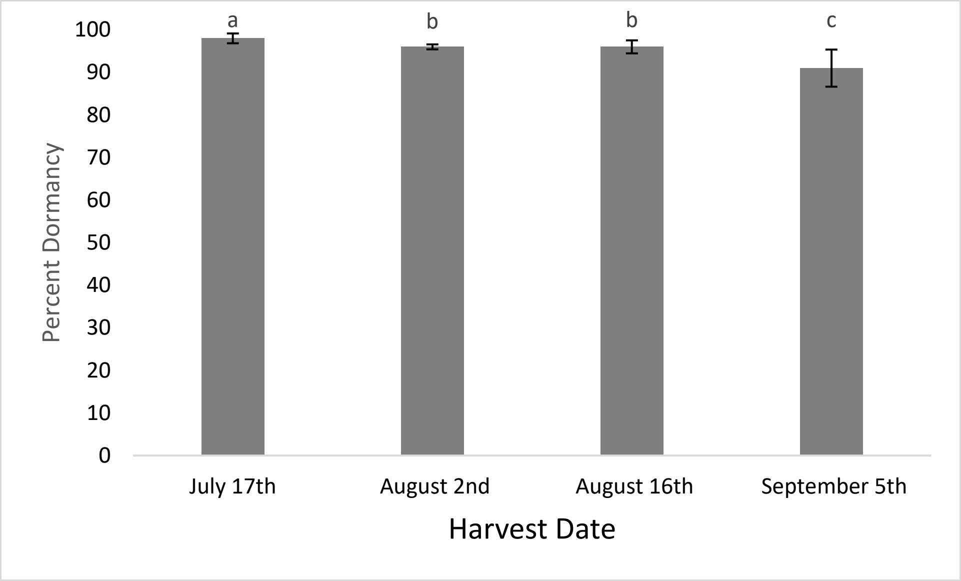


Figure 1. Dormancy of untreated buffalograss burs at different harvest dates (based on 100 seeds). Error bars show standard deviation from three replications and letters show statistical groupings based on Fisher's LSD test.

Figure 2. Buffalograss seedlings in the field, two weeks after sow date. Untreated (1), water soaked followed by five-week chill (2), KNO_3 treated followed by five-week chill (3), and acetone treated without stratification (4) burs were planted in four ft rows.

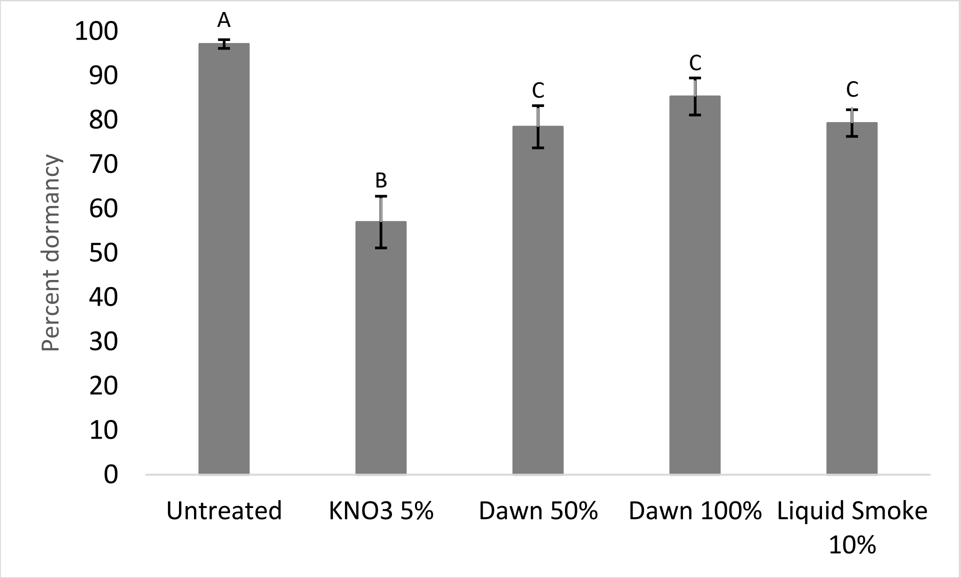


Figure 3. Dormancy of buffalograss following dormancy breaking treatments (based on 100 seeds). Error bars show standard deviation among six replications and letters indicate statistical groupings based on Fisher's LSD.

USGA ID#: 2017-33-643

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

Project Leader: Steven Smith
Affiliation: University of Arizona

Objectives: Working with the two species of interest (sprucetop grama and curly mesquite):

1. Describe field seed production procedures and estimate grain yield potential (sprucetop grama),
2. Establish seed germination testing protocols,
3. Optimize broadcast seeding rates and methods, and
4. Establish demonstration plantings.

Start Date: 2017
Project Duration: 2 years
Total Funding: $26,190

Summary Points:

- Expected grain yields for sprucetop grama are in the range of 0.11-0.14 lb/ac in Tucson, AZ.
- Curly mesquite seed should not be sown earlier than 6 months following harvest.
- Germination of curly mesquite seed (fascicle) samples should be evaluated before sowing using a technique we developed.
- Seeding rates of 468-562 PLS/ft^2 for sprucetop grama and 1524 PLS/ft^2 for curly mesquite produced LAI > 0.7 after 16 weeks in a greenhouse trial.

Summary Text:
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). The current research provides answers to remaining questions related to use of these species in turfgrass plantings at elevations below about 1000 m (3281 ft) in the Southwest.

1. Field seed production

Procedures developed at the NRCS-Tucson Plant Materials Center (TPMC) for native grass seed production were used to produce BOCH seed at the Center in 2014-2018. Approximately 3500 plants were transplanted in May 2014 at 24-in spacings on 6-in tall beds in rows 30 inches apart in a 0.40-ac field. Harvest was done using a Woodward flail-vac seed stripper in Sep.-Nov. Harvested material was air dried and grain yield determined by hand threshing samples of spicate branches. Yield of naked grains in these two years were (0.11 and 0.14 lb/ac). Similar procedures were used to produce seed on clones of HIBE at the Tucson Campus Agriculture Center (CAC) in 2014-2017. Fascicles were hand-harvested in Aug. and Sep.

2. Seed germination testing protocols

Conditioning to produce naked BOCH grains (1.1-1.3 mg/grain) is straightforward using hammermilling and air separation (Mary Wolf, NRCS, TPMC, pers. comm.). Germination percentages of BOCH naked grains samples was determined using standard techniques for warm-season grasses (AOSA, 2009).

Seed (fascicles) of HIBE is commercially available, primarily for use in revegetation projects. This uncertified “seed” is sold as un-conditioned fascicles, and often without analysis information needed to determine effective seeding rates. Conditioned (naked) HIBE grains would be expensive to produce and the grains

(0.6-0.8 mg/grain) would be difficult to sow with drill-type seeders. We developed methods for assessing pure live seed (PLS) contents of HIBE seed lots and used these to determine change in germination rate in the 52-week period following harvest in 8 clones grown in the field at CAC.

Naked HIBE grains were obtained by rubbing fascicles on a ribbed rubber mat and winnowed using gentle shaking and low-pressure air. Grains were placed on #2 filter paper within 100-mm^2 Petri dishes. The filter paper was wetted with 3 mL of a fungicide solution (0.4 g Captan WP/400 mL water), grain added, and-dish sealed within a Ziploc bag with a moistened paper towel. These were held in the dark at 22-26° C for up to 6 days when germination was evaluated.

We developed a protocol that could be used by turf managers to plan HIBE seeding projects. Replicates of 20 fascicles were placed on tap-water-moistened paper toweling inside of a Petri dish that was sealed inside a Ziplock bag. These were exposed to ambient light under normal workplace conditions (25-27° C). Germination was evaluated after 6 days and was considered to occur if a radicle and coleoptile longer than 4 mm from a grain or 2 mm from a fascicle.

Using fascicles harvested in 2017, and stored at 25-27° C, initial germination for grains extracted from fascicles immediately before testing was about 5% and increased steadily for about 40 weeks to an apparent maximum (Fig. 1). This suggests that to achieve maximum PLS, HIBE fascicles should not be planted before six months following harvest.

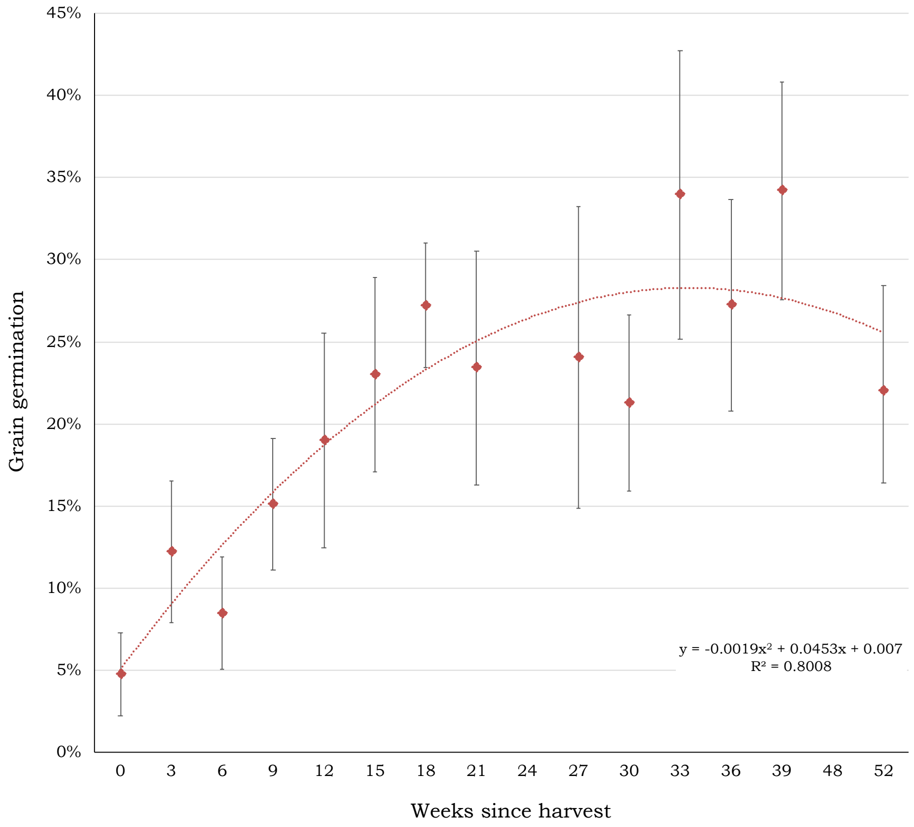


Figure 1. Germination percentage of naked HIBE grains extracted from fascicles immediately before testing over the period 0-52 weeks following harvest.

3. Seeding rates and methods

Seeding rates and methods were determined in a greenhouse study from Oct. 2017-Sep. 2018. For HIBE, we evaluated different broadcast sowing methods using an unconditioned commercial seed lot containing mostly fascicles (mean: 529 grains/g of sample with fascicle germination = 10.1% = 53 PLS/g of sample). For BOCH, we used naked grains produced in 2014 at the Tucson PMC.

Initial seedings were made in 11.0 × 21.4 × 2.4-in (“1020”) trays in Sunshine® Professional Growing Mix #4 and sand in a 4:1 volume ratio. We later used Scotts SuperSoil® Potting Soil. Sodium vapor lamps provided supplemental light and temperatures were 18-30° C. All plants were clipped when total plant height was 12-18 cm. BOCH was clipped to a height of 6.25 cm and HIBE to 5 cm.

BOCH was sown at seeding rates of 94, 187, 281, 468, and 562 grains/ft^2 (PLS) in furrows at depths of 1 and 2 cm. HIBE was initially sown as both naked grains and as fascicles at 15, 29 and 44 grains or fascicles/ft^2 (PLS) also at 1 and 2 cm depths. Later HIBE fascicle seeding rates were increased to 13.0 and 28.8 g/ft^2 (approximately 688 and 1524 PLS/ft^2). These HIBE seeding rates were assessed using three sowing techniques: surface placement with rolling, surface placement with mulched straw cover, and surface placement with 1 and 2-cm soil cover followed by rolling.

Percentage emergence was measured 14 days post sowing and leaf area indices (LAI) were assessed three times at 60-day intervals. We calculated LAI as visible leaf area per unit ground surface area, which was defined as the bounding rectangle of the planted area. This definition suited BOCH, which increases surface area primarily through basal tillering. HIBE also produces stolons that appear on erect culms that then become decumbent and root. This species has a greater tendency to spread laterally than BOCH, but lateral establishment outside the planted area is not reported here.

Our goal was to determine seeding rates and methods for both species that would produce at least 0.750 LAI within 16 weeks. We believed this was a reasonable value given that the growth habit of these species may require more time to produce complete cover compared to traditional warm-season turf species.

Overall, BOCH grains had 42.8% (998/2332) emergence, HIBE grains 28.2% (122/432), and HIBE fascicles 30.0% (1436/4788). There was no significant difference in emergence based on planting depth for BOCH. The best sowing method for HIBE proved to be surface fascicle placement with 2-cm soil cover followed by rolling. BOCH seeding rates of 468-562 PLS/ft^2 produced suitable ground coverage, as did HIBE rates of 1525 PLS/ft^2 (Table 1).

Table 1. Seeding rates and mean leaf area indices (LAI) for BOCH grains and HIBE fascicles 16 weeks post emergence in greenhouse experiments involving 2-cm soil covering and rolling.

BOCH grains		HIBE fascicles	
Seeding Rate (PLS/ft^2)	Mean LAI	Seeding Rate (PLS/ft^2)	Mean LAI
281	0.662	688	0.625
468	0.731	1525	0.796
562	0.755		

4. Establishment of demonstration plantings

Demonstrating plantings involved two seeding rates for BOCH (280 and 468 PLS/ft^2) and HIBE (688 and 1524 PLS/ft^2 as fascicles) and one seeding rate of 'NuMex Sahara' bermudagrass (1441 PLS/ft^2) in 21.5 x 15.5 x 4-in metal flats filled with a peat-soil-sand greenhouse soil mix. After broadcasting into an 11 x 13-inch area, fascicles or grains were covered with 2-cm soil mix, and the soil surface rolled.

The experiment was established on 9 July 2018 in a greenhouse at 30-35° C and the resulting 1-ft^2 planted microplots (Figs. 2-4) transplanted from establishment flats to the field at Karsten Turfgrass Research Facility in Tucson on 18 Sept. They are irrigated following standard practices for bermudagrass and mowed at 7.6 cm (3 in) weekly. Turf quality, LAI, and density were evaluated monthly beginning in mid-November.

Goals for 2019

Our goals for 2019 are to continue to evaluate field performance in the demonstration plantings, and to then summarize our findings to produce recommendations for agronomic and seed production practices in *Plant Guides* for each species. These guides will be produced working with TPMC staff.

Reference

AOSA, 2009. Rules for testing seed. Association of Official Seed Analysts, Ithaca, NY.

Figure 2. Curly mesquite sown at 1524 PLS/ft^2 6 weeks after sowing and clipped once at 7.6 cm (3 in).

Figure 3. Sprucetop grama sown at 468 PLS/ft^2 6 weeks after sowing and clipped once at 7.6 cm (3 in).

Figure 4. NuMex Sahara bermudagrass sown at 1441 PLS/ft^2 6 weeks after sowing and clipped once at 7.6 cm (3 in).

USGA ID#: 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: 11 years
Total Funding: $110,000

Summary Points:

- Sequencing technology now allows for analysis of microbes associated with the rhizosphere of turfgrass plants
- We compared several prairie junegrass accessions for associated rhizosphere microbial populations.
- These results suggest that prairie junegrass accessions differ in how they affect the development of rhizosphere microbial populations. These differences could be exploited in a turfgrass improvement program.

Summary Text:

Prairie junegrass (*Koeleria macrantha*) is a native, perennial, prairie grass that has demonstrated characteristics that are desirable in low-input turfgrass situations. This grass is native to many parts of North America, especially the Great Plains. The traits that allow this grass to survive and flourish in a cool-arid environment of temperature extremes (both low and high) as well as periods of reduced water availabiliy, could be exploited in a turfgrass breeding program. The University of Minnesota breeding program has evaluated and selected this species for a number of years. 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, such as poor mowing quality, susceptibility to rust disease, and low levels of seed production when grown for that purpose. A major advantage of using this species in low-input golf course roughs is its slow vertical growth habit which would lead to a reduced mowing requirement.

Throughout the course of this project, we have conducted field, greenhouse, and laboratory research to improve this species for turf use. Recently, plant science researchers have been exploring manipulation of the phytobiome, which refers to a plant and the microbes in, on, and around the plant. Of the components of the phytobiome, we are most interested in the soil microbiome, and we are paritcularily interested in how plants affect the composition of the soil microbiome. Therefore, during the past year, we have further analyzed results from a greenhouse experiment aimed at determining if different prairie junegrass accessions would lead to different microbial populations in the soil. To do this, we randomly selected 32 genotypes from each accession or cultivar (Barleria and Barkoel, both European cultivars), seeded them in the greenhouse, and then transplanted them at the three-leaf stage. Each of the randomly selected plants was vegetatively propagated into 16 single tiller clones which were potted into 4-inch pots into a 2 part Sunshine MVP (Sun Gro Horticulture, Agawam, Washington) to 1 part Turface (Profile Products LLC, BuffaloGrove, Illinois) mix. For comparisons between accessions, five individual genotypes were randomly selected from the initial group of 32 plants and were then vegetatively cloned so that each genotype could be replicated three times (three clonal plants for each genotype within a population). In order to assess turf performance, each genotype was scored for turf quality using a 1-9 scale with 9 representing best quality based on color, freedom from disease, mowing quality, and crown density.

In order to study the bacterial community in the *Koeleria* rhizosphere, bacteria DNA was extracted using rhizosphere soil from each sample. To construct the Illumina sequencing library, 16S rDNA was amplified by PCR using a universal primer. Amplicons were purified and barcoded. Sequencing was done via Illumina MiSeq platform, 150 bp read length paired-end sequencing mode. Raw reads were trimmed with Illumina adaptor and barcode sequences. Primer mismatches and nucleotides with Phred score below 30 were also removed. Quality filtered reads were analyzed using Mothur pipeline. Downstream analysis was conducted using bioconductor package “phyloseq” in R. Figures were plotted using ‘ggplot2” package in R.

Understanding how collections from different regions or countries might affect the soil microbe community in the rhizosphere could lead to new knowledge on how to focus collection efforts. In our study, we used operational taxonomic unit (OTU) to classify groups of closely related individuals. We wanted to determine if turf quality and bacterial communities have some association so we used a permutation test; the results suggested there is a significant correlation between turf quality and the microbeal community associated with the grass ($p<0.001$). This is an interesting assoication; however, it will be useful to see if these associations exist for important functional traits useful in a low-input turfgrass, such as persistance or summer stress tolerance.

There are a number of different analyses that could be used to identify how different accessions affected soil microbial populations; we utilized three of these approaches. First, to visualize the phylum composition of each sampling country of origin, the normalized dataset was quality controlled so only bacteria data are used for analysis. As can be seen in Figure 1, there were differences in bacterial community diversity based on prairie junegrass accession. Next, we utilized a Principal Component Analysis (PCoA), which indicated that most *Koeleria* genotypes from the same country of origin share similar bacterial community (Fig. 2). In our study, *Koeleria* genotypes from Afghanistan resulted in the most diverse bacterial community. Finally, we wanted to visualize how prairie junegrass genotypes might cluster based on the microbes that were found in their rhizosphere. In order to do this we constructed a phylogenetic tree using bacterial species occurrence, frequency, and richness. As can be seen in Figure 3, we identified approximately 8 branches within our dataset. We generally found that accessions from different countries were separated into different branches. Roughly, 8 branches within the dataset, most genotype biological replicates are clustered within a branch, *Koeleria macrantha* from different countries of origin are somehow separated.

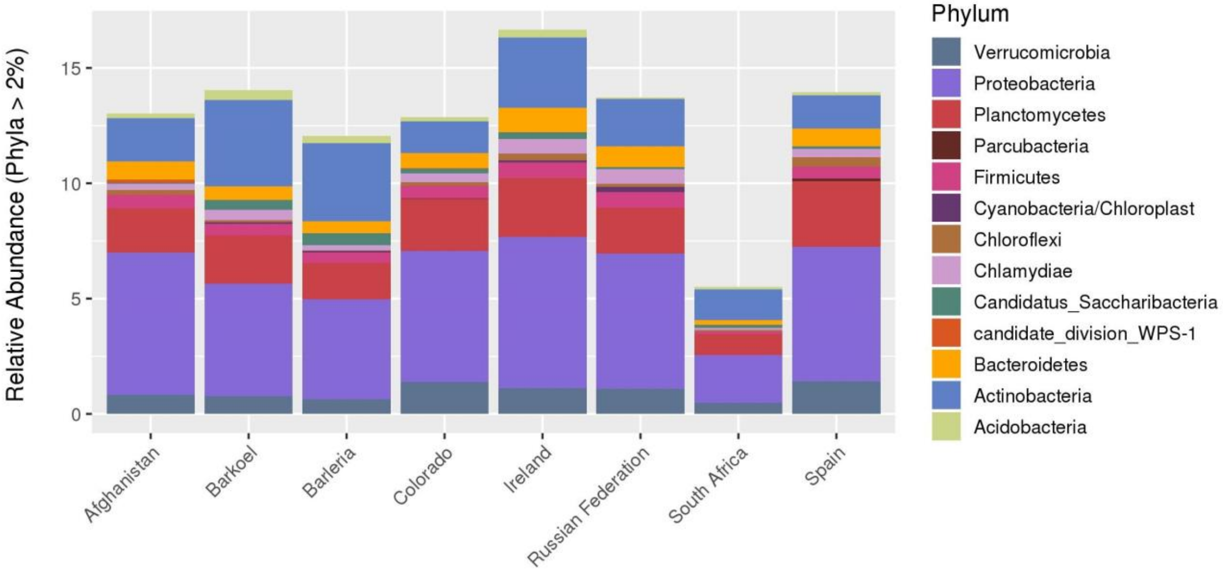


Figure 1. Phylum composition of *Koeleria macrantha*-associated bacterial communities.

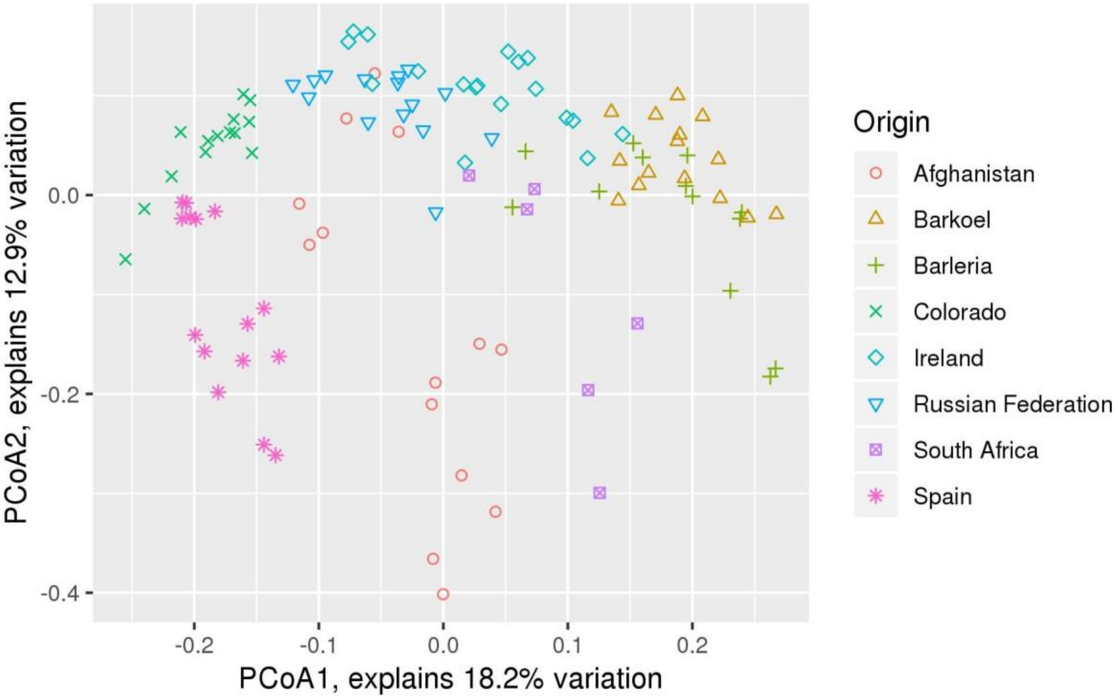


Figure 2. Principal component analysis (PCoA) plot of the bacterial community inhabiting *Koeleria macrantha* rhizosphere soil.

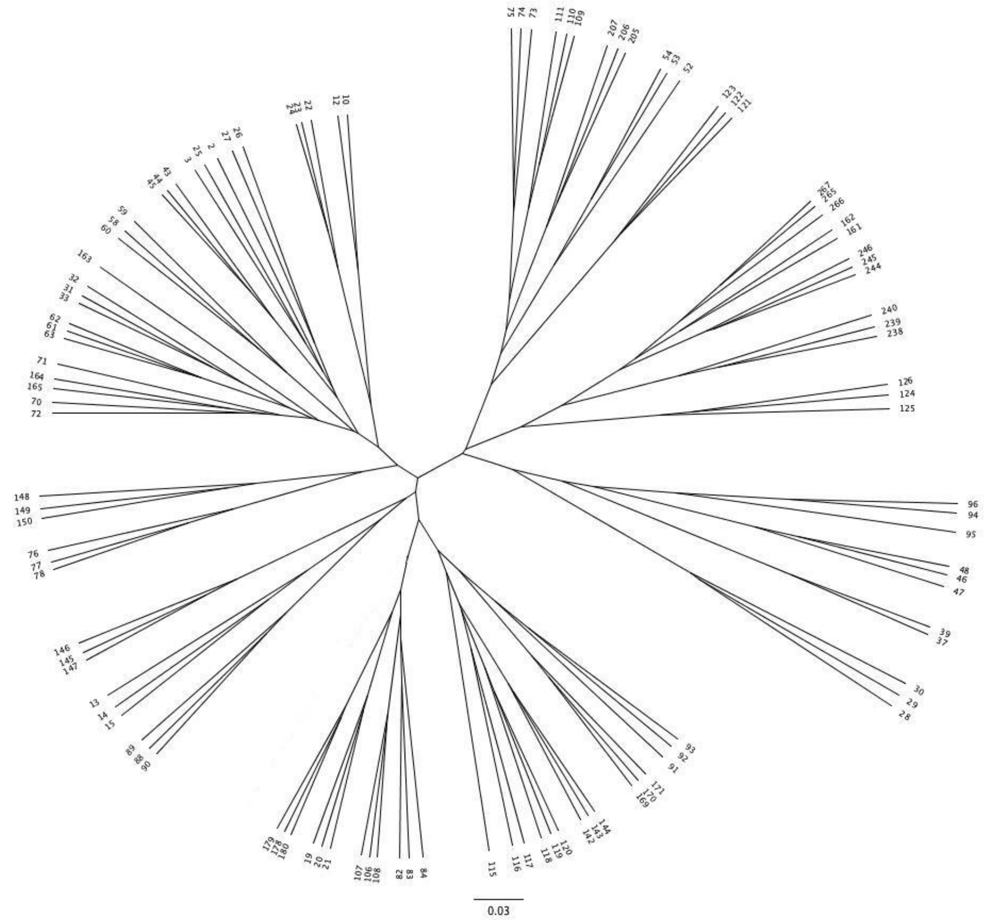


Figure 3. Phylogenetic tree of OTUs associated with each sampled *Koeleria macrantha* genotype. Each line represents a different genotype.

USGA ID#: 2016-04-554

Title: Development and Release of Turf-Type Saltgrass Variety

Project Leaders: Yaling Qian and Tony Koski
Affiliation: Colorado State University

Objectives:

1. 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.
2. 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.
3. Continue to evaluate several seeded lines for potential release; and collect data and prepare document for potential release of seeded saltgrass varieties.

Start Date: 2016
Project Duration: 3 years
Total Funding: $90,000

Summary Points:

- Two lines with different turf characteristics were selected for potential release as vegetative cultivars.
- Several lines with adequate commercial seed production yields have been established in the field for evaluation for potential release as seeded cultivars.
- Mini-rhizotron images indicated that root growth in container grown saltgrass showed increased flushes of fine root growth in response to moderate levels of salinity (8 dS/m) compared to the control.
- Field-grown saltgrass plots of varying stand age (1, 4, 5, and 8 years) demonstrated that saltgrass root mass was greater with increasing stand age.

Summary Text:

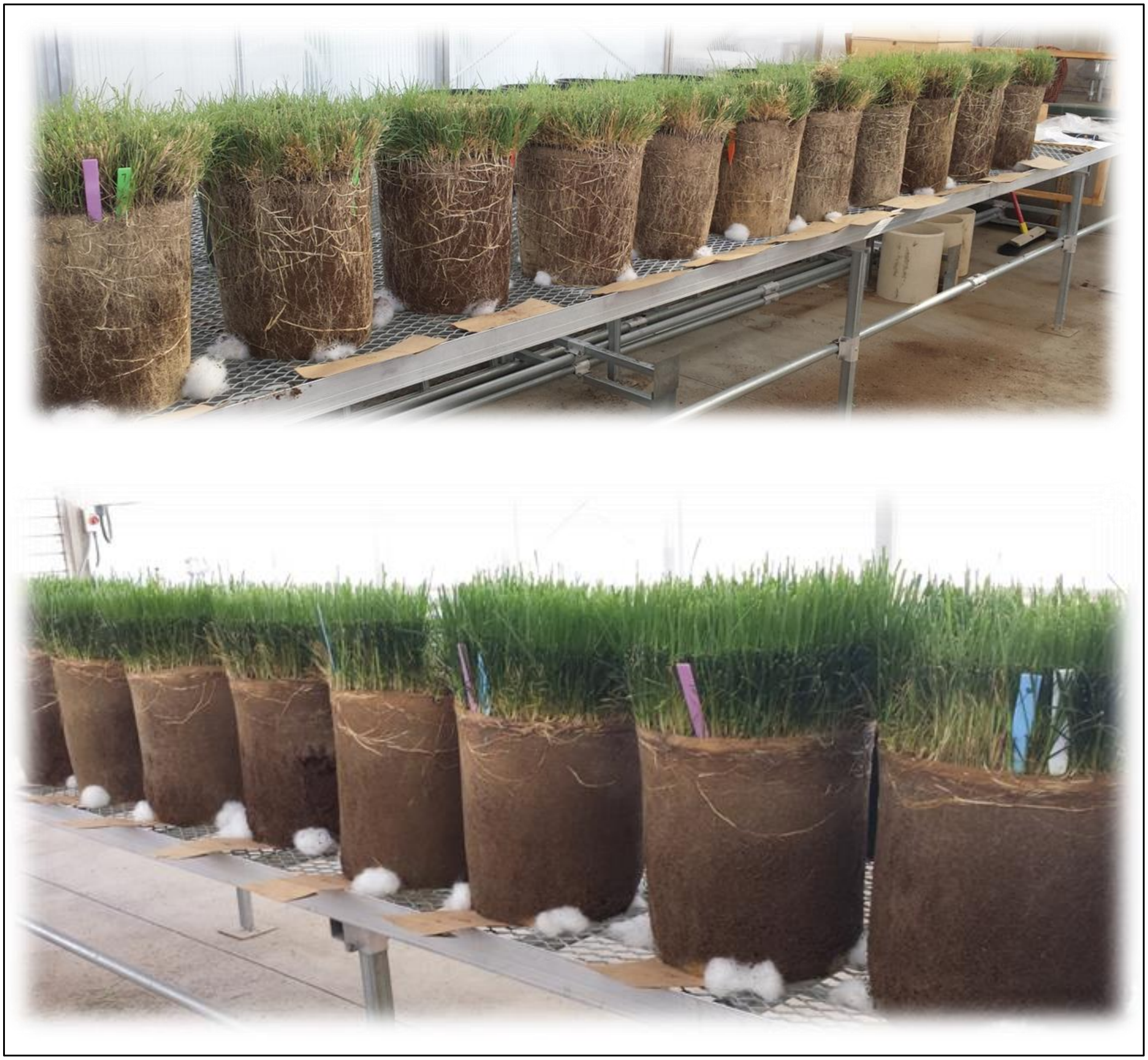
In the United States salinity related plant growth reductions occur on an estimated 25-30% of all irrigated land. In Colorado alone, almost 1 million acres of irrigated land are negatively impacted by salinity. In California, 4.5 million acres of irrigated land is affected to some degree by soil salinization. Inland saltgrass is indigenous to western North America, it is adapted to specific niches of alkaline and saline soils. The use of saltgrass on landscapes and golf courses could help turf industry to conserve potable water because of its tolerance to lesser quality water. Saltgrass has value for use as turfgrass and as a remediation/revegetation plant in areas that commonly have high soil salinity levels.

Cycle 3 Breeding Effort: In a continuing effort of the development of turf-type saltgrass, seeds from the third generation crossing block were harvested. Individual seeds were stratified and germinated in the greenhouse. Resulted single seed plugs were used to initiate field plots in the spring of 2017. In 2017 and 2018, data was collected monthly on turf quality, growth height, disease incidence, number of tillers per unit area, and cover percentage during the growth season, sex, and the number of seed heads per unit area. Data collected indicated that most of the lines did well during the second season. Five lines of third generation of saltgrass that showed the best turf quality in terms of cover, color and density were selected. The top lines with very few seedheads were selected for future development as vegetative lines. The top five female lines and 5 male lines with abundant seedheads were also selected. In 2018, seed yield data was collected for selected females. In 2018, most female lines produced seeds but few of them produced significant amount. Typically, female plants produced significantly more seeds during the second season than the year of establishment. One line showed the highest seed production at 1504.0 lb per acre.

Vegetative lines: Among numerous saltgrass lines evaluated, two lines with distinguished different characters were selected for potential release as vegetative cultivars. We are in contact with a sod producer to grow vegetative saltgrass lines on a sod farm. The deep rhizome growth characteristics of saltgrass makes conventional sod production for saltgrass difficult (Picture 1). Therefore, we have set up a study to evaluate the feasibility for using plastic netting for saltgrass sod production. We will try to harvest next year to test the tensile strength of saltgrass. The vegetative inland saltgrass lines have been established using sprigging establishment. Results indicated that saltgrass sprigged in May established adequate coverage in September with sprigging rates at > 270 bush/acre. Our experiment indicated that the growing degree day requirements are higher to establish sprigged vegetative saltgrass lines when compared to seeding establishment of saltgrass. Although labor and time intensive, it is also feasible to establish saltgrass using plugs. We are looking into interested companies to grow these saltgrass lines via plugs and sprigs.

Evaluation of Seeded Lines and Seed Production: The saltgrass accessions selected from previous nurseries were planted as open pollination crossing blocks to evaluate seed production. About 60% of all females produce seeds. Twenty percent of females showed promise for further evaluation since those lines reached commercial seed production yields in our research plots. Some parental materials have been planted in 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. In the meantime, we are evaluating trait stability and turf quality of several potential seeded saltgrass cultivars. Five potential seeded lines have been established in the field for evaluation. Several plots are small due to limited availability of seeds. If these plots prove to have acceptable turf quality and trait persistence, they will have potential to be released to interested parties.

Saltgrass Root Growth and Characteristics: Two separate experiments were conducted to (I) evaluate root growth of inland saltgrass under saline conditions in a growth chamber and (II) observe unrestricted root growth in the field both over time with a minirhizotron camera system, and in stands of differing age with a soil coring method. In the first experiment, root growth in container grown saltgrass under salt stress showed increased flushes of fine root growth in response to moderate levels of salinity (8 dS/m) compared to the control. Root growth started to increase about 3 weeks after salt treatments began. In-growth root tubes placed in the soil of the salt stressed saltgrass showed trends of increasing rhizome growth under moderate levels of salinity. In experiment II, field-grown saltgrass plots of varying stand age (1, 4, 5, and 8 years) had less root biomass in the top 30 cm of soil compared to bluegrass. However, saltgrass had roots down to 275 cm in stands that had been growing longer than 4 years. In soil depths to 1.8 m, saltgrass root mass was greater with increasing stand age (Figure 1). Findings that saltgrass produced roots deeper in the soil profile and root growth was stimulated by moderate saline soil may impact where and when it is used. If stored moisture is present deep within the soil, saltgrass has a unique ability to mine this water. Deep rooting can also have implications for slope stabilization which can be important in the arid west where bare slopes can be stripped of soil during heavy and infrequent rainstorms. The responsiveness of rooting in saline soils may be the underlying mechanism explaining the enhanced growth of saltgrass under mild saline conditions.



Picture 1. Saltgrass (upper panel) and Kentucky bluegrass (bottom panel) grown in growth chambers, showing the deep rhizomes and root growth characteristics of saltgrass when compared to Kentucky bluegrass.

Figure 1. Average root biomass by depth in soil cores sampled from saltgrass (SG) field plots of different ages.

USGA ID#: 2016-05-555

Title: Improved Wheatgrass Turf for Limited Irrigation Golf Course Roughs

Project Leaders: Joseph G. Robins and B. Shaun Bushman
Affiliation: USDA ARS Forage and Range Research, Logan, UT 84322

Objectives:

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

Summary Points:

- All data collection is complete except for the final species composition.
- Refereed journal article submitted for review in 2019.

Summary Text:

Population growth continues in drier areas of the US exacerbates limited freshwater sources and puts pressure on the ability of available sources to meet culinary, industrial, agricultural, and landscaping needs. There is a need for turfgrass species for landscape and recreational purposes, such as golf courses, that require substantially less supplemental irrigation. Native North American and Eurasian wheatgrass species are well-adapted to grow and persist in these arid and semi-arid regions and have great potential for production in lesser-used areas of golf courses. 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.

To address the need for wheatgrass turf production, the USDA (Logan, UT) turfgrass breeding program develops improved germplasm of crested, intermediate, thickspike, and western wheatgrasses. The subject of this research project was the characterization of improved sources of these species compared to standard varieties under monoculture and mixture conditions.

In fall 2016, we established plots 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 and , 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 the data collection component of the study in October 2018. We are now converting the digital images to numerical values using a software algorithm. Once completed, we will analyze the numerical data to determine which species and mixtures resulted in the highest turfgrass quality across mowing heights. Next spring, we will also determine the species composition of each plot to determine which species, and mixtures, persisted best over the course of the evaluation. 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.

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

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 focus on reducing the use of water, pesticides, fertilizers, and energy. The objectives of these studies include:

- Developing cultural practices that allow efficient turfgrass management under unique conditions such as drought and deficit irrigation, irrigation with marginal quality water, poor quality soils, and shade
- Determining the range of adaptability and stress tolerances of turfgrasses
- Evaluating direct and interacting effects of two or three cultural practices such as irrigation, mowing, fertilization, cultivation, compost utilization
- Investigating 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

USGA ID#: 2016-14-564

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

Project Leaders: Kai Umeda and Worku Burayu
Affiliation: University of Arizona

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

Summary Points:

- Amount and uniformity of irrigation markedly affected the overall quality of plants;
- At Scottsdale, AZ, Kurapia, plains lovegrass, alkali sacaton, blue grama, big galleta, and alkali muhly performed well for all quality parameters;
- In Sun City West, AZ, big galleta, blue grama, Kurapia, and sand dropseed performed well;
- The evaluations and observations at both sites indicated that Kurapia was very aggressive and vigorous as a groundcover.
- Differential growth between tall and short stature nativegrasses provided information for potential sites where each type of grass could be utilized.

Summary Text:

The recent water restrictions in the desert southwest indicate an urgency to find horticultural planting materials that are appropriate for satisfying the landscaping needs of the low desert, while at the same time minimizing inputs and maintenance needs. 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. Two field trials consisting of nine grass species, a native forb, and an introduced horticultural groundcover (Table 1) were initiated in May 2016 at Camelback Golf Club in Scottsdale, AZ and in June 2017 at Briarwood Country Club in Sun City West, AZ. Treatment plots were arranged in a randomized complete block design with 3 or 4 replicates. The project is the continuation of our recent findings (2016 & 2017 reports) on germination, emergence and establishment of nativegrasses and groundcovers in the low desert environment of Arizona. This report is a summary of results for the third-year with special emphasis on the overall plants' quality data for greenness, percent ground cover, and growth uniformity at varying levels of irrigation practices per four growing seasons: summer, fall, winter, and spring. Overall visual quality rating was evaluated each week for greenness, ground cover, and uniformity. The quality ratings from 1 to 9 were (1 = poor and 9 = excellent). Greenness ratings from 1 to 9 were (1 = brown and 9 = dark green). In this study, nativegrasses and groundcovers with potential desirable qualities were determined as those showing moderate to high quality (average ratings $\geq$ 5) across the years and seasons. Visual ground cover ratings from 0 to 10 were measured for plots with almost no vegetative cover (0) and complete coverage of the area with no visible soil (10). Data were analyzed using JMP ver. 13 statistical software and means compared using Student's t-test. The project's ultimate goal is to provide the professionals of the Arizona green industry and golf courses with specific recommendations for the best management practices including low-input crop management practices (fertilizer and water applications, pesticide use, and cultural maintenance practices), integrated pest management strategies, soil and erosion management, and conserving water by using low-input new groundcovers and native grass species. More reliable results obtained over multiple years of research, replicated over locations and seasons, and varying site management practices will lead to achieving the ultimate goals.

Results:

Nativegrasses and groundcovers exhibited variable performance for the overall plant qualities including greenness (Figure 1), area coverage (Figure 2), and growth uniformity (Figure 3). Big galleta, blue grama and Kurapia exhibited the best stand uniformity at both locations also provided the best total coverage of the plot areas. Kurapia, alkali sacaton, blue grama, plains lovegrass, and alkali muhly remained green throughout the year, even through the winter. Kurapia exhibited the most appealing and aesthetic cover when mowed, and proliferation of flowers when not mowed (Figure 4). Plant area coverage was significantly correlated to the growth uniformity of the plants (Figure 6). It was observed that uniform irrigation was required to obtain even establishment and full plot area coverage. Continued research replicated over locations and seasons are needed to obtain more reliable information about each species desirable growth characteristics, their required inputs, and pest management requirements.

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*

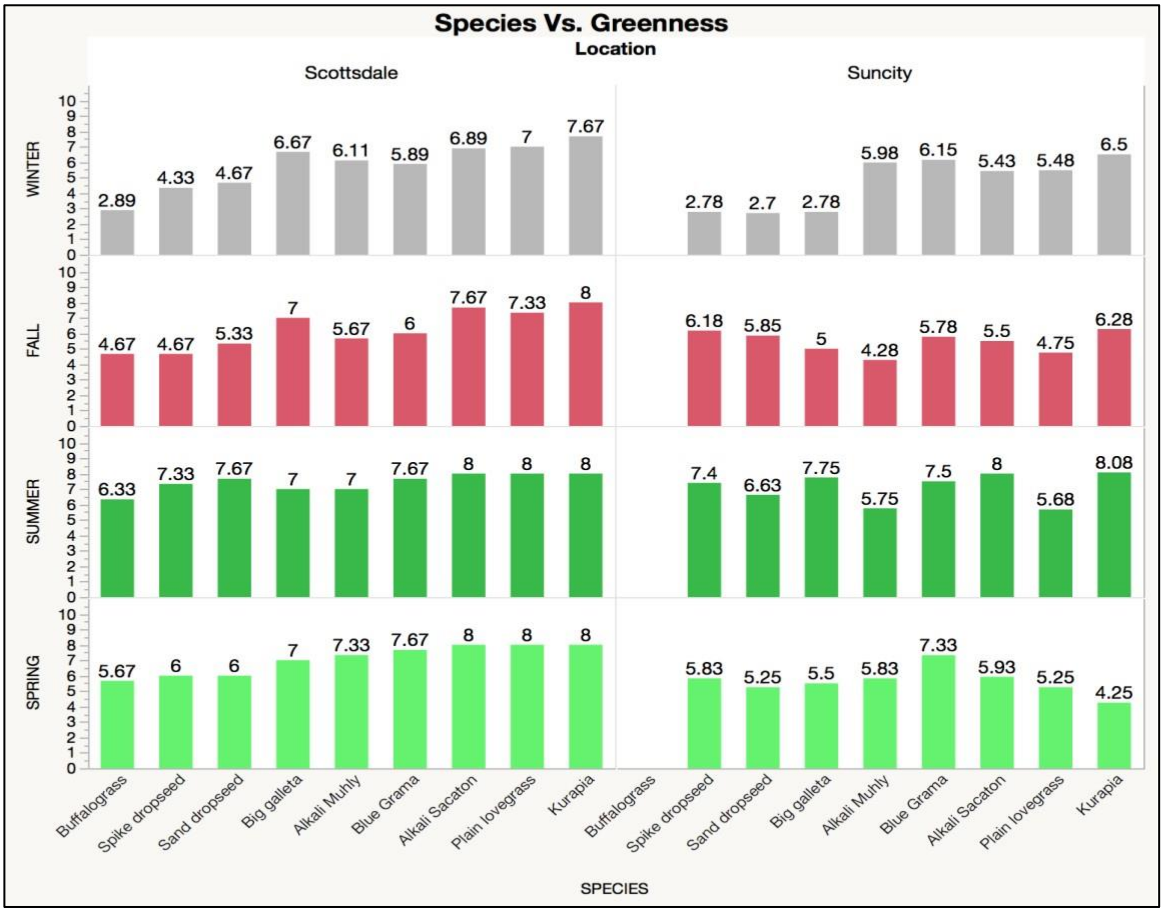


Figure 1. The performance and qualities of nativegrasses and groundcovers for greenness across four seasons (summer, fall, winter and spring) at Scottsdale and Sun City West, AZ. Note the quality values of $\geq$ 5 is acceptable quality for each parameter.

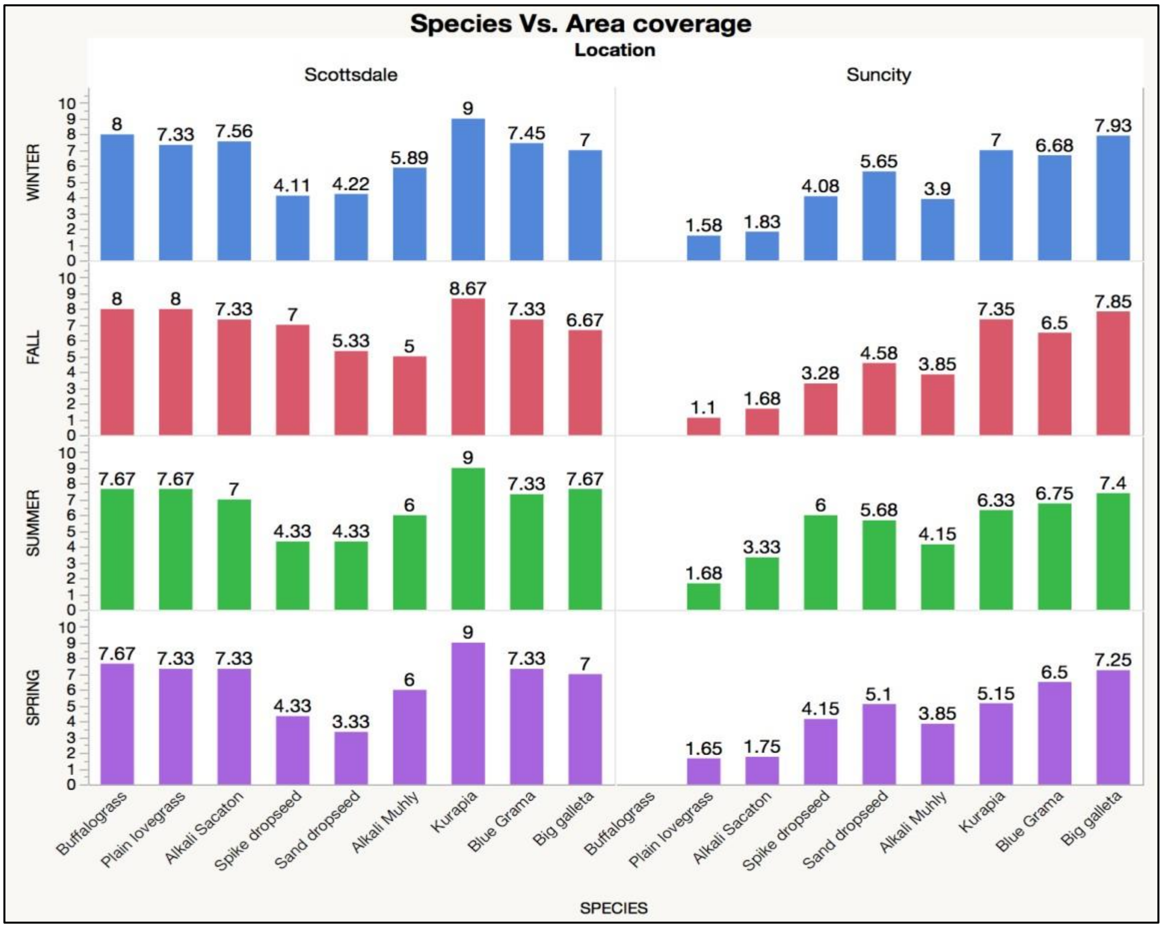


Figure 2. The performance and qualities of nativegrasses and groundcovers for area coverage across four seasons (summer, fall, winter and spring) at Scottsdale and Sun City West, AZ. Note the quality values of $\geq$ 5 is acceptable quality for each parameter.

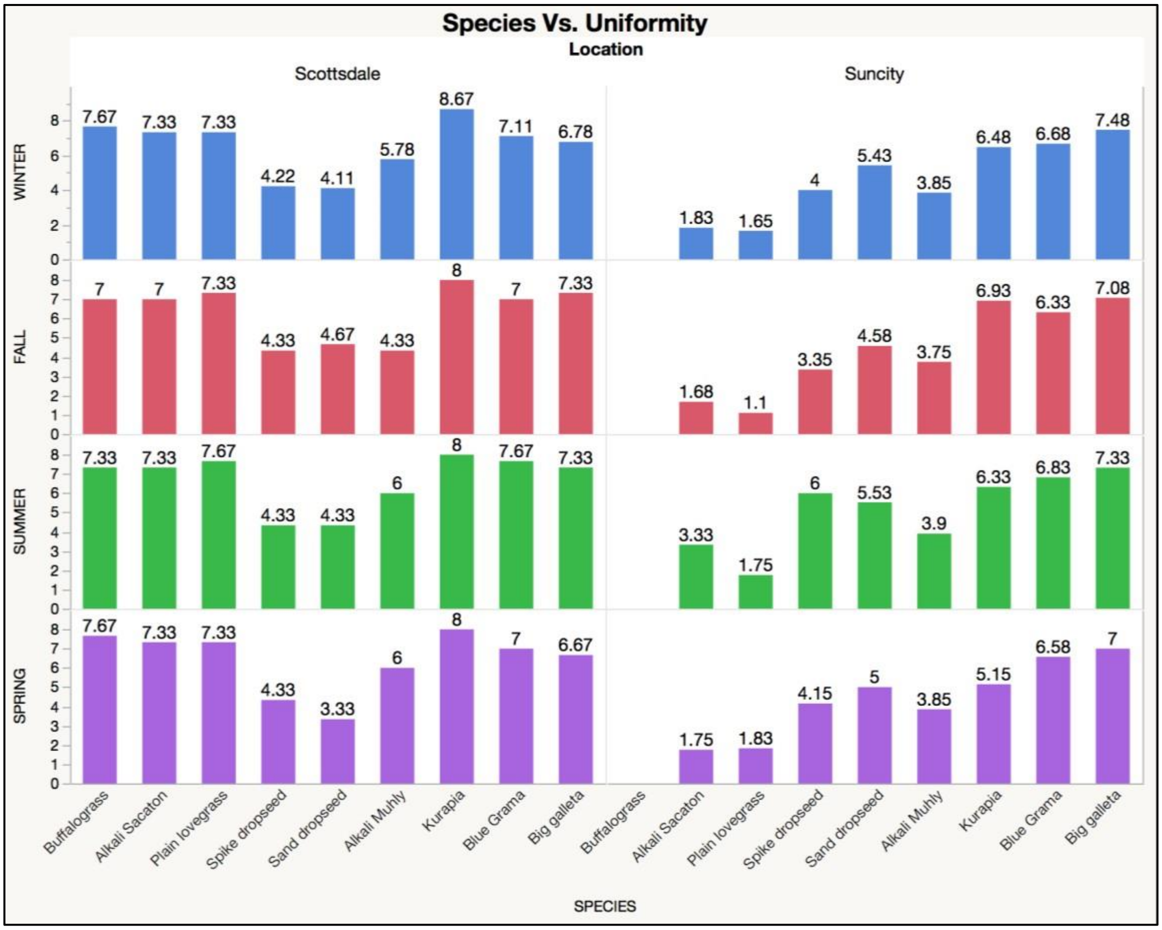


Figure 3. The performance of nativegrasses and groundcovers in growth uniformity across four seasons (summer, fall, winter and spring) at Scottsdale and Sun City West, AZ. Note the quality values of ≥ 5 is acceptable quality for each parameter.

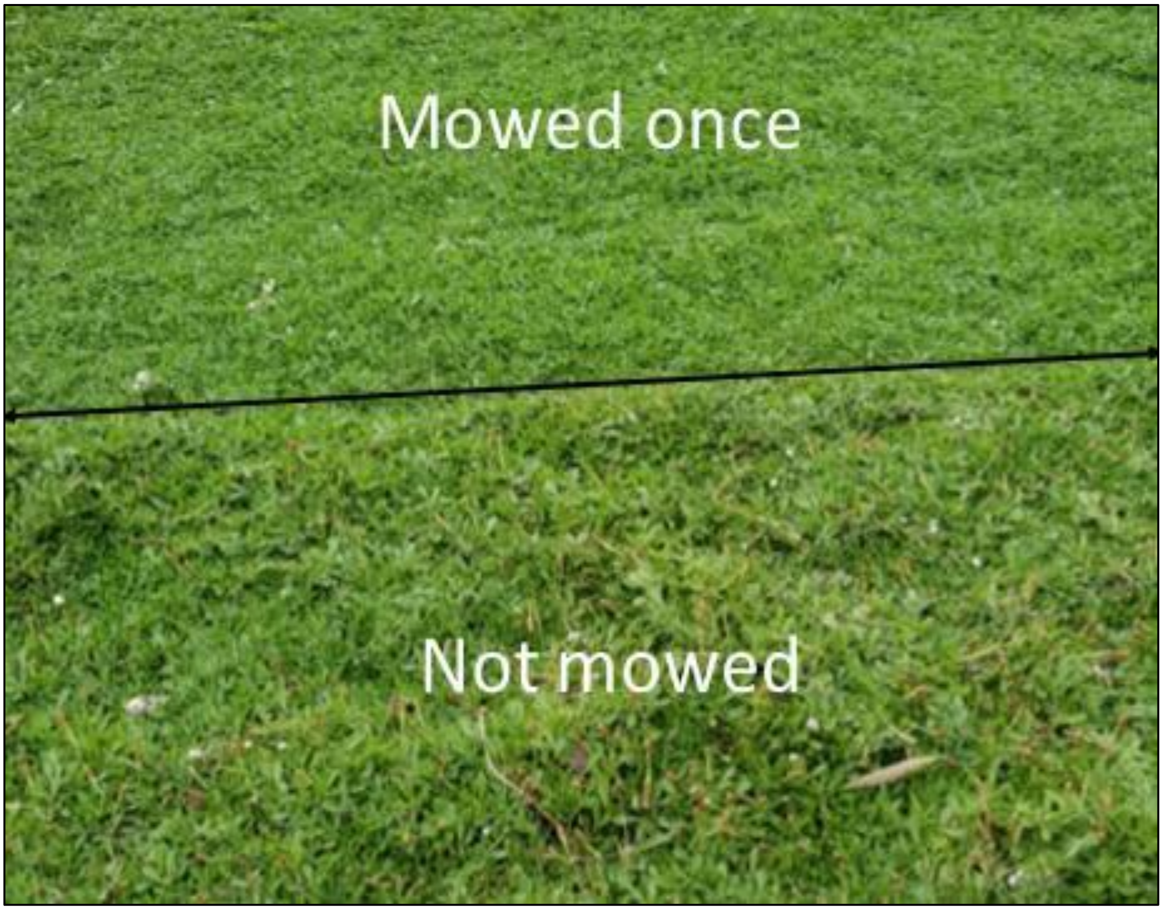


Figure 4. The aesthetic appearance of Kurapia when mowed and proliferation of flowers when not mowed during the 2017-2018.

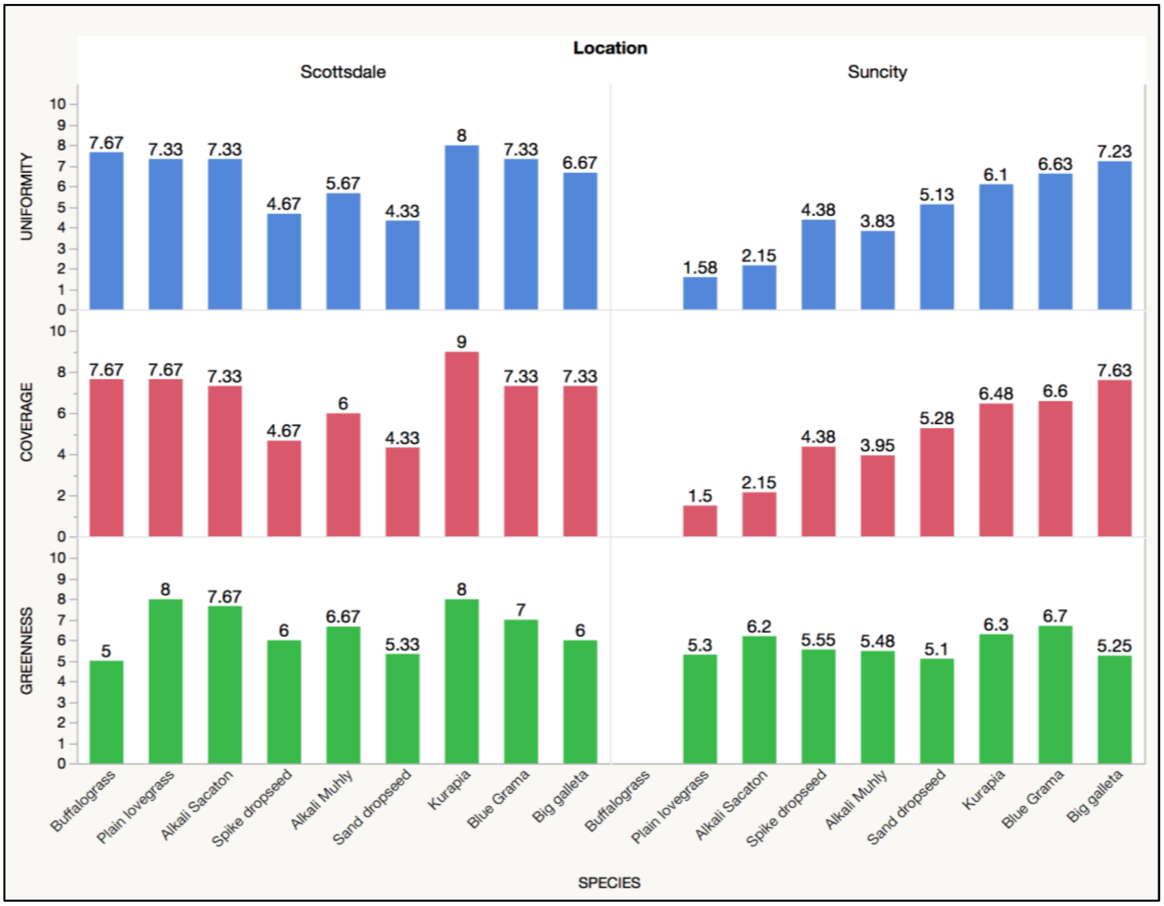


Figure 5. Greenness, area coverage and uniformity of nativegrasses and groundcovers under field conditions of two locations (average of the four seasons). Note the quality values of $\geq$5 is acceptable quality for each parameter.

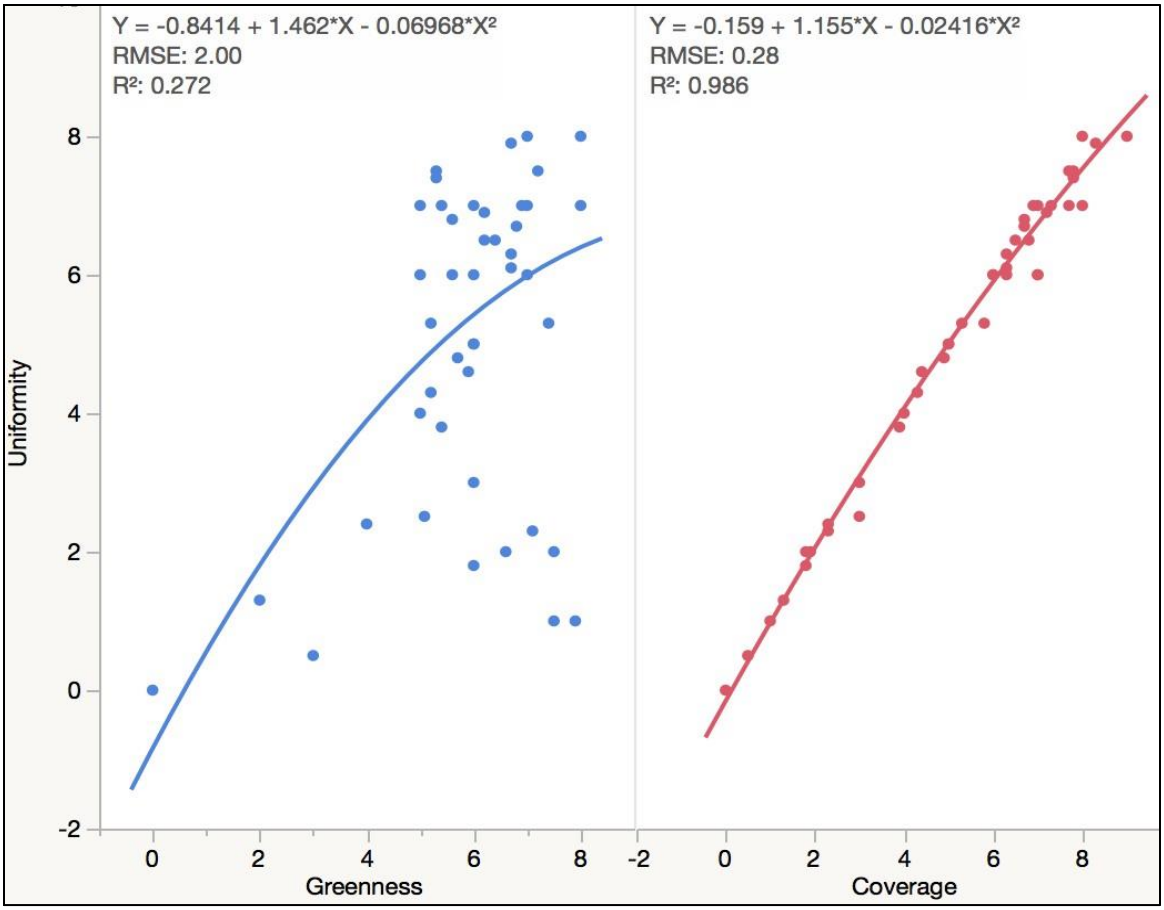


Figure 6. The significant correlation of area coverage to the growth uniformity of species.

USGA ID#: 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 Points:

- Twenty alternative and native grass species were established at 3 sites in Central California.
- Differences were detected for NDVI, plant density, and stand height.
- Overall, *Festuca ovina* (sheep fescue), *Koeleria macrantha* (prairie junegrass), and *Muhlenbergia rigens* (deer grass) established poorly and do not show promise for establishment from seed.

Summary Text:
To conserve natural resources, increase economic savings, and comply with legislative restrictions, golf course managers have 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, native 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, and mowing. 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.

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 functional, low-input stand of vegetation.

Objectives 1 and 2
Three field trials were established to measure the performance of different grasses:

1. a cool-season variety trial at a golf course in San Luis Obispo, CA
2. a cool-season variety trial at a UC Research and Extension Center in Parlier, CA
3. a warm-season variety trial at a UC Research and Extension Center in Parlier, CA

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 5 replications at the San Luis Obispo site and 4 replications at the Parlier (Fresno) site (Figure 3a). Ten warm-season species were seeded May 2018 in 3.7 x 1.5 m plots, at a rate of 324 pure live seed/m^2 (Table 2). Plots were arranged in a randomized complete block with 4 replications at the Parlier site (Figure 3b).

No fertilizer was provided. For all trials, plots were well-watered for the first 3 weeks; then, irrigation was applied 2 times per week at 100% reference evapotranspiration (ET_0) for the following 6 weeks. No subsequent irrigation was provided for the cool-season species trial in Fresno and seasonal precipitation occurred from November 2017 to April 2018. Regular irrigation was provided for the San Luis Obispo site. For the warm-season trial in Fresno, subsequent irrigation was provided every 10 days at 30% ET_0 from July 2018 to present. Broadleaf weeds were controlled with 3 applications of carfentrazone + 2,4-D + MCPP + dicamba (Speedzone Southern). At the San Luis Obispo site only, kikuyugrass weeds were controlled with quinclorac (Drive) and glyphosate (Roundup).

Data were collected to measure establishment success, playability, and stand health with the following metrics: Normalized Difference Vegetation Index (NDVI) collected with a Trimble GreenSeeker handheld crop sensor, plant density counts (established plants/area) collected with a quadrat, and stand height. Data were collected when plots reached maximum stand height, which was 6 months after seeding the cool-season species trials and 3 months after seeding the warm-season species trial. To demonstrate variety effects and statistical significance, confidence intervals (95%) were constructed for the sample means in R (Figure 1). Data collection will continue for the duration of this project, with additional data collected on seedhead density (inflorescences/area), above ground biomass (dry weights), and lodging.

Established plant density was lowest for *Festuca ovina*, *Koeleria macrantha,* and *Muhlenbergia rigens*. These low levels of density are not desirable because they leave exposed soil and provide opportunity for weed encroachment. Overall, the San Luis Obispo site had lower plant densities than the same species at the Fresno site, and we hypothesize this is due to variable irrigation and/or the use of recycled irrigation water at the San Luis Obispo site. Plant height was highest for *Agrostis exarata, Bromus carinatus, Stipa pulchra,* and *Eragrostis curvula*. Field observations suggest higher stand height obstructs visibility of golf balls and will hinder the ability the find golf balls (Figure 2).

Objective 3

A healthy stand of bermudagrass on an active golf course rough will be subjected to different termination methods in late summer 2019. Treatments for bermudagrass removal will include non-selective synthetic herbicide (glyphosate), non-selective organic herbicide, solarization, sod removal, scalping, and weed steaming. Data will be collected on recalcitrant bermudagrass and other weed invasion.

Objective 4

Weed management in these systems is long-term and complex. A publication of guidelines for weed management in naturalized areas of golf course roughs will be developed in 2019. The publication will include integrated concepts and will be framed in an Adaptive Management approach.

Table 1. Cool-season grass species seeded fall 2017 in San Luis Obispo and Fresno.

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

*California native

Table 2. Warm-season grass seeded summer 2018 in Fresno.

Purple threeawn	*Aristida purpurea*	*
Buffalograss	*Buchloe dactyloides* 'SWI 2000'	
Sideoats grama	*Bouteloua curtipendula*	*
Blue grama	*Bouteloua gracilis*	*
Bermudagrass	*Cynodon dactylon* blend of 'Princess' and 'Arden 15'	
Weeping lovegrass	*Eragrostis curvula*	
Big galleta	*Hilaria rigida*	*
Deer grass	*Muhlenbergia rigens*	*
Little bluestem	*Schizachyrium scoparium*	
Alkali sacaton	*Sporobolus airoides*	*

*California native

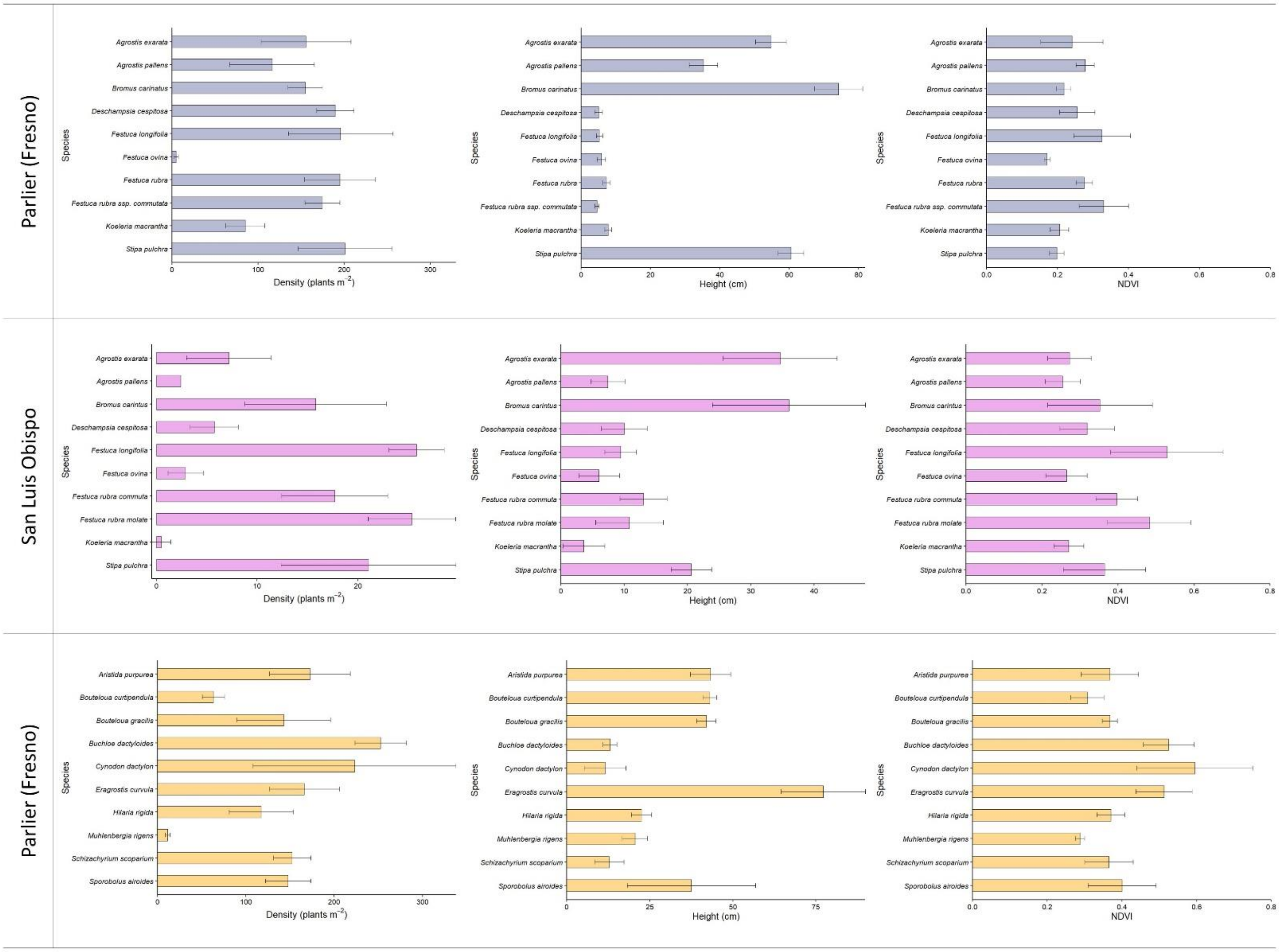


Figure 1. Density, height, and NDVI measurements for field trials in Fresno and San Luis Obispo. Bars represent means and error bars represent 95% confidence intervals.

Figure 2. Project presentation to over 70 turf managers and associated professionals at a Central California Golf Course Superintendents Association event in San Luis Obispo in July 2018.

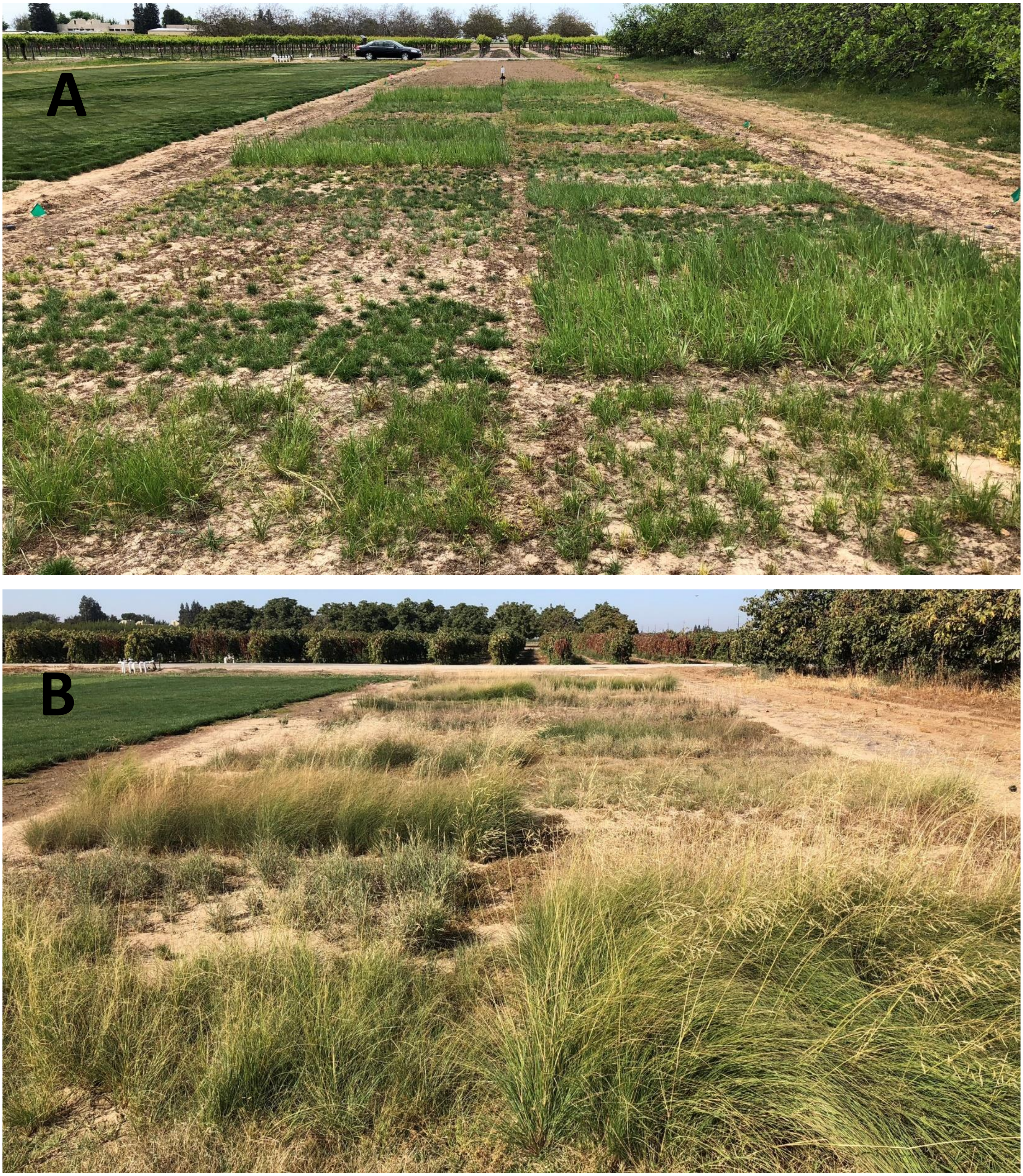


Figure 3. Cool-season (A) and warm-season (B) species field trials in Fresno, CA.

USGA ID#: 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

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.
- Seeding rate influenced seed head density, grassy weed coverage, lodging, and possibly biomass.
- The results from this project will clarify fine fescue rough establishment and management strategies.

Summary Text:

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. 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. Beacon has done well in other low-input cultivar evaluations and is well-suited for the types of environments common in lower-input out-of-play areas on golf courses. The two factors include seeding rate based on pure live seed (PLS) (3 levels: 1, 2, and 3 PLS cm^{-2}) and mowing regime (4 levels: spring mowing; fall mowing; spring and fall mowing, and no mowing). The height of cut for each mowing event was 10.2 cm and clippings were removed. All plots were mowed in the fall of 2017 to provide uniform stands prior to 2018 data collection.

In 2018 the following data were collected in St. Paul: living fine fescue coverage and weed pressure (grid counts); seed head density (culms in a 0.09 m^2 subsample per plot); overall quality; total biomass at each mowing (dry biomass weights of 0.09 m^2 subsample per plot); maturity (days after April

1 until seed head is fully emerged); lodging (visual assessment as needed); golf ball lie (golf ball visibility image analysis). In 2019 this data will be collected in Maple Grove and a second year in St. Paul.

Seed heads and uniform fine fescue stands of high turfgrass quality provide aesthetic value to low maintenance areas on golf courses. In 2018, full seed head emergence fell on May 29th in St. Paul (Fig. 1). Density of the culms were influenced by the seeding rate. Culm density increased as seeding rate decreased (Fig. 2). Neither mowing treatment nor seeding rate influenced turfgrass quality, percent fine fescue coverage, and percent broadleaf weed coverage. Fine fescue coverage ranged from 72.5-100% in the fall. We expected to observe tall broadleaf weeds as the plots grew, but the most common broadleaf weeds were white clover, broadleaf plantain, and black medic. A higher percentage of grassy weed coverage was only observed in the 1 PLS cm^{-2} treatment in the spring compared. Generally, grassy weeds were greatly reduced to inconsequential levels from spring to fall in all treatments. We expect mowing treatments to eventually reduce weed pressure even further during the 2019 growing season.

Unmown fine fescue stands are commonly mowed in the fall, and biomass removal can be laborious. Dry biomass collected in the spring and fall were not influenced by seeding rate, however the 3 PLS cm^{-2} treatment generally had less biomass than the other seeding rate treatments in the fall. Biomass collected ranged from 0-11 grams m^{-2} and 129-452 grams m^{-2} in the spring and fall, respectively. Low biomass in the spring was likely due to a limited growing period following the fall 2017 mowing event. Fall biomass was also a significant predictor for lodging. As collected biomass increased, so did the severity of lodging. Additionally, the 1 PLS cm^{-2} treatments had more severe lodging than the other seeding rate treatments in the fall.

Playability in unmown fine fescues is difficult as it serves as a penalty for unfortunate golf shots. Challenges 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. To quantify this playability characteristic, we tossed a red golf ball into the plot, and then took a digital image of the golf ball from a vantage point directly over the plot. This allows for quantifying the pixels of the golf ball that are visible. Fewer red pixels would indicate a ball that is more difficult to locate and more difficult to play. Digital images of golf balls tossed in each plot were taken in 2018 (Fig. 3), and ball visibility estimations will be determined via image analysis software in 2019. We expect ball visibility to be influenced by seed head density, biomass, and lodging.

Figure 1. Seed head emergence during spring 2018 in St. Paul.

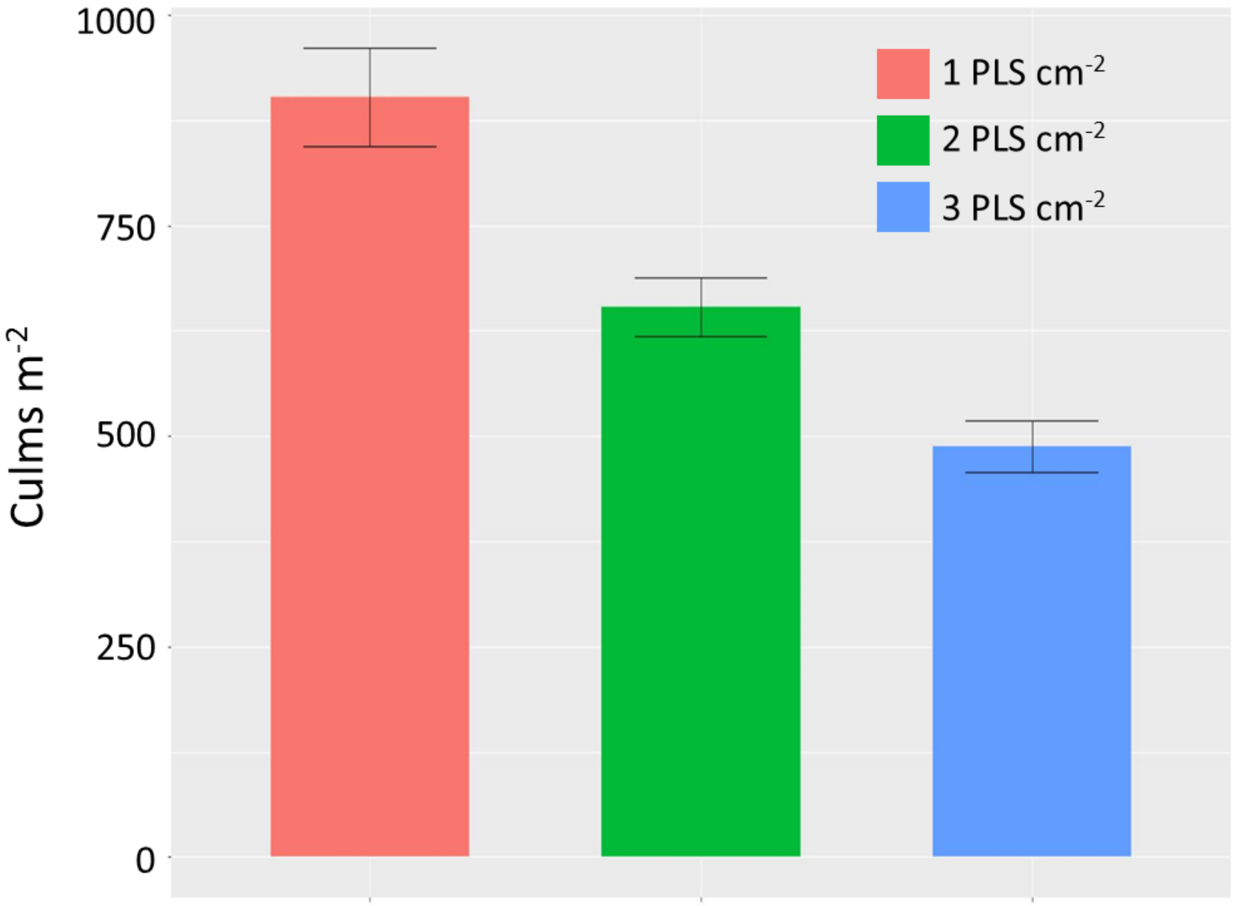


Figure 2. Culm density of each seeding rate treatment on May 30th, 2018 in St. Paul. Error bars represent standard error.

Figure 3. Red golf ball tossed into a 3 PLS cm^{-2} plot in fall 2018 for digital image analysis.

USGA ID#: 2017-13-623

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

Project Leaders: Bill Kreuser, Michael Carlson, 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 superintendent 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 regiment and nitrogen fertility on pest incidence, and corresponding total pesticide use in fairways of an improved buffalograss cultivar.

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

Summary Points:

- Quality ratings were lower this year than in the previous year, as winterkill and poor maintenance in the fall reduced the quality of the grass early in the growing season.
- Pest control and fertilizer had a greater effect on quality than irrigation throughout the growing season.
- Species had the greatest effect on NDRE, whereas within species fertilizer and irrigation had effects on NDRE values, as the standard fertilizer had the highest NDRE values for both KBG and buffalograss, and irrigation had higher NDRE values among all species.
- The CBG quality and NDRE values were reduced this year because of the poor maintenance the previous fall into winter. There were many areas of bare soil which reduced the quality rating and altered the NDRE values.

Summary Text:

It's commonly assumed that buffalograss (*Buchloe 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 savings compared to other species are quantified.

Methodology

We established 'Prestige' buffalograss, 'Barvette' KBG, and 'Pure Select' CBG in three, 20 ft x 30 ft plots with three replications for a total of nine plots each during 2016 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 x 3 fertilizer x 2 pest control factorial treatment structure. Irrigation levels are 1) no supplemental irrigation or 2) standard reference evapotranspiration (ET_o) replacement (i.e. 80% ET_o for CBG and KBG or 60% ET_o for buffalograss). Fertilizer levels are 1) non-fertilized, 2) "standard" fertilizer (1 lb N/1000 ft^2 in May, Sept., Oct. and Nov. for CBG and KBG, 1 lb

N/1000 ft^2 in June and July for buffalograss), or 3) a threshold program where 0.25 lbs N/1000 ft^2 is applied when NDRE values of the plots are beneath a threshold value. Pest control levels are 1) nontreated or 2) “standard” strategies to control weeds, disease and insects. Experimental management for these plots began in May of 2018. The entire experimental area was mowed when needed over the duration of the season. . Soil moisture was measured using a Spectrum Technologies Field Scout TDR 300 with 3 inch probes in plots that received supplemental irrigation. Plots that received pest control were checked for broadleaf weed pressure and for dollar spot pressure bi-weekly throughout the season. The entire plot was applied with a broadleaf herbicide when these weeds were spotted. Dollar spot was treated following the disease pressure based on data from GreenKeeper. Turfgrass visual quality and normalized difference red edge (NDRE) of were rated weekly. Turfgrass visual quality was rated on a 1- to -9 scale where 1 represented dead turf, 9 was perfect turf and 6 was minimally acceptable. NDRE was measured using a Holland Scientific RapidScan handheld crop sensor (active light source) over the length of the plot.

Preliminary Results

Quality

The combined effects of species x fertilizer x pest control produced the highest order interaction that affected average turf quality over the 2018 growing season. The standard fertilizer KBG and buffalograss treatments and threshold fertilizer buffalograss treatments that received pest control had the highest average quality rating (6.6) and were the only treatments to maintain a quality rating that was acceptable throughout the season. The non-fertilized CBG that received no pest control had the lowest average quality rating (3.1). Considering average turf quality and main effects, buffalograss (5.7) > KBG (5.4) > CBG (3.8), plots that were irrigated to ET-replacement (5.0) > non-irrigated plots (4.9), standard fertilizer (5.3) > threshold-based (5.1) > non-fertilized (4.5), and plots were pests were controlled (5.4) > untreated plots (4.6). The KBG and buffalograss species had the higher average quality ratings than the CBG treatments throughout the whole season. The quality of the treatments, especially CBG, were reduced this year because the experimental area was under-maintained in the fall and winterkill from the winter. The quality of the CBG was greatly reduced up until mid-summer.

NDRE

The combined effects of species x fertilizer x irrigation produced the highest-order interaction affecting NDRE of the plots. The irrigated KBG with standard fertilizer had the highest average NDRE value (0.329) and then the non-irrigated KBG with standard fertilizer had the second highest average NDRE value (0.316). The irrigated CBG with standard or threshold fertilizer and non-irrigated KBG with threshold fertilizer had similar and lower NDRE values (0.286) than the KBG standard fertilizer treatments. The threshold fertilized irrigated KBG and non-irrigated CBG had similar NDRE values (0.277), and the next statistical group of the irrigated and non-fertilized KBG and CBG, and non-irrigated CBG with standard fertilizer and non-irrigated and non-fertilized KBG had an average NDRE value of 0.255. The NDRE values of the threshold and standard fertilizer buffalograss treatments were similar to the non-irrigated and non-fertilized CBG treatment and averaged 0.224. The non-fertilized CBG treatments, for both irrigated and non-irrigated treatments had similar and the lowest NDRE Values (0.190). Considering NDRE and main effects, KBG (0.287) > CBG (0.264) > buffalograss (0.213), plots that were irrigated to ET-replacement (0.260) > non-irrigated plots (0.248), and standard fertilizer (0.273) > threshold-based (0.261) > non-fertilized (0.229). The pest control main effect was not significant. The under-maintenance of the CBG the previous year and winterkill on the grass reduced the NDRE values with exposed soil often found in many treatments.

Table 1. Average turfgrass visual quality ratings from 23 May to 16 October 2018. Letters denote significance at p = 0.10.

Species	Irrigation	Fertilizer	Quality
Kentucky Bluegrass	Irrigated	Standard	6.74 a
		Threshold	5.92 b
		Non-fertilized	5.40 c
	Non-irrigated	Standard	5.38 c
		Threshold	4.99 de
		Non-fertilized	4.19 f
Creeping bentgrass	Irrigated	Standard	4.00 fg
		Threshold	4.10 f
		Non-fertilized	3.52 h
	Non-irrigated	Standard	4.07 f
		Threshold	3.83 g
		Non-fertilized	3.10 i
Buffalograss	Irrigated	Standard	6.53 a
		Threshold	6.53 a
		Non-fertilized	5.83 b
	Non-irrigated	Standard	5.28 c
		Threshold	5.20 cd
		Non-fertilized	4.94 e

Table 2. Average NDRE values from 23 May to 16 October 2018. Letters denote significance at p = 0.10.

Species	Irrigation	Fertilizer	Quality
Kentucky Bluegrass	Irrigated	Standard	0.329 a
		Threshold	0.280 d
		Non-fertilized	0.259 e
	Non-irrigated	Standard	0.316 b
		Threshold	0.283 cd
		Non-fertilized	0.252 e
Creeping bentgrass	Irrigated	Standard	0.292 c
		Threshold	0.283 cd
		Non-fertilized	0.255 e
	Non-irrigated	Standard	0.254 e
		Threshold	0.275 d
		Non-fertilized	0.224 f
Buffalograss	Irrigated	Standard	0.226 f
		Threshold	0.227 f
		Non-fertilized	0.193 g
	Non-irrigated	Standard	0.223 f
		Threshold	0.220 f
		Non-fertilized	0.188 g

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USGA ID#: 2018-14-664

Title: On-Site Golf Course Evaluation of New Turfgrasses for Putting Greens

Project Leader: Brian Schwartz
Affiliation: The University of Georgia

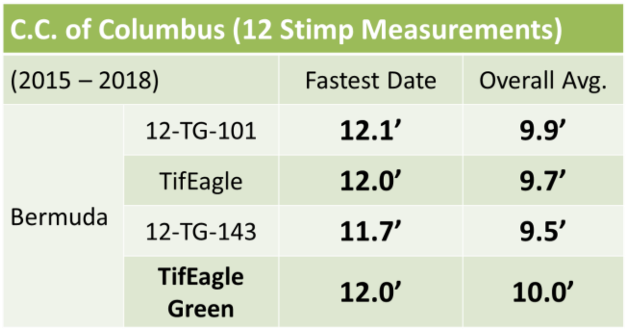
Objectives:
1. Evaluation of advanced experimental turfgrasses for putting greens under realistic management intensity and performance expectations.
2. Initiation of a USGA sponsored graduate student worker position in the UGA Turfgrass Breeding Program at Tifton, GA.

Start Date: 2018
Project Duration: 3 years
Total Funding: $28,500

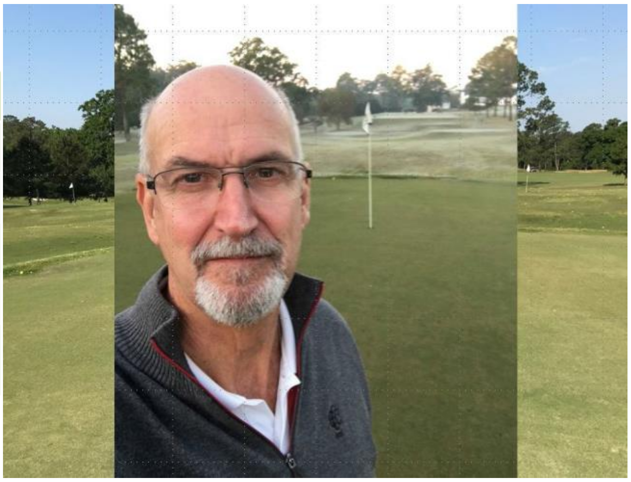
Summary Text:
During 2012 we began testing new hybrid bermudagrasses and zoysiagrasses as a way for me to develop relationships with golf course superintendents who had collaborated with the Tifton program in the past. Since then, we have had research trials at the Atlanta Athletic Club, Atlanta Country Club, Big Canoe Golf Course, Country Club of Columbus, East Lake Golf Club, Ford Plantation, Landings Club, Sea Island Golf Club, University of Georgia Golf Course, and Valdosta Country Club. In addition to the 7 ongoing trials planted during 2016 or before, we established new tests at Adena Golf & Country Club and The Streamsong Resort in Florida during 2018.

1) <u>Country Club of Columbus</u>

William Smith renovated the old research green prior to planting on July 15th, 2015. All three bermudagrasses (TifEagle, 12-TG-101, and 12-TG-143) established very quickly. A picture of the green during October 2018 is below, as well as a summary of the 12 stimp measurements taken to-date.



C.C. of Columbus (12 Stimp Measurements)			
(2015 – 2018)		Fastest Date	Overall Avg.
Bermuda	12-TG-101	**12.1’**	**9.9’**
	TifEagle	**12.0’**	**9.7’**
	12-TG-143	**11.7’**	**9.5’**
	TifEagle Green	**12.0’**	**10.0’**



2) Landings Club

Chris Steigelman renovated a portion of the old practice green prior to planting on July 21st, 2015. All three bermudagrasses (12-TG-39, 12-TG-101, and 12-TG-143) established very quickly. A picture of the green during the fall of 2018 is below, as well as a summary of the 9 stimp measurements taken to-date.

The Landings Club (9 Stimp Measurements)			
(2015 – 2018)		Fastest Date	Overall Avg.
Bermuda	TifEagle	**11.3’**	**9.8’**
	12-TG-101	**12.2’**	**9.7’**
	12-TG-39	**11.4’**	**9.7’**
	12-TG-143	**10.5’**	**9.5’**
	TifGrand	**12.5’**	**8.8’**
Paspalum	SeaStar	**10.8’**	**9.0’**

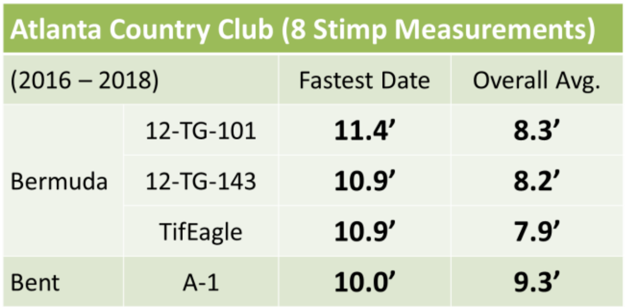
3) Valdosta Country Club

Barry Bennett renovated the old practice green prior to planting on May 25, 2016. Tom Howard and Randall Bice have been managing the green for the last two years. All five bermudagrasses (Tifdwarf, TifEagle, 12-TG-39, 12-TG-101, and 12-TG-143) established fairly quickly. A picture of the green during September of 2018 is below, as well as a summary of the 8 stimp measurements taken to-date.

Valdosta C.C. (8 Stimp Measurements)			
(2016 – 2018)		Fastest Date	Overall Avg.
Bermuda	TifEagle	**11.5’**	**9.0’**
	12-TG-143	**10.8’**	**9.0’**
	12-TG-39	**10.7’**	**9.0’**
	12-TG-101	**9.9’**	**9.0’**
	Tifdwarf	**10.4’**	**8.4’**

4) Atlanta Country Club

Mark Esoda constructed a new research green adjacent to his bentgrass research green prior to planting on June 16, 2016. Scott Lambert and James Rauhuff have been managing the green for the last year. All three bermudagrasses (TifEagle, 12-TG-101, and 12-TG-143) established quickly, but six large trees surrounding the green were removed September 6, 2016 because the green was only getting 2 hours of sunlight. A picture of the green during August of 2018 is below, as well as a summary of the 8 stimp measurements taken to-date.



Atlanta Country Club (8 Stimp Measurements)			
(2016 – 2018)		Fastest Date	Overall Avg.
Bermuda	12-TG-101	**11.4’**	**8.3’**
	12-TG-143	**10.9’**	**8.2’**
	TifEagle	**10.9’**	**7.9’**
Bent	A-1	**10.0’**	**9.3’**

5) Big Canoe Golf Course

Lydell Mack converted a bentgrass nursery green to a research plot during 2017. This test site is divided in two equal areas, one treated as a “no-till” soil profile and the other “cored-out” and refilled with a new green’s mix. Two bermudagrasses (TifEagle and 12-TG-101) and two zoysiagrasses (Diamond and Primo) were planted in long strip-plots that span across both soil profiles on May 25th, 2017. Pictures of the green during 2018 are below, as well as a summary of the 3 stimp measurements taken to-date. The most important information to be gleaned from this trial will be the long-term survival potential of each genotype over several winters when covered, and where left unprotected during the winters.

Big Canoe Golf Course (3 Stimp Measurement)			
(2017 – 2018)		Fastest Date	Overall Avg.
New Rootzone	12-TG-101	**8.9’**	**8.5’**
	TifEagle	**9.3’**	**8.4’**
	M-85	**8.6’**	**8.3’**
	Diamond	**8.9’**	**7.6’**
No-Till	12-TG-101	**9.3’**	**8.2’**
	TifEagle	**8.9’**	**8.2’**
	Diamond	**8.2’**	**7.4’**
	M-85	**8.1’**	**7.3’**

6) TPC Sawgrass

Jeff Plotts constructed a large research site during the summer of 2017. Our experimental bermudagrass (12-TG-101) is being compared to four bermudagrass (TifEagle, Sunday, Imperial, and G12) and three zoysiagrass (Primo, Prizm, and DALZ1308) cultivars. A picture of the plots during March October 2018 is below, as well as a summary of the first stimp measurements taken to-date.

TPC Sawgrass (1 Stimp Measurement)			
(2017 – 2018)		Stimp	Overall Avg.
Bermuda	Imperial	**9.5’**	-
	12-TG-101	**8.8’**	-
	G12	**8.8’**	-
	TifEagle	**8.7’**	-
	Sunday	**7.7’**	-
Zoysia	Prizm	**8.6’**	-
	Primo	**8.2’**	-
	Tambika	**7.3’**	-

7) Adena Golf & Country Club

Asa High renovated a portion of the old TifEagle nursery green prior to planting in May of 2018. Two experimental bermudagrasses from UGA (11-T-56 and 12-TG-101) and four from UF were establishing very quickly, but unfortunately the Golf & Country Club was unexpectedly closed during June of 2018 and the experiment was lost. Pictures of the green at planting and in June are below.

8) Streamsong Golf Resort

Rusty Mercer constructed a new research site during 2018 to compare MiniVerde, TifEagle, Mach1, and the UGA experimental variety 12-TG-101. Sprigs were planted during September of 2018 and have been establishing very quickly. The goals of this research site are to test adaptation to the long-season growing environments and very intense topdressing and growth regulator management. Pictures of the green during planting and six weeks later are below.

9) USGA Sponsored Students

Mr. Jonathon Fox successfully defended his M.S. thesis “Methods for Analyzing Shade Tolerance in Warm Season Turfgrasses” this fall and is now contemplating a leap into the work force versus continued education. During the fall of 2017 he individually won 1st Place in the graduate student poster competition at the national Crop Science Society meetings. Mr. Tyler DaSilva was the USGA sponsored undergraduate student through graduation in the spring of 2018, and is now an assistant golf course manager at Queen’s Harbour Yacht and Country Club. Mr. Cooper Thornton is currently pursuing a B.S. in Environmental Horticulture on the Turfgrass & Golf Course Management track. These students have been instrumental in propagating plant materials for the USGA sponsored research trials, as well as for those planted at the UGA Tifton Campus and at Pike Creek Turf.

USGA ID#: 2018-15-665

Title: Evaluation of Warm-Season Species, Blends and Mixtures to Reduce Golf Course Rough Inputs

Project Leader: Kevin Morris
Affiliation: National Turfgrass Evaluation Program (NTEP)

Start Date: 2018
Project Duration: 3 years
Total Funding: $45,000

Summary Points:

- A national evaluation of warm-season grasses to reduce golf course rough inputs was established at eleven locations in the southeastern, southern and western U.S.
- Ten entries, consisting of bermudagrass, buffalograss, zoysiagrass and a mixture of buffalograss, curly mesquite and blue grama were mailed to trial locations and planted in summer 2018.
- After full establishment of each entry, the trial will be maintained at a mowing height of two inches or greater, with minimal fertilization, irrigation and weed control to simulate a low input golf course rough.
- Data on establishment rate, turfgrass quality, winter survival, spring greenup, percent living cover, freedom from weeds, and rate of top growth will be collected over a five-year period.

Summary Text:

Due to droughts in California, Oklahoma, Texas, the southeast U.S. and other locations, the golf course industry needs grasses that perform well with little, if any, supplemental irrigation. In addition, fertilizer and pesticide restrictions in various states or localities require golf courses to use less of these inputs. Finally, as a result of the recent recession and subsequent economic pressures, golf courses are investigating new cost saving strategies.

To address these issues within golf, and the turf industry in general, NTEP initiated a national low input trial in 2015, evaluating cool-season (C3) species, blends and mixtures. This trial of 32 entries, including several C3 grass species and even mixtures of various clover types, is planted at seventeen locations in mid and northern-tier U.S. states. With very minimal inputs of fertilizer, water and pesticides, and reduced mowing requirements, this trial has yielded very interesting results in its first two years.

Several interesting new native warm-season (C4) species, some resulting from USGA funding, are currently under development. Additionally, improvements in buffalograss, bermudagrass, zoysiagrass and other more traditional turf species may show that significant reductions in water, fertilizer, pesticides and mowing are possible. Therefore, we feel the time is now to evaluate C4 species, blends and potentially, even mixtures of species (and legumes) for their ability to reduce input in golf course roughs.

Information from this project will be valuable to the golfing industry because it will determine the adaptation of C4 grasses for golf course use. Information obtained from these evaluations will be of interest to plant breeders, researchers, extension educators, USGA agronomists, golf course architects, and superintendents who need to select the best adapted species, cultivars, blends and/or mixtures to reduce maintenance and inputs.

Location and Number of Trial Sites

The evaluation trials are jointly sponsored by the United States Golf Association (USGA) Green Section and the National Turfgrass Evaluation Program (NTEP). An advisory committee consisting of turfgrass researchers, breeders and NTEP personnel developed trial protocols, evaluation parameters and selected trial locations.

Trial sites are located at land grant university research sites, or in close proximity of a land grant university with a research component. Eleven (11) evaluation trial sites throughout the southern and western U.S. were selected, in accordance with the number of expected entries (see map).

Trial Specifics and Protocols

NTEP will function as the coordinating agent for this five-year cultivar trial. Daily maintenance will be conducted by the host universities. Trials are maintained according to the following procedures developed by the advisory committee and approved by the NTEP Policy Committee (to conform with management used in roughs):

Management protocol during establishment

- Standard irrigation and fertility to enhance establishment
- Weed control as needed, including pre-emergent applications

Management protocol after establishment period

- Mowing height of 2" or higher
- Mowing frequency: once per week during growing season
- Nitrogen rate: 0 – 2 lbs./1000 sq. ft/year
- Irrigation: 50% ETo or lower (depends on location) or irrigation only during severe drought stress
- Pest control: minimal weed control to avoid significant stand loss

Data Collection and Publication

The research cooperator will be responsible for data collection. The following is representative of the data to be collected annually (may be altered by the advisory committee):

1. Percent establishment every 14 days until plots are fully established
2. Percent living ground cover of planted species in spring to assess winter survival
3. Spring greenup ratings in years two through five
4. Turfgrass quality ratings each month throughout the growing season
5. Percent living ground cover of planted species monthly throughout each growing season
6. Percent grassy and broadleaf weed encroachment two times per year (excluding planted species)
7. Canopy height measurements monthly just prior to mowing (average of three locations in each plot)

NTEP will request annual data by December 15th of each year, organize, review and statistically analyze submitted data, and will publish on the NTEP web site (www.ntep.org) in spring or summer of the next year.

Progress to Date

Ten (10) entries were received by NTEP in late May/early June 2018. The entries consist of eight vegetatively-established and two seed-established entries. Species included in the trial include multiple entries of bermudagrass, zoysiagrass, buffalograss, as well as one mixture entry consisting of buffalograss, curly mesquite and blue grama. Entries were shipped to cooperators in mid-June 2018 and subsequently planted at the eleven locations. Data on establishment rate has been collected thus far and will be collected in 2019 until all entries are fully established.

Future Plans

Thjs trial will be evaluated for five years at the eleven geographically diverse locations. We expect considerable variability in performance among the entries based on location. This trial should give us a good baseline of information on potential entries and species to reduce inputs in warm-season turf growing areas.

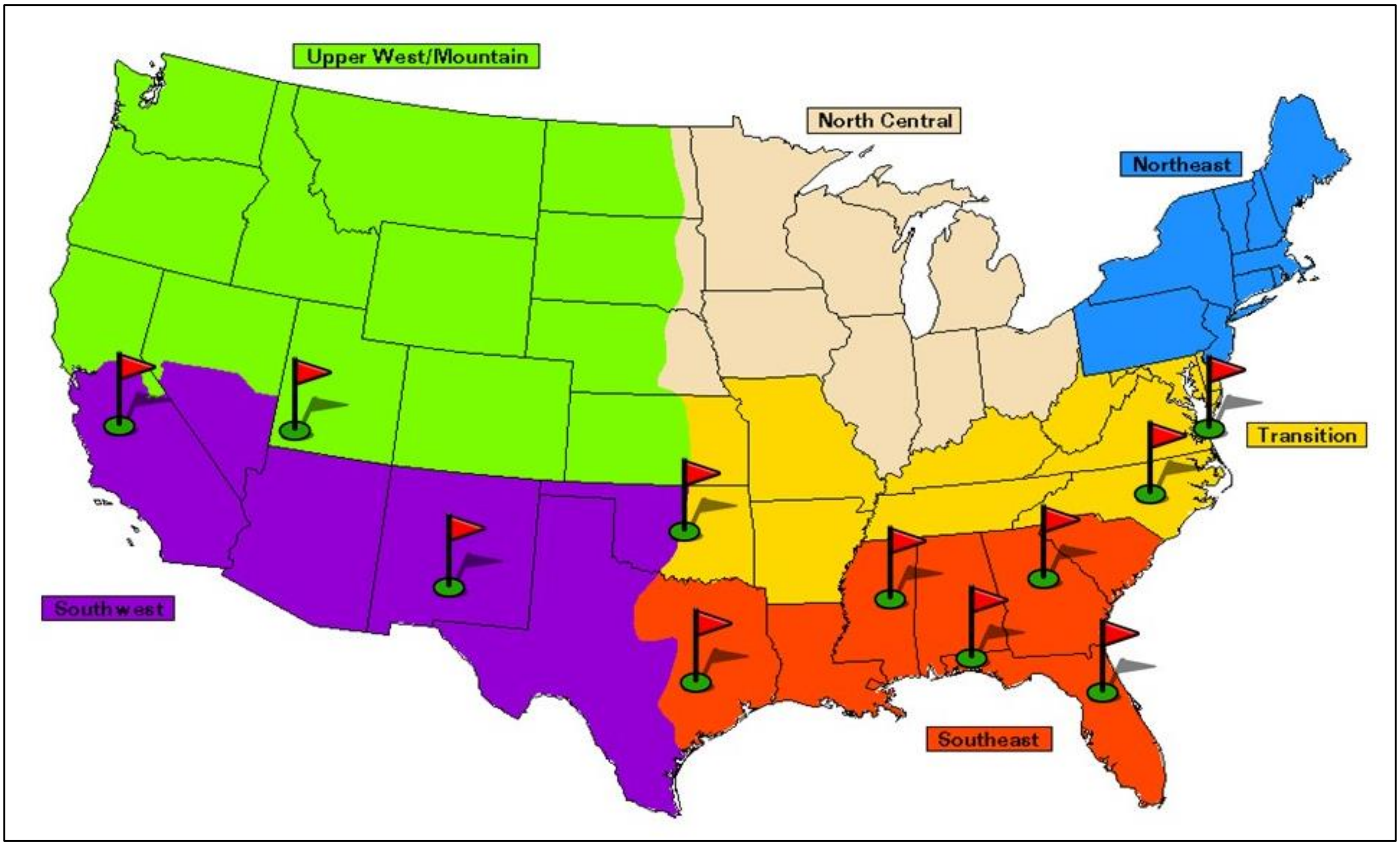


Figure 1. Locations for the evaluation of blends and mixtures of warm-season species to reduce golf course rough inputs.

Figure 2. Ten entries, consisting of bermudagrass, buffalograss, zoysiagrass and a mixture of buffalograss, curly mesquite and blue grama were mailed to trial locations and planted in summer 2018.

USGA ID#: 2017-09-619

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

Project Leaders: Ning Wang[1], Yanqi Wu[1], Justin Moss[1], Charles Fontanier[1], Jack Fry[2], and Dale Bremer[2]
Affiliation: [1]Oklahoma State University; [2]Kansas State University

Objectives:
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 evaluation 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).

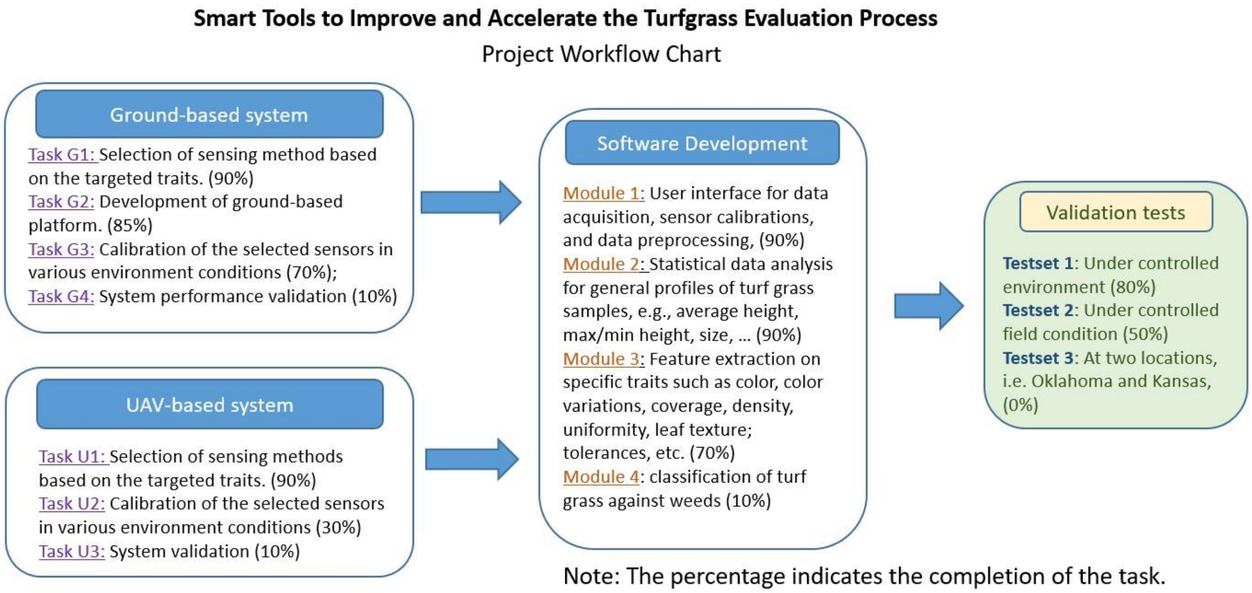
Start Date: 2017
Project Duration: 3 Years
Total Funding: $89,305

Summary Points:
1. A ground-based platform for turfgrass evaluation was designed and developed, which could easily attached on an off-road vehicle to implement field data acquisition. A human interface was developed for the easy uses during the field operations. An image processing and analysis program was also developed to extract traits of interests. We are currently fine-tune the program. Before the next season comes, we will be ready to conduct field tests with the turfgrass scientists (co-PIs).
2. The UAV-based platform with an RGB camera and a thermal camera was still under constructed. We plan to complete the UAV platform before the end of February 2019 and test it before the next season starts. As we have algorithms developed to process the RGB and thermal images from UAV for another similar project, we will modify them and finalize the data processing algorithms before the next season.
3. The results from the image analysis showed that the green color shades were hard to measure without shade. An alternative design is being developed and will be tested under controlled-environment conditions in January 2019.
4. Due to an unexpected resign of a graduate student who was assigned to work on this project in May 2018 (move to another university), the progress of this project was affected during the summer 2018. From the end of the August, we reformed the team and made significant progress on the development.

Summary Text:
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. However, quality evaluation of turfgrass has been one of the major and tedious work inputs in golf course management. Visual quality evaluation of turfgrass plots are widely used by turfgrass breeders and researchers, which is slow, subjective and laborious. The collected data are highly variable and difficult to repeat. *Hence, we proposed this research to develop a field evaluation tool with a goal of accelerating field data collection and data processing and analysis*.

Recent development in electronics, computer, networking, and machine learning have been bringing in opportunities and potentials to improve current field evaluation practice to achieve rapid quantification of the traits of interest for turfgrass. In 2017, we explored various off-the-shelf technologies and had been developing a turf-field evaluation system, which could collect quantitative data for multiple traits simultaneously. Preliminary study we conducted in 2015 – 2016 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, we proposed to develop a field evaluation system, which would include a ground-based platform and a UAV-based platform. Figure 1 shows a project workflow map (presented in the 2017 Annual Report) with percentages to show the up-to-date progress status.


Smart Tools to Improve and Accelerate the Turfgrass Evaluation Process

Project Workflow Chart

Ground-based system

Task G1: Selection of sensing method based on the targeted traits. (90%)
Task G2: Development of ground-based platform. (85%)
Task G3: Calibration of the selected sensors in various environment conditions (70%);
Task G4: System performance validation (10%)

UAV-based system

Task U1: Selection of sensing methods based on the targeted traits. (90%)
Task U2: Calibration of the selected sensors in various environment conditions (30%)
Task U3: System validation (10%)

Software Development

Module 1: User interface for data acquisition, sensor calibrations, and data preprocessing, (90%)
Module 2: Statistical data analysis for general profiles of turf grass samples, e.g., average height, max/min height, size, … (90%)
Module 3: Feature extraction on specific traits such as color, color variations, coverage, density, uniformity, leaf texture; tolerances, etc. (70%)
Module 4: classification of turf grass against weeds (10%)

Validation tests

Testset 1: Under controlled environment (80%)
Testset 2: Under controlled field condition (50%)
Testset 3: At two locations, i.e. Oklahoma and Kansas, (0%)

Note: The percentage indicates the completion of the task.

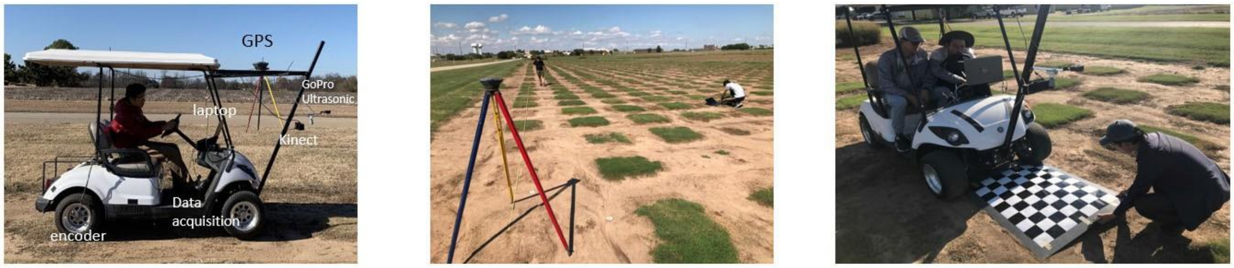
Figure 1. Updated project workflow map.

Ground-Based Platform

From December 2017 to November 2018, our team has been conducting lab and field experiment to validate the selection of various sensors and design the housing of the sensing system. The criteria of selecting the sensors included the spatial resolutions, sampling frequency, accuracy, tolerance of outdoor conditions, and cost. The design of the housing mechanism of the sensing system considered the needs of high-quality and stable measurements, measurement speed, and easy installation and field operations.

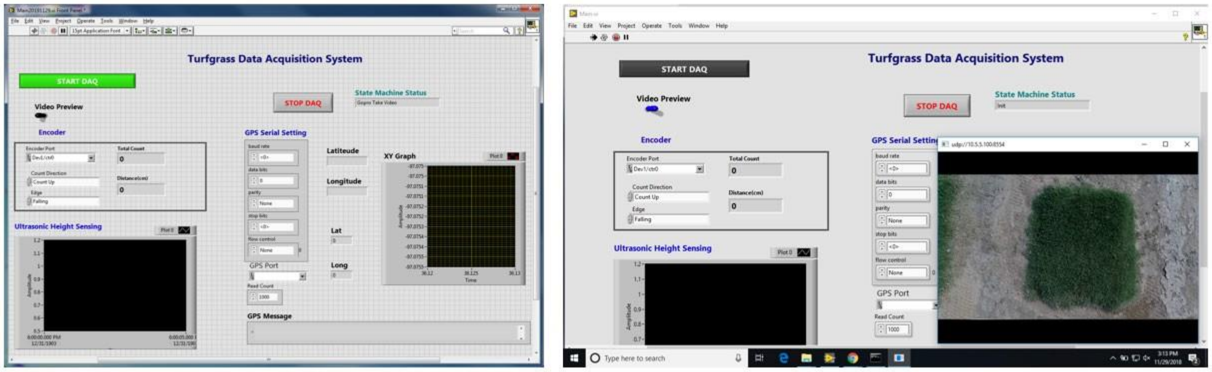
Figure 2. Designs of sensing mechanism

Design 3 was selected especially due to its simplicity. However, the MS Kinect sensor we proposed to collect RGB color and depth images sometimes showed strong interferences from sunlight and environment. Hence, we added a GoPro camera and an ultrasonic sensor to compensate the MS Kinect sensor. Another challenge we faced during the field tests was the shadow in the collected RGB images with the open mechanism (Design 3, Figure 3). As the sunlight direction kept changing during the tests, shadow from the golf cart and frames could not always be avoided. Hence, we added algorithms to remove the shadow effect on the images in the data processing program. The software for the project included two parts, a program for field data acquisition and a program for data processing and analysis. The program for field data acquisition was developed using LabView program (National Instrument, Texas), which integrated the controls and data collections for all the sensors (Figure 4a). It also allowed a preview of the sensing area before a field scouting (Figure 4b).



(a) Measurement System (b) Field scouting (c) Sensor calibration

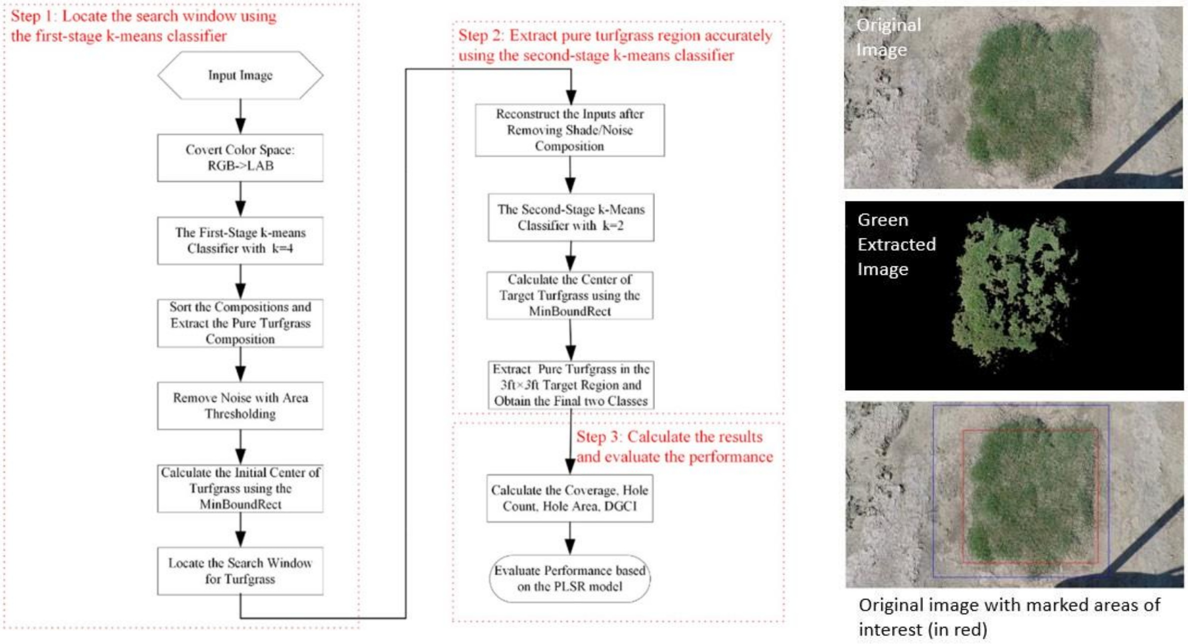
Figure 3. Developed measurement system and field tests



(a) Front Panel of the software for field data acquisition (b) Front Panel of the software with an image of field of view

Figure 4. The software for field data acquisition

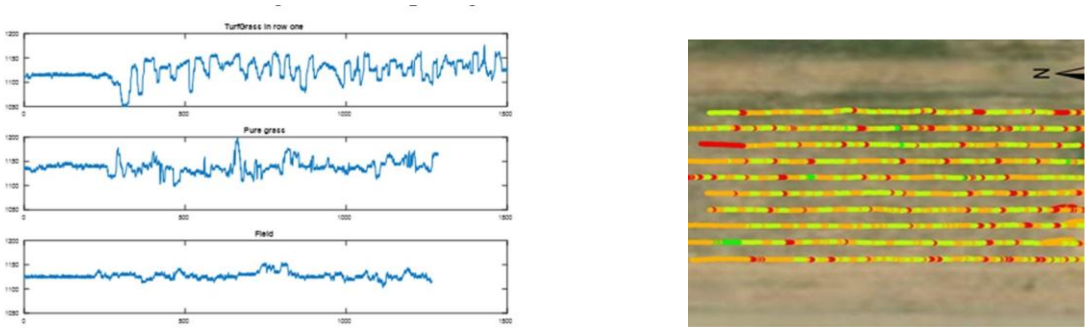
The program for data processing and analysis were developed using MATLAB (Mathworks, MA). The major function is to process the time-stamped and location stamped images from the GoPro camera and the Kinect camera. Figure 5 shows a flowchart of the program developed to preprocess the raw RGB images and extract features of the sampled turfgrass. The results from the program were a set of indices to describe green coverage, uniformity, texture variations, and green color levels. A journal publication on the image processing and algorithm is being prepared.



(a) Program flowchart (b) Sample images

Figure 5. The RGB image processing algorithm

The ultrasonic sensor data were also processed and analysis with a program using MATLAB. The program removed noise from the measurements, extracted height from each turfgrass plot, and plotted the georeferenced, calculated height on a map (Figure 6).



(a) Sample of ultrasonic data (b) Processed, georeferenced height data

Figure 6. Height measured by an ultrasonic sensor.

UAV-based platform

We collected some RGB color images of the whole testing field with the UAV (Figure 7a) at the OSU experimental farm and started to develop a program to process the UAV images. We were not able to collect thermal images due to the challenges on integrating the thermal camera to the UAV we had been using. We are currently designing and constructing a mechanism to mount the FLIR infrared camera stably. Several design ideas were evaluated and tested. The final design included a set of extended legs and a mounting bracket which were 3D printed, but yet tested (Figure 7). The extension of the legs gave us more space to add a gimbal, the thermal camera, and a radio transceiver to the UAV.

(a) The off-the-shelf DJI P3 UAV with an RGB camera (b) The UAV with four extended legs (c) A field image taken by the UAV platform

Figure 7. The UAV platform

USGA ID#: 2016-07-557

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

Project Leaders: Benjamin Wherley[1], Zhaoxin Chen[1], Casey Reynolds[2], and Russell Jessup[1]
Affiliation: [1]Texas A&M University Department of Soil & Crop Sciences; [2]Turfgrass Producers International

Objectives:

1. Determine seasonal minimum daily light integral (DLI) requirements for acceptable turf quality and cover of 9 zoysiagrass and bermudagrass cultivars commonly utilized on southern/transition zone golf courses of the United States.
2. Evaluate whether minimum DLI requirements change seasonally (spring, summer, and fall months).
3. Assess the effect of fairway vs. rough heights of cut on DLI requirement.
4. Determine the effect of monthly trinexapac-ethyl (gibberellic acid inhibitor) application on DLI requirement.
5. Conduct golf course validation study to corroborate DLI requirements for one of the cultivars used in the field study.

Start Date: 2016
Project Duration: 2.5 years
Total Funding: $40,090

Summary Text:

Selecting the best adapted species/cultivars for long-term success in shaded environments is an important consideration for golf course superintendents. In the past, this has been challenging due to difficulty in quantifying light levels particular to different areas of the golf course as it relates to light requirements of specific grass species/cultivars. The complexity and differences among shade environments can make it difficult to specify a minimum light requirement in terms of ‘hours per day’ or ‘percent shade’ that can extend across different situations. Furthermore, soil temperature in shade can be an interacting factor contributing to delayed spring green-up, transition issues, and winter injury. Relative humidity levels can also be elevated as well, causing extended leaf wetness and higher disease pressure under shaded environments. Biologically speaking, rather the responding to a number of hours of sunlight or percent shade level, plants ultimately respond to the cumulative daily total number of photons (mols/m^2/d) they receive within the photosynthetically active wavelengths (400-700 nm), termed ‘daily light integral’ (DLI). For reference, in Houston, TX, ambient DLIs in full sun fluctuate from approximately 45 mols/m^2/d during summer months to less than 20 mols/m^2/d during the winter months. Furthermore, minimum DLI levels for a particular cultivar may not remain constant across the season, but may vary by month of the year, and could be influenced simultaneously by temperature effects on photosynthetic/respiratory balance. Therefore, determination of minimal DLI values to achieve acceptable quality may be necessary for each season.

With the recent development of relatively inexpensive and easy to operate DLI meters, a superintendents can more easily determine the approximate DLI levels within particular areas of their course. Furthermore, apps are now available that allow turf managers to predict the sun’s path for a given month of the year, and thus, selectively remove only limbs or trees that may be of concern only for particular months of the year corresponding to the DLI requirements of the turf. Use of DLI data along with these types of technologies can aid the superintendent in making data-driven decisions to support tree pruning, removal, or cultivar selection decisions.

There is growing interest by turfgrass researchers in quantifying DLI requirements as they relate to turf quality of various cultivars/species, however, published field study data of this type have been limited to dwarf/ultradwarf bermudagrass greens (Bunnell et al., 2005a). In that work, the authors also found that applications of gibberellic acid inhibitor trinexapac-ethyl benefited shaded ultradwarf greens by significantly reducing the minimum light requirements (Bunnell et al., 2005 b). Although previous research has generally reported favorable responses of shaded turfgrass to trinexapac ethyl, some reports have shown mixed or adverse responses, depending on the time of year and species on which it is used (Baldwin et al., 2009; Gardner and Wherley, 2005; Meeks et al. 2015). More recently, shorter-term greenhouse studies were conducted under controlled environments to quantify DLI for warm-season turf species (Glenn et al., 2014). The authors reported reduction in DLI requirements with increasing mowing height for some cultivars, suggesting that DLI may differ between fairway/tees and rough on the golf course. Currently, DLI data from longer-term studies conducted under field management conditions are needed. Data of this type would be of significant value to golf course superintendents and would also contribute to the sustainability of golf.

The objectives of this project were to 1) Determine minimum DLI requirements for acceptable turf quality and cover of 9 zoysiagrass and bermudagrass cultivars commonly utilized on southern/transition zone golf courses, 2) Evaluate whether minimum DLI requirements change seasonally (spring, summer, and fall months), 3) Assess the effect of lower vs. upper-end heights of cut (0.75” vs. 2”) on DLI requirement, 4) Determine the effect of monthly application of trinexapac-ethyl on DLI requirement, 5) Validate DLI cultivar data from the field study with that observed under actual golf course conditions.

Methodology

A two-year field study was conducted over the 2016-2017 growing seasons in College Station, TX. A 15,000 sq. ft. irrigated shade research facility was constructed to accommodate replicated shade treatments offering 0 to 90% reductions in photosynthetic photon flux (PPF). Turfgrasses utilized in this project included commonly used cultivars of bermudagrass and zoysiagrass, as well as a shade tolerant check ‘Palmetto’ St. Augustinegrass (Table 1). Two parallel studies were conducted: A fairway study conducted at 0.75” mowing height, and a rough study managed at 2” mowing height. Both studies were 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. Plots were established from washed sod in July 2015 and provided 6-weeks to establish under full sun conditions before shade structures were moved onto plots. Shade structures remained on plots throughout the entire project, including winter months, and were only removed for short periods for routine maintenance and data collection (Figure 1).

During the study, plots were irrigated one to two times per week to supply 60% x historical evapotranspiration (ET_o) from a local weather service. Plots were mowed one to two times weekly, depending on time of year. Mowing was performed at either 0.75” height of cut using a walk-behind reel mower or at 2” using a walk behind rotary mower. Fairway height plots were further subdivided to receive trinexapac-ethyl (TE) monthly at a rate of either 0 or 0.2 lbs. a.i./Acre from May through September using a handheld boom sprayer. Preventative fungicides were applied monthly using a granular fungicide containing pyraclostrubin and triticonazole. A 21-7-14 sulfur coated urea fertilizer was supplied to all plots at a rate of 0.75 lbs. N per 1000 sq. ft. every six weeks from May through September (total annual application of 3 lbs. N/ 1000 sq. ft.).

Photosynthetic photon flux measurements were continually recorded during the study on 15 minute intervals using PAR sensors and data loggers mounted underneath each shade structure. Data were then used to calculate mean monthly DLI levels within each respective shade treatment. Turf quality, digital image analysis of percent green cover, and NDVI were measured monthly during the study. Root dry weights for the 0-12" soil depth were also determined for fairway height plots during the fall of each year within Full Sun and 50% Shade plots. At the end of the study, polynomial regression was used to determine minimal DLI thresholds for acceptable Turf Quality in each entry. For Turf Quality assessment, a 1-9 scale was used, with 1= dead, brown turf, 5.5= minimally acceptable turf, and 9= perfect turf. Daily Light Integral values were calculated for summer (June-Aug), spring (March-May), and fall (Sept.-Nov.) seasons during the final year (2017) of the three-year project and are presented in Figure 2.

Near the end of the field study, a golf course validation study was conducted at Bluejack National Golf Club, Montgomery, TX, in an attempt to validate field DLI data collected during the study. Over three consecutive five-day periods during late September/ early October 2017, five PAR sensors and corresponding data loggers were positioned at varying distances in from the south edge of a heavily-shaded, tree lined Zeon zoysiagrass fairway. At each point where sensors were placed, visual turf quality and percent green cover data were also recorded. After three weeks, all data were then subjected to linear regression analysis in order to determine minimal DLI requirements.

Results

DLI Levels in Shade Treatments

When averaging across both years of the study, DLI produced by the shade treatments were highest during summer months, peaking at ~47 mol/m^2/d under Full Sun, and decreasing proportionally to around 5 mol/m^2/d under 90% shade levels (Figure 2). During spring, DLI were ~38 mol/m^2/d in Full Sun and decreased proportionally to ~4 mol/m^2/d under 90% shade levels. Full Sun DLI for fall approached 33 mol/m^2/d and decreased to ~3 mol/m^2/d under 90% shade levels.

Soil Temperatures

Soil temperatures for the 0-1" soil depth were also affected by shade treatment, decreasing as shade intensity increased during all seasons, but was most pronounced during summer and fall months (Figure 3). In January, mean soil temperatures decreased by ~2 ^{o}F when moving from Full Sun to 90% Shade. In July and November, mean soil temperatures decreased by closer to ~5 ^{o}F when moving from Full Sun to 90% Shade.

Bermudagrass Cultivar DLI Requirements

Daily Light Integral requirements needed for achieving acceptable turf quality during the final season were generally higher for bermudagrass than for zoysiagrass entries (Tables 2 and 3). At fairway height, bermudagrass DLI requirements in spring ranged from 16 to 20 mol/m^2/d (Table 2). Tifway required the highest overall spring DLI (20 mol/m^2/d), while Tifgrand and Latitude 36 tolerated slightly lower but similar DLI (16 mol/m^2/d). During summer, DLI requirements increased slightly, with all bermudagrass cultivars requiring 24 to 26 mol/m^2/d to achieve acceptable quality. Interestingly, TE application had little to no effect on DLI for any bermudagrass cultivars during the summer months. Fall DLI were again lower than those for summer, and a slight benefit due to TE was observed in Tifway and Latitude 36 cultivars during fall months.

The DLI levels needed to achieve acceptable bermudagrass quality were generally higher at rough compared to fairway mowing heights during spring and summer months (Table 2). DLI values in spring ranged from 19 mol/m^2/d in Tifgrand and Celebration, to 20 mol/m^2/d in Latitude 36, to 25 mol/m^2/d in Tifway. For summer, DLI of rough height bermudagrass increased to 32 mol/m^2/d in Tifway and 34 mol/m^2/d in Tifgrand bermudagrass, and were lowest in Latitude 36 (23 mol/m^2/d). Similar to fairway turf, DLI requirement decreased in fall to 17 mol/m^2/d for all cultivars except Tifway, which again required 25 mol/m^2/d to achieve acceptable quality.

Zoysiagrass DLI Requirements

During spring, DLI requirements of fairway height zoyisagrass ranged from 10 mol/m^2/d in Zorro to 13 mol/m^2/d for Geo and Palisades. As with bermudgrasses, zoysiagrass DLI increased during summer months, however, TE noticeably reduced DLI requirements for all zoysiagrass cultivars (Table 3). In the absence of TE, JaMur exhibited the highest zoysiagrass summer DLI requirements (26 mol/m^2/d), while Zorro exhibited the lowest summer DLI requirements (18 mol/m^2/d). With TE application, DLI requirements were reduced to 15 mol/m^2/d for Zorro and Zeon. As with bermudagrass, zoysiagrass DLI were decreased in fall compared to summer. In the absence of TE, ranged from 13 mol/m^2/d in Zorro and Geo to 17 mol/m^2/d in JaMur. With TE, DLI requirements dropped to 12 mol/m^2/d for cultivars Zorro and Geo.

In contrast to bermudagrass, zoysiagrass DLI requirements were unaffected or even reduced by increased mowing heights (Table 3). In spring, Zorro and Palisades had a DLI of 9 mol/m^2/d compared to DLI of 11 mol/m^2/d for all other zoysiagrass cultivars at rough height. During summer, rough DLI increased slightly relative to spring for all cultivars except Zeon and Zorro. During fall, DLI ranged from 9 mol/m^2/d (Zeon and Zorro) to 12 mol/m^2/d (JaMur). Somewhat surprisingly, with the exception of JaMur during fall, all zoyisagrasses performed similar to or better than the shade-tolerant Palmetto St. Augustinegrass check. It should be noted that the relatively low mowing height (2”) used in the study could have contributed to this, as this would be at or just below the lowest recommended St. Augustinegrass mowing height..

Shade Effects on Cultivar Root Growth

Rooting was affected by both shade level and cultivar in the study, and response to TE application varied by species and cultivar (Figures 3 and 4). With the exception of Tifgrand +TE, root dry weights of all bermudagrass cultivars decreased when moving from Full Sun to 50% Shade Levels (Figure 4). Trinexapac-ethyl improved rooting under shade only in Tifgrand. All other cultivars exhibited similar or decreased root dry weights when treated with TE in shade. The highest overall root dry weights in 50% shade were associated with Tifgrand +TE and Celebration –TE treatments.

With the exception of Palisades +TE and JaMur –TE, all zoysiagrass cultivars also showed decreased root dry weights in 50% Shade compared to Full Sun (Figure 5). Similar to bermudagrass cultivars, only 3 of the 5 zoysiagrasses (Zeon, Geo, and Palisades) increased root dry weights in response to TE application.

DLI Field Validation Study

In the golf course validation study, Zeon zoysiagrass Turf Quality ranged from as low as ~3.5 in heavily shaded areas near the edges of the fairway to ~8 further in towards the center (Figure 6 and 7). Due to lack of Turf Quality data below ~3.5 and corresponding DLI data below ~11, linear regression provided the best fit to the observed data. Based on the golf course data, Zeon zoysiagrass would be predicted to require a DLI of ~20 mol/m^2/d during this late September/ early October timeframe, slightly higher than our field study-derived Zeon DLI values of 15 mol/m^2/d for the 2017 fall. The somewhat elevated DLI requirements observed on the golf course could be due to relatively lower mowing heights (0.5” compared to 0.75” in our study), compacted soils, tree root competition, or increased traffic at the golf course study site.

Conclusions

This long-term field shade study sought to determine DLI requirements for acceptable quality of zoysiagrass and bermudagrass cultivars. The data show that minimal DLI requirements for most cultivars are highest in summer, and decrease during spring and fall months. Increased mowing height and trinexapac-ethyl application were beneficial in reducing DLI requirements primarily in zoysiagrass cultivars. Minimal DLI for fairway bermudagrasses were generally highest in Tifway, but relatively similar among Tifgrand, Celebration, and Latitude 36. In zoysiagrass, minimal DLI were lowest for Zorro at both fairway and rough heights, with coarser textured cultivars Palisades and JaMur requiring somewhat higher DLIs compared to finer textured cultivars at fairway height. Zoysiagrass cultivars Zorro, Zeon, and Palisades required lower DLI than Palmetto St. Augustinegrass. Knowledge of minimal DLI for zoysiagrass and bermudagrass cultivars should allow for improved species selection for shaded golf course fairway and rough environments, and contribute to improved sustainability of golf course management.

Literature Cited

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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
	Celebration	Sod Solutions
	Latitude 36	Sod Solutions
Zoysiagrass	Zeon	BladeRunner Farms, Inc.
	Zorro	Texas A&M AgriLIFE Research
	Geo	Sod Solutions
	Palisades	Texas A&M AgriLIFE Research
	JaMur	BladeRunner Farms, Inc.
[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. Minimal Daily Light Integral Requirements for bermudagrass cultivars during Spring, Summer, and Fall seasons as influenced by monthly Trinexepac-Ethyl application and mowing height. Data are for the final year (2017) of the 3-year Texas A&M shade study and have been rounded to nearest whole DLI value.

		Daily Light Integral Requirement (mol/ m^2/ d)		
Cultivar	Trinexapac-Ethyl	Spring	Summer	Fall
		Fairway Height		
Tifway	-	20	26	25
	+		26	17
Tifgrand	-	16	25	20
	+		25	20
Celebration	-	17	24	19
	+		24	19
Latitude 36	-	16	24	19
	+		24	18
		Rough Height		
Tifway	-	25	32	25
Tifgrand	-	19	34	17
Celebration	-	19	25	17
Latitude 36	-	20	23	17

Table 3. Minimal Daily Light Integral Requirements for zoysiagrass cultivars during Spring, Summer, and Fall seasons as influenced by monthly Trinexepac-Ethyl application and mowing height. Data are for the final year (2017) of the 3-year Texas A&M shade study and have been rounded to nearest whole DLI value. Palmetto St. Augustinegrass was included at the rough mowing height as a shade tolerant check.

		Daily Light Integral Requirement (mol/ m^2/ d)		
Cultivar	Trinexapac-Ethyl	Spring	Summer	Fall
		Fairway Height		
Zeon	-	11	19	15
	+		15	14
Zorro	-	10	18	13
	+		15	12
Geo	-	13	23	13
	+		20	12
Palisades	-	13	23	17
	+		18	14
JaMur	-	12	26	17
	+		17	14
		Rough Height		
Zeon	-	11	10	9
Zorro	-	9	9	9
Palisades	-	9	13	11
JaMur	-	11	14	12
Palmetto S.A.	-	11	14	11

Figure 1. Image of the Texas A&M Research Field Laboratory shade study facility with shade structures in place.

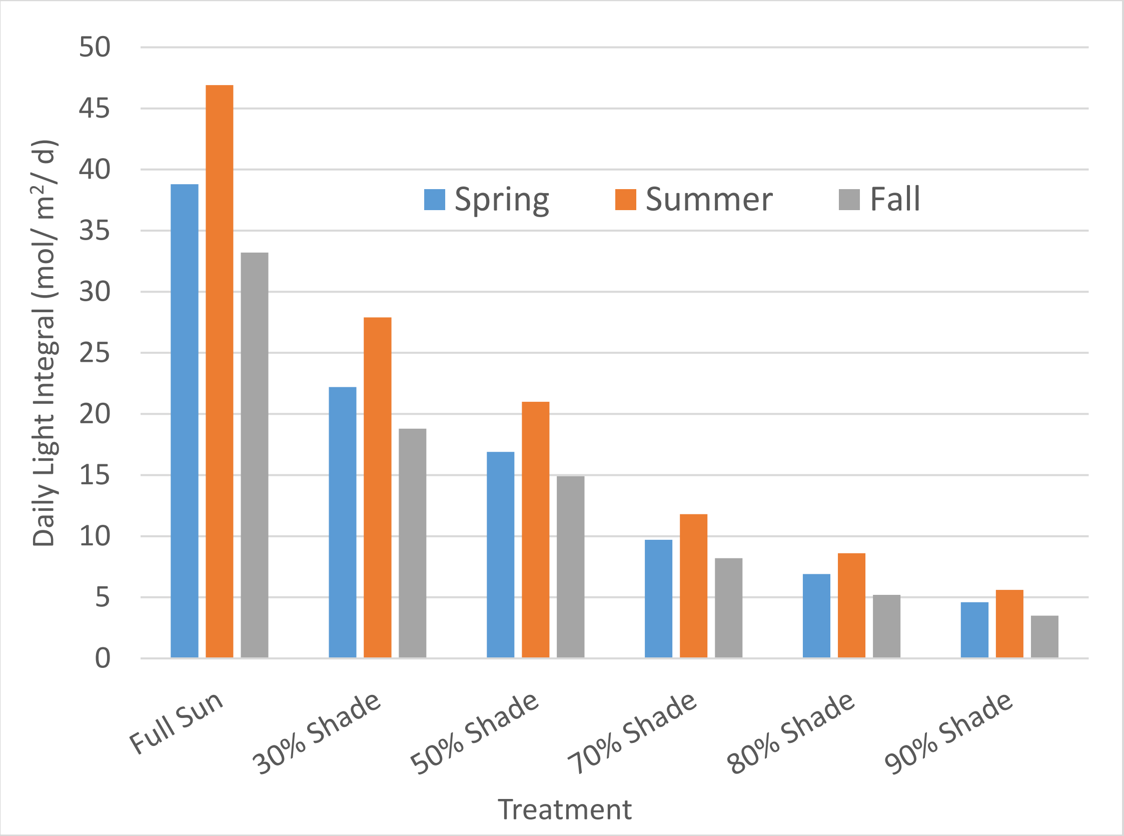

Figure 2. Seasonal Daily Light Integrals produced by shade treatments in the Texas A&M Shade Study (Spring = March - May, Summer = June - August, and Fall = September - November). Data are averaged across the 2016 and 2017 seasons.

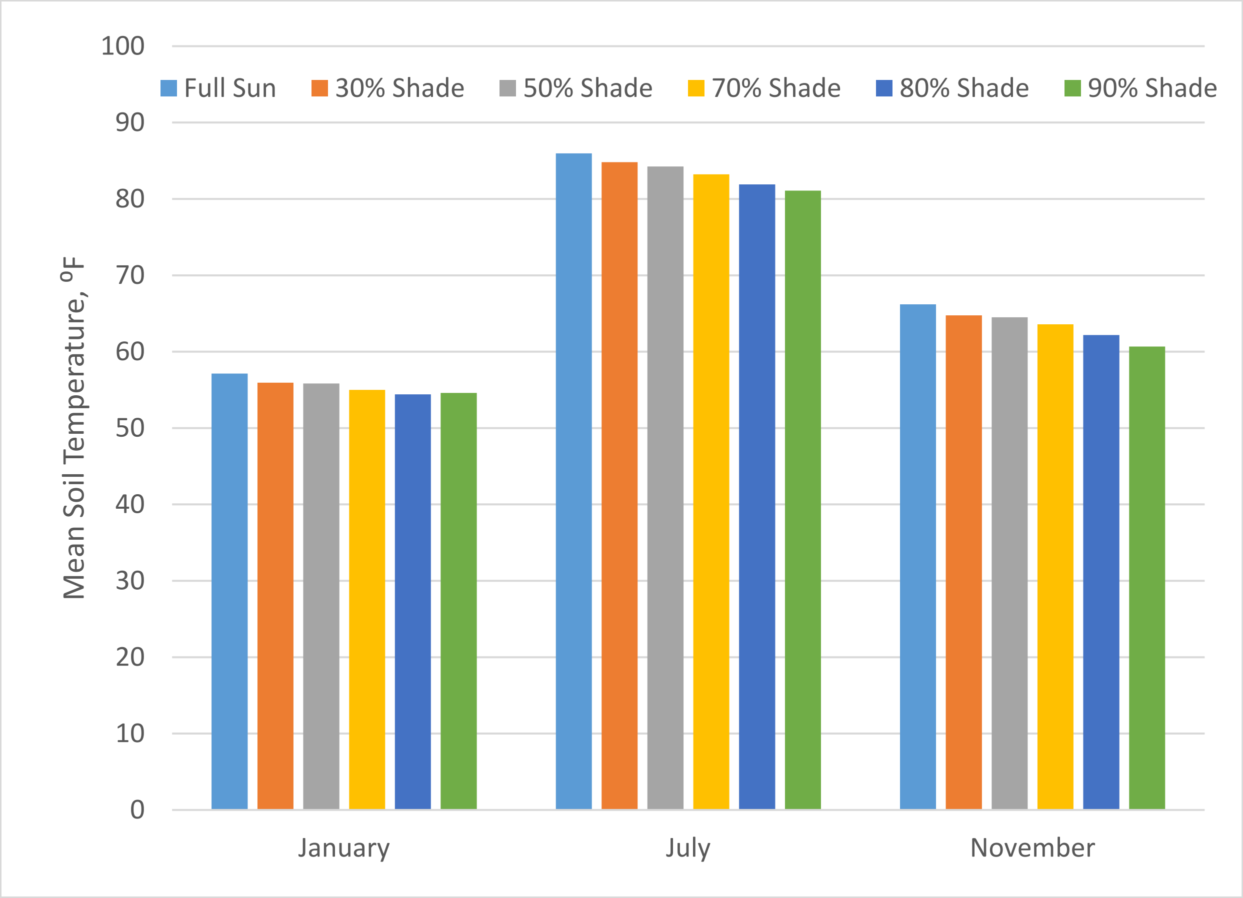

Figure 3. Mean Soil Temperature as affected by Shade Treatment Level during Winter, Summer, and Fall (January, July, and November) months. Soil Temperature data were measured at the 0-1" soil depth.

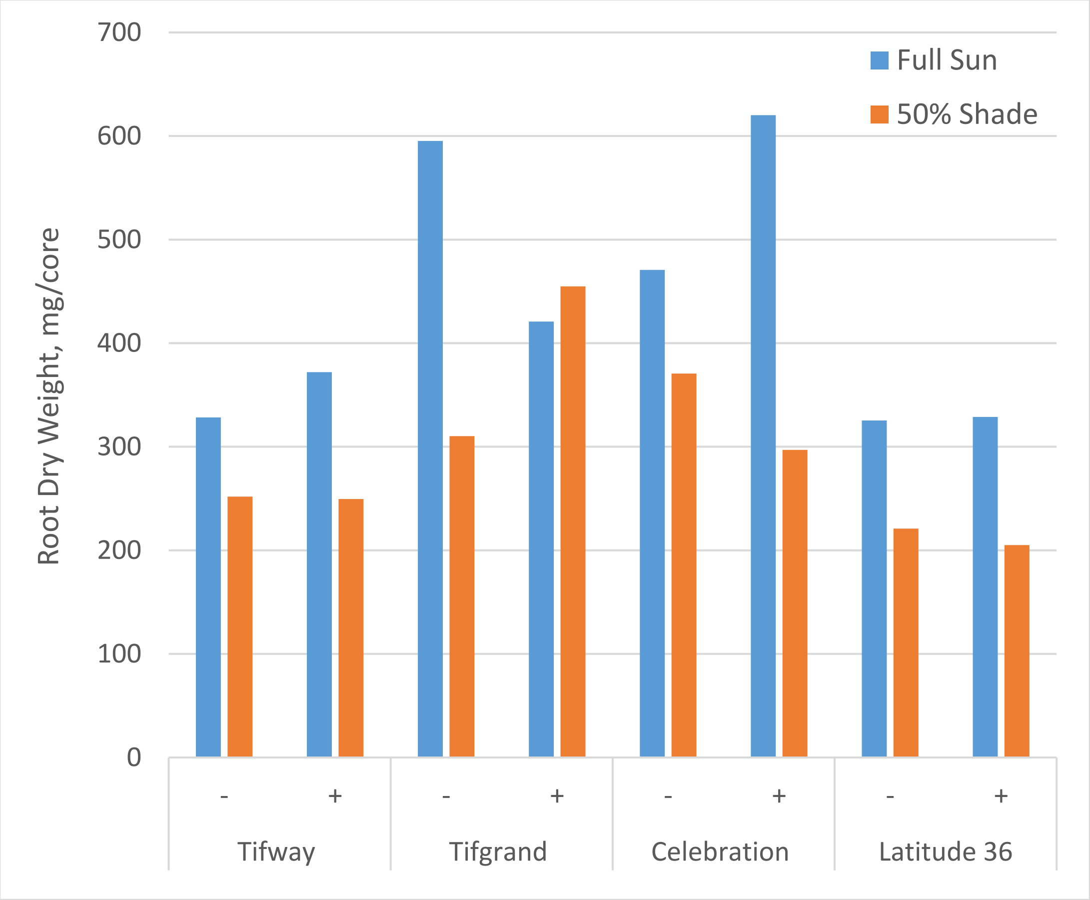

Figure 4. Root dry weights for bermudagrass cultivars at fairway height as influenced by Trinexapac-ethyl application (- Untreated, + Applied Monthly) in Full Sun and 50% Shade environments. Root data were obtained at the conclusion of the final year (2017) of the 3-year study for the 0-12" depth.

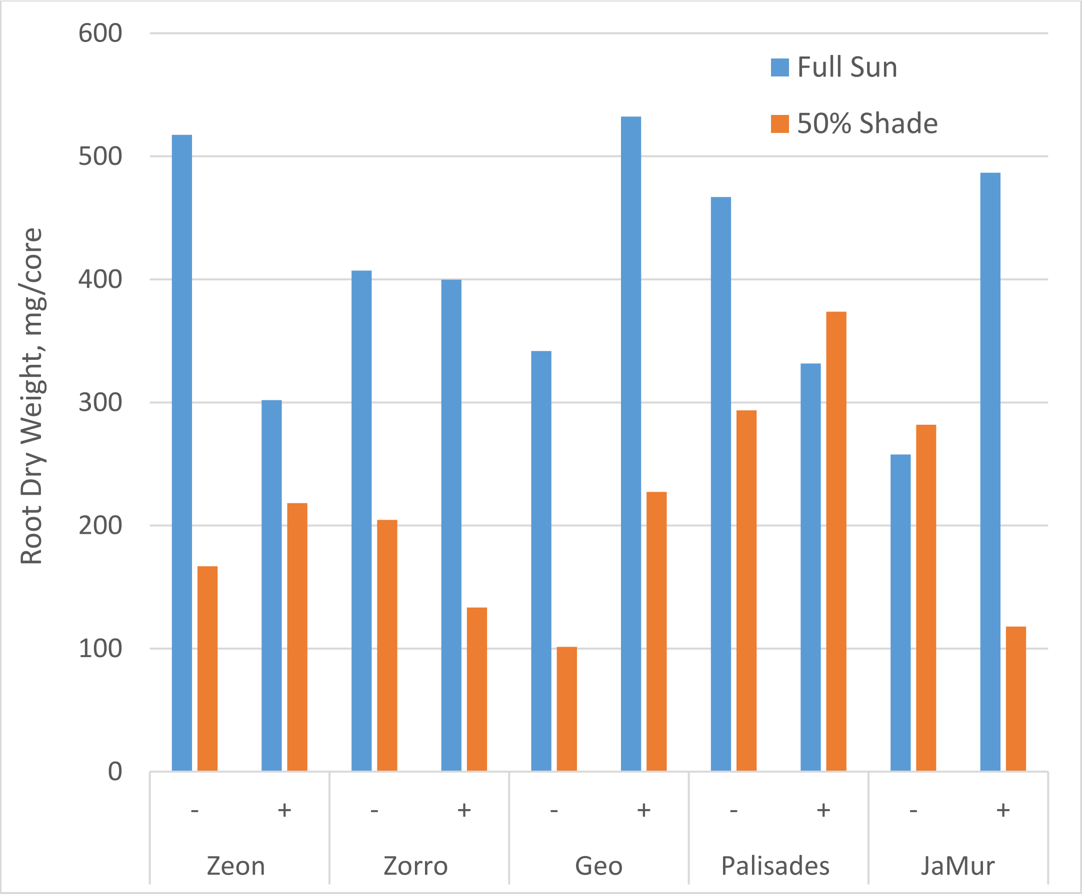

Figure 5. Root dry weights for bermudagrass cultivars at fairway height as influenced by Trinexapac-ethyl application (- Untreated, + Applied Monthly) in Full Sun and 50% Shade environments. Root data were obtained at the conclusion of the final year (2017) of the 3-year study for the 0-12” depth.

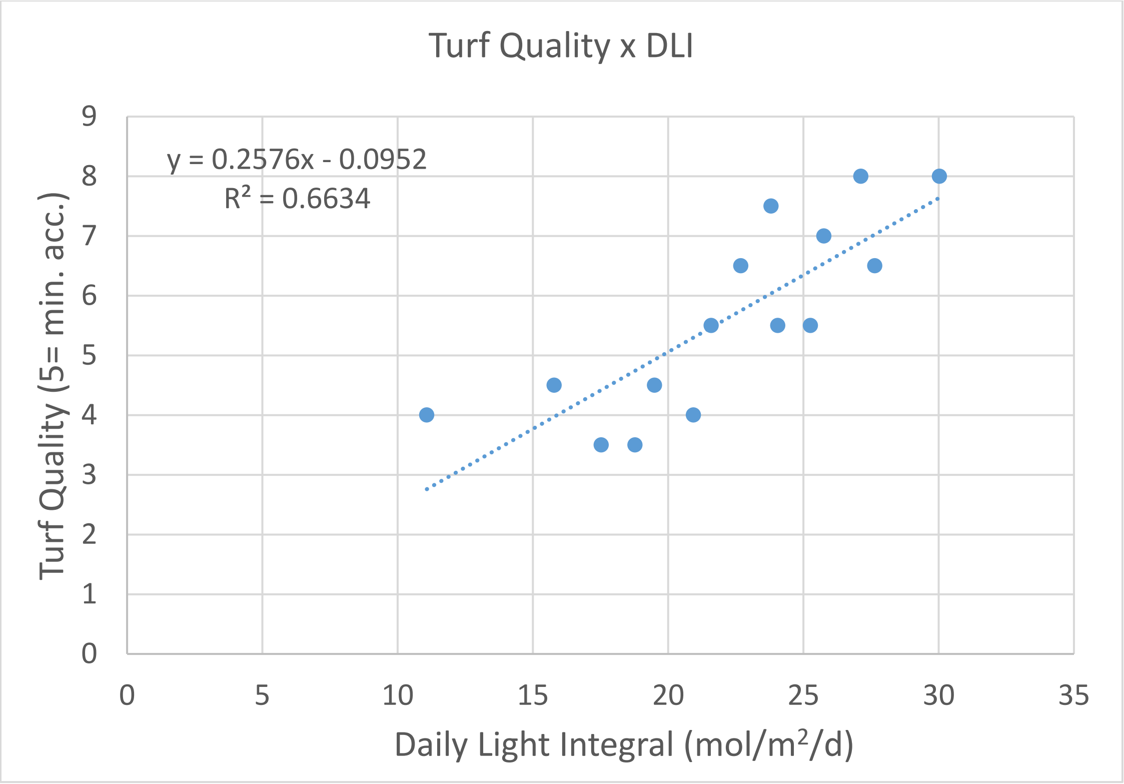

Figure 6. Regression analysis of Zeon Zoysiagrass Turf Quality (1-9, 5= min. accept.) with Daily Light Integral for the field validation study. Study was conducted late Sept. through early October 2017 at Bluejack National Golf Club, Montgomery, TX.

Figure 7. Mounted PAR sensors being installed in a Zeon zoysiagrass fairway at Bluejack National Golf Club, Montgomery TX for determination of minimal DLI needed to achieve acceptable turf quality. Five PAR sensors were mounted at varying distances into the fairway from the pine tree shade line at the south edge of the fairway during late September and early October 2017.

USGA ID#: 2017-15-625

Title: Modeling Gibberellin (GA) Production Improves Prediction of Turf Growth and PGR Performance

Project Leader: William C. Kreuser
Affiliation: University of Nebraska-Lincoln

Objectives:

1. Quantify growth response across a range environmental and management factors in growth chambers and field plots.
2. Pair GA production models with PGR GDD research to find solutions to problems of PGR over-regulation, with particular emphasis on bentgrass collars.
3. Fully integrate the results into an easy to access web-app, GreenKeeper.

Start Date: 2017
Project Duration: 3 years
Total Funding: $88,160

Summary Points:

- Clipping yield response was highly correlated to GA production within the turfgrass leaves. Nitrogen fertilizer rate and air temperature strongly influenced clipping yield and GA production in perennial ryegrass (PRYE), Kentucky bluegrass (KBG) and creeping bentgrass (CBG).
- From the greenhouse experiment, peak clipping yield responsiveness to nitrogen occurred when mean daily air temperature was 15C for PRYE, 22C for KBG and 25C for CBG. The ideal air temperatures for CBG were greater than expected for cool-season grasses. It isn't clear how carbon assimilation dynamics mirrored growth responsive.
- Application of PGRs on putting green intervals to collar height CBG lead to >80% clipping yield suppression, despite the low-labeled application rates. This lead to decreased turfgrass quality and increased phytotoxicity. We hypothesize this is a leading cause of golf course collar decline.
- Manipulating GA presence with exogenous GA application or through increased GA production with increased nitrogen fertilizer and reduced mowing height (0.4" to 0.3") rescued PGR over-regulation. Exogenous GA applications needed to be made curatively while reduced mowing height and increased nitrogen fertilization needed to be started preventatively.

Summary Text:

Greenhouse Growth Responsiveness Study

This experiment evaluated three grass species, four temperature regimes, and two nitrogen fertilization program. There were four replicates of each treatment, and the experiment was ran two times. 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) 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 four Environ growth chambers with average air temperatures at 7, 15, 25, or 35C. Light intensity, relative humidity, and day length were all constant in the three chambers. Two nitrogen fertilizer treatments tested were 0.6 and 2.4 g m^{-2} applied weekly from urea. 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. Clippings were collected, dried, and weighed weekly starting two weeks after treatments began and continuing for four weeks. Tissue was flash froze with liquid nitrogen to determine GA concentrations with LC-MS.

There was a positive correlation of GA content and clipping yield. However, the correlation wasn't as strong as cited in prior literature. This was likely the result of sample location. Clipping yield result from cell elongation slightly above the base of the leaf; a region called the zone of elongation. Our sampling included the upper portion of the leaf were elongation stopped and older leaves with minimal leaf elongation. Our research does indicate roughly 95% of clipping yield is the result of new leaf elongation which is known to be highly correlated to GA content. Therefore, an increases in leaf elongation are likely the result of greater GA production within the plant.

Peak clipping yield responsiveness to nitrogen fertilization occurred when mean daily air temperature was 15C for PRYE, 22C for KBG and 25C for CBG. Most textbooks suggest maximum carbon assimilation in cool-season (C_3) plants occurs are roughly 20C. Growth rate is highly correlated to assimilation rate, however, clipping yield is not the sole source of growth rate. Shade affected turfgrass frequently has greater clipping yield than turf growing in full sun. This response is the result of increased GA production in the presence of far-red light. Nitrogen fertilizer can also stimulate clipping yield when production despite deficits in carbon assimilation during to photorespiration. These finds suggest that either carbon assimilation efficiency is greater than expected for creeping bentgrass or GA production is more linked to nitrogen status that carbon status. The duration of this experiment was short. It is unclear if several months of enhanced growth would continue at supra-optimal air temperatures and a negative carbon balance.

PGR Over-regulation recovery

This field experiment was conducted on a 'T1' CBG golf fairway at the East Campus Turf Plots. The stand was mowed at 0.400" in 2017 and 0.325" in 2018. The stand was irrigated to prevent will and fertilized with 0.2 lbs N/M every 14 days from urea. The experimental design was a split-strip plot design with replicate blocks. The three replicate PGR strips measured 5x50 feet and were a non-treated control, Primo Maxx (trinexapac-ethyl) applied at 5.5 oz/A every 200 GDD (base 10C) or Trimmit 2SC (paclobutrazol) applied at 8 oz/A every 260 GDD (base 10C). These rates and intervals have been shown to provide uniform 20 and 35% clipping yield suppression on 'TI' CBG putting greens. PGR treatments began in early May during 2017 and 2018 and continued through July of each year. The PGR strips were then split with various recovery treatments including increased N fertilization (0.2 and 0.4 lbs N/1000 ft^2 in addition to the normal maintenance quantity), reduced mowing height, GA application at 0.15, 0.3, and 0.6 oz RyzUp/A, and other unsuccessful treatments (iron fertilizer, seaweed extracts) at various rates. Clippings and quality ratings were taken weekly during the experiment. All treatments were applied as curative treatments in July 2017. Increased N fertilization was considered to be a preventative treatment in 2018. As a result, those additional N application treatments began in conjunction with the first PGR applications of 2018.

During 2017, both PGR application regimes resulted in sustainable growth suppression of 80-95% on average. This led to severe phytotoxicity and discoloration. Leaves were sunken and the leaf tips were damaged from regular mowing and reduced recuperative potential. Practices and products that enhanced GA levels in the plant successfully rescued the PGR over-regulation. They included application of exogenous GA at all application rates – although the 0.15 oz/A RyzUp application rate is recommended – increased nitrogen fertilization, and reduced mowing height from 0.400 to 0.300 inches in 2018. Reducing mowing height and increased nitrogen fertilizer applications rates should be used as preventative measures. Excluding PGR applications from collars while spraying greens is also recommended, if at least during every other PGR application. GPS sprayer technology can help make this a reality in the future.

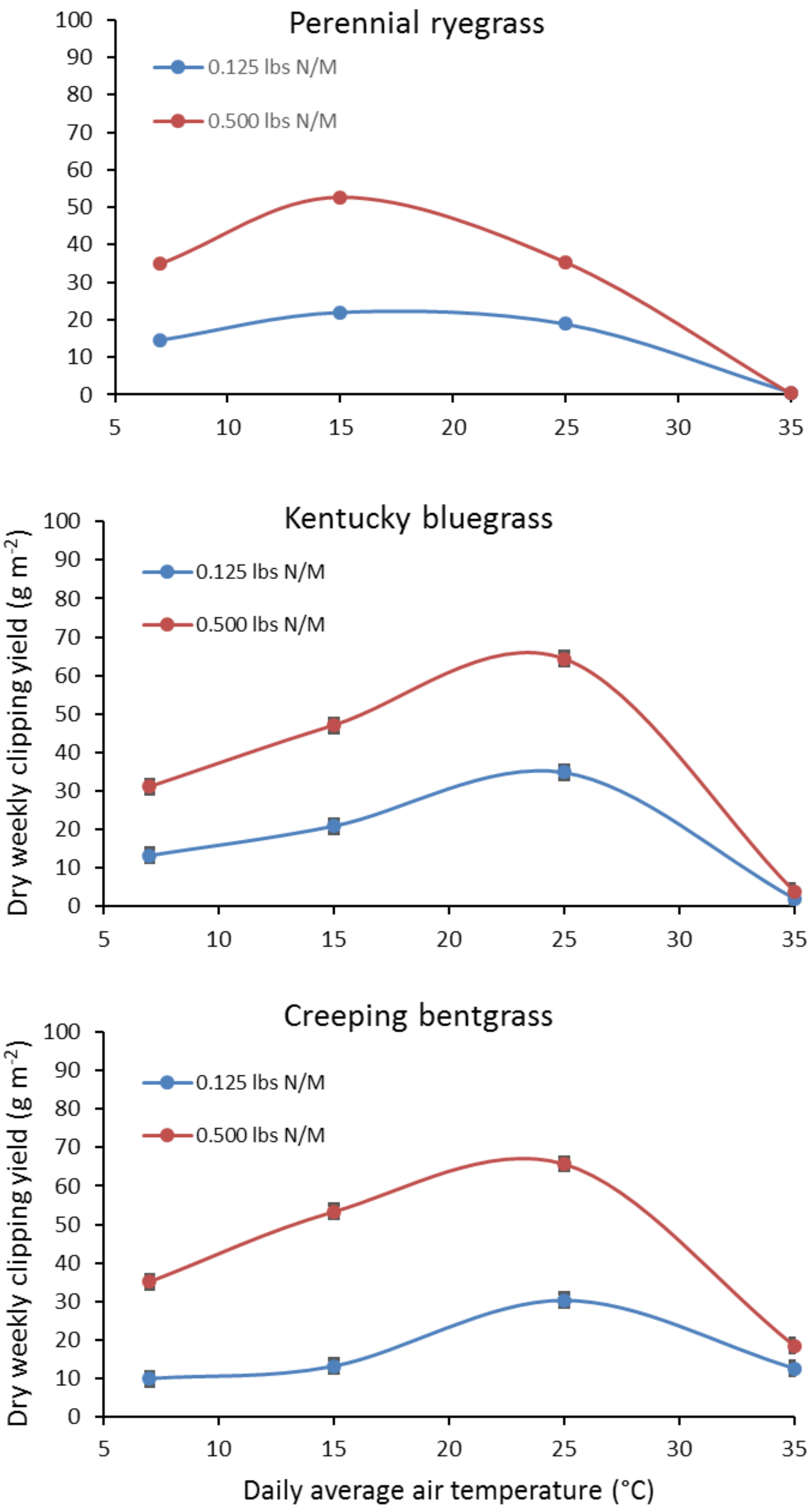

Figure 1. Clipping yield response to nitrogen fertilization rate and daily average air temperature. Run 1 and 2 were pooled together and LSD (5%) = 5.1.

USGA ID#: 2018-09-659

Title: Growing Degree Day Models to Guide PGR Application Rates

Project Leaders: William C. Kreuser
Affiliation: University of Nebraska-Lincoln

Objectives:

1. Develop PGR GDD models for various PGR active ingredients and application rates on cool and warm-season greens and fairways.
2. Quantify and correlate PGR metabolite levels to different points on the GDD models from the first objective.
3. Calculate critical PGR levels to sustain suppression and base temperatures for PGR metabolism.
4. Integrate GA production results and growth potential models from our 2016 USGA grant to account for physical removal of PGRs during mowing.
5. Use field research from objective one and lab research from objective two to develop a “flipped” PGR algorithm for application rate selection.

Start Date: 2018
Project Duration: 3 years
Total Funding: $120,000

Summary Points:

- Developed PGR GDD models for three cultivars of ultradwarf bermudagrass putting greens in NC, MS, and TN with our collaborators. Peak suppression for prohexadione-calcium ranged from 50-54% with ideal re-application intervals of 120-126 GDD (base 10C). Peak suppression ranged from 49-62% with re-application intervals ranging from 216-230 GDD (base 10C) for trinexapac-ethyl. Warm-season results were published in Crop Science. Results have been added to GreenKeeper App.
- Developed PGR GDD models for paclobutrazol applications on creeping bentgrass putting greens. Clipping yield suppression ranged from 29 to 62% of the non-treated control depending on application rate. The ideal re-application interval ranged from 269 to 302 GDD (base 0C) and model R^2 values ranged from 0.41 to 0.86. Results have been added to GreenKeeper App.
- “Flipped” PGR models were tested to estimate the amount of PGR remaining in the plant when the PGRs were applied prior to their ideal re-application interval. A half-life approach model was used to schedule PGR application rate. The models tested resulted in an intensification of clipping yield suppression and increased phytotoxicity overtime. This indicates the models were too aggressive. A different PGR degradation model will be evaluated in 2019.
- PGR metabolomics research will be started in fall of 2019.

Summary Text:

The goal is to create a PGR model that guides managers with the correct partial PGR application rate when a follow-up application is made prior to the ideal re-application interval. This will limit the stacking effect and intensification of growth suppression that has been document in our past research. This experiment was started on a creeping bentgrass golf fairway mowed at 0.400 inches. The ten treatments included a non-treated control for normalization and a 3x3 factorial of three PGRs (trinexapac-ethyl, paclobutrazol, and prohexadione-Ca; called TE, PC, PH) applied weekly at either the standard rate or two different fractions of the standard rate depending on GDD accumulation. There were three replicates. The equation used to estimate PGR degradation was based on the half-life equation:

Replacement PGR Rate (oz/A) = Full PGR Rate - (Full PGR Rate*(0.5)^(Current GDD/half-life in GDD))

The full rates for the TE, PC, and PH were 7, 16, and 11 oz/acre, respectively. The tight and long estimated half-lives for the TE, PC, and PH were 116/175 GDD, 160/240 GDD, and 140/210 GDD. Clippings were collected several times each week to determine if clipping yield suppression was static or intensifying over time.

The experiment was concluded after four weeks because the clipping yield intensifies over the three applications for all treatments except for the trinexapac-ethyl with the 175 GDD half-life (Fig. 1). This lead to strong phytotoxicity (Fig. 2) and greater than 80% clipping yield suppression for all other treatments relative to the non-treated control. Future research will evaluate other degradation models (i.e. linear) and different proposed half-live coefficients. This research is important because it will help with variable rate sprayers and minimize PGR-induced collar decline.

References

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Reasor, E. H., J. T. Brosnan, J. P. Kerns, W. J. Hutchens, D. R. Taylor, J. D. McCurdy, D. J. Soldat, and W. C. Kreuser. 2018. Growing Degree Day Models for Plant Growth Regulator Applications on Ultradwarf Hybrid Bermudagrass Putting Greens. Crop Sci. 58:1801-1807. doi:10.2135/cropsci2018.01.0077

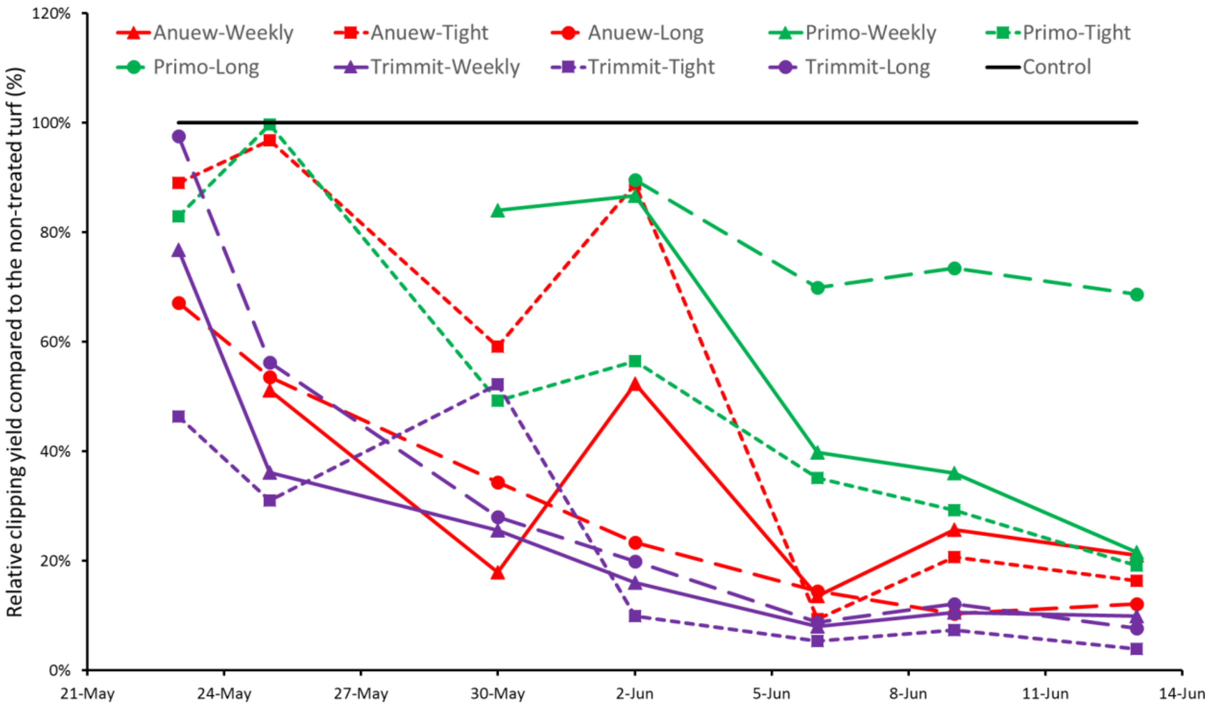

Figure 1. The impact of different PGR re-application models on the relative clipping yield suppression of a creeping bentgrass fairway mowed at 0.400 inches.

Figure 2. The impact of different PGR re-application models on the turfgrass quality of a creeping bentgrass fairway mowed at 0.400 inches.

USGA ID#: 2017-20-630

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

Project Leader: Emily Merewitz Holm
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: 2 years
Total Funding: $20,000

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, DGCI was greater than chemical priming hormones without Primo.
- Civitas and Civitas + Primo treatments had greater regrowth when compared to the untreated control.

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 for the second year. After one year, ABG treated with Civitas or JA had greater recovery when compared to the untreated control after 40 and 80 d after ABG was initially frozen. Fatty acid analysis will be evaluated following the completion of the growth chamber treatments.

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*.

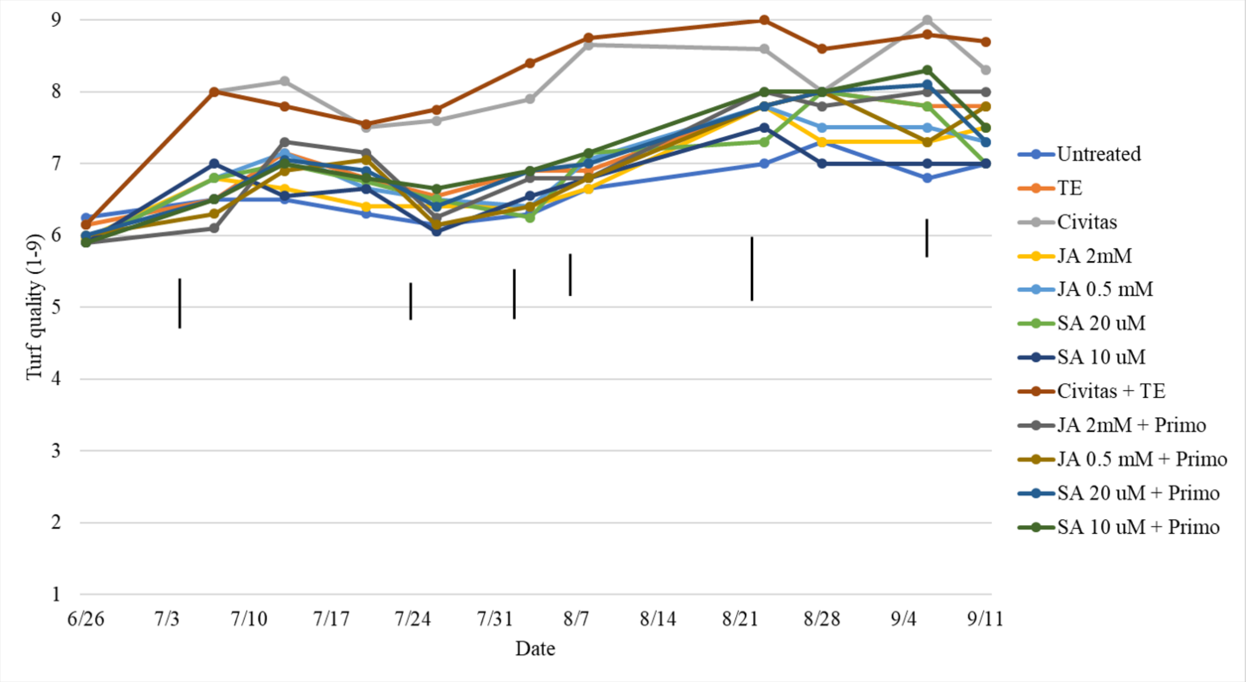

Figure 1. Turfgrass quality (1–9 scale with 1 (poor) and 9 (best), with 6 being acceptable) of annual bluegrass under chemical priming treatments in 2017 and 2018. Bars represent Fisher's protected least significant difference at $P \leq 0.05$ for the comparison of means on each date.

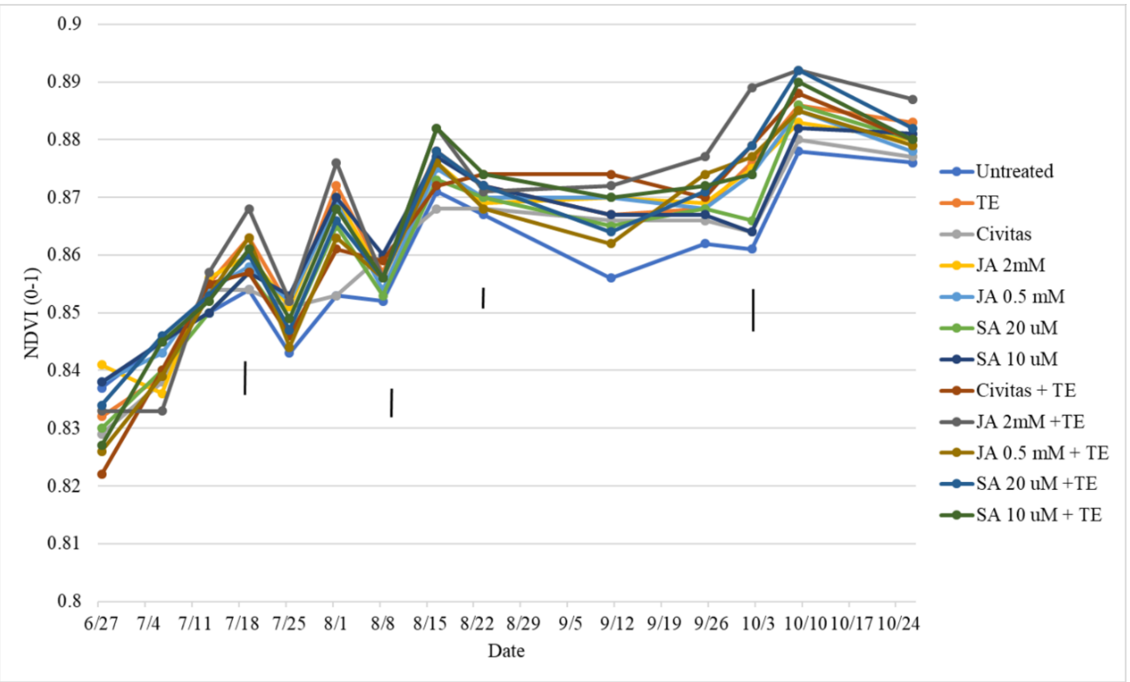

Figure 2. Normalized difference vegetation index of annual bluegrass under chemical priming treatments in 2017 and 2018. Bars represent Fisher's protected least significant difference at P ≤ 0.05 for the comparison of means on each date.

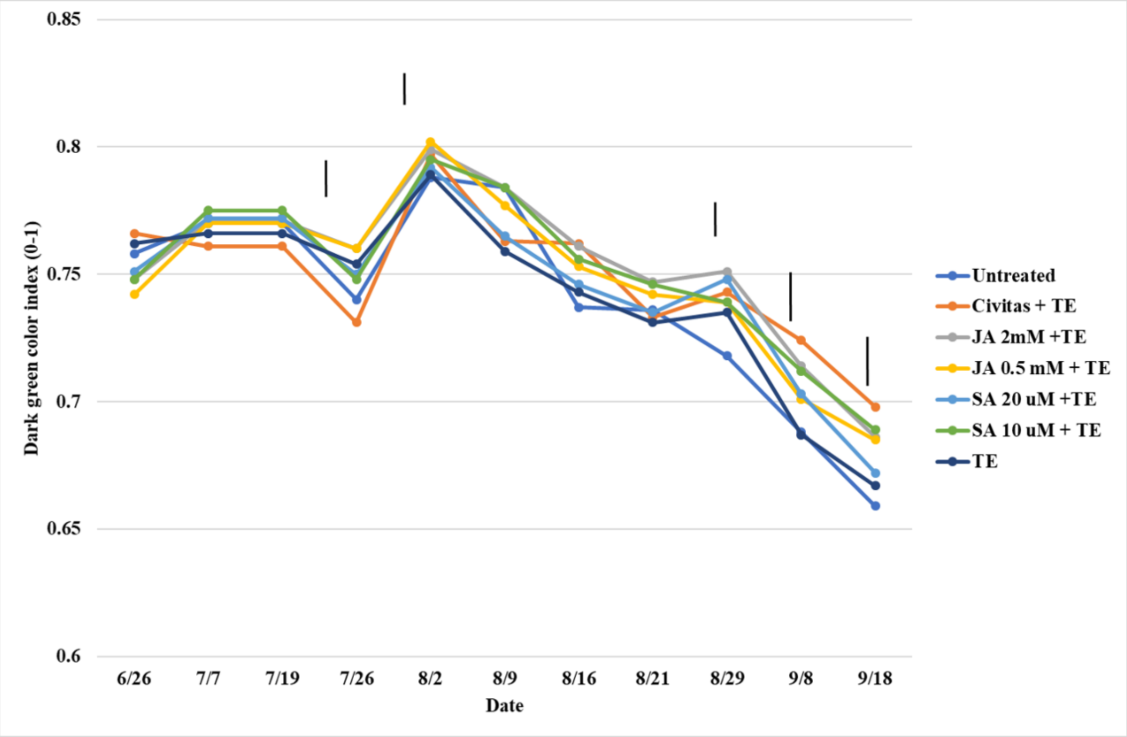

Figure 3. Dark green color index of annual bluegrass under chemical priming treatments in 2017 and 2018. Bars represent Fisher's protected least significant difference at P ≤ 0.05 for the comparison of means on each date.

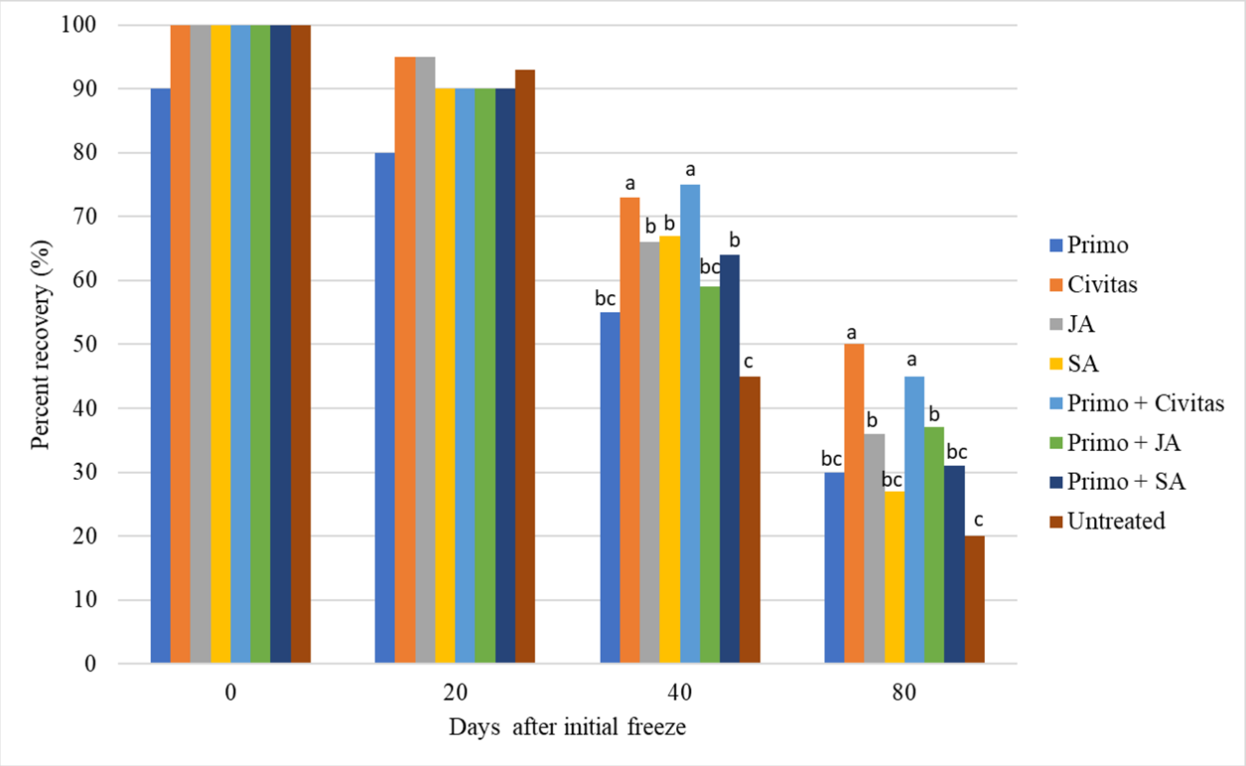

Figure 4. Percent recovery of annual bluegrass under chemical priming treatments in 2017 after 0, 20, 40 and 80 days after initial growth. Bars with different letters are significantly different (P ≤ 0.05) due to treatment within a given day.

USGA ID#: 2016-06-556

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

Project leaders: James A. Murphy, Hui Chen, Kyle Genova, James W. Hempfling and Charles J. Schmid
Affiliation: Department of Plant Biology, Rutgers University

Objectives:

1. Determine the effects of eliminating coarse particles from topdressing sand (subsequently increasing the quantities of medium, fine and very fine particles) on the performance of creeping bentgrass maintained as putting green turf.
2. Assess the impact of core cultivation and backfilling holes with medium-coarse sand to ameliorate the potential negative effects of finer-textured topdressing sands on turf performance and the physical properties at the surface of a putting green root zone.

Start Date: 2016
Project Duration: 3 years
Total Funding: $90,000

Summary Points:

- Water infiltration was slowed by topdressing with sand that contained a greater amount of fine sand; however, core cultivation was capable of offsetting this effect and increased water infiltration rate.
- Topdressing produced a firmer surface compared to the non-topdressed control at both levels of cultivation. Firmer surfaces were observed on plots that received the greatest rate of mid-season topdressing and were core cultivated.
- The Clegg Soil Impact Tester indicated that differences in surface hardness among sand sizes were only evident under non-cultivated conditions; surfaces were softest when topdressed with the fine-medium sand.
- Sand topdressing increased the mass-content of organic matter (kg/m^2) in the mat layer; however, the organic matter concentration (% by weight) was decreased (diluted) by topdressing sand. The 100 lbs. topdressing rate increased the mass-content and decreased the concentration of organic matter more than the 50 lbs. rate. Core cultivation reduced both the mass-content and concentration of organic matter in the mat layer.
- Medium-fine and fine-medium sands increased the fineness of sand within the mat layer. However, surface wetness (VWC) of the medium-fine plots was very similar to medium-coarse plots; whereas, the fine-medium plots frequently had much greater surface wetness than the other sands.
- Core cultivation was very effective at decreasing surface wetness of non-topdressed plots as well as plots topdressed with fine-medium sand.
- Core cultivation reduced the normalized difference vegetation index (NDVI) values compared to non-cored plots throughout 2018. Similarly, plots topdressed at 100 lbs./1,000-ft^2 had lower NDVI values than plots topdressed at 50 lbs./1,000 ft^2 through 2018. Thus, more aggressive management of thatch accumulation lowered vegetative cover.

Summary Text:

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 evaluated the effect of topdressing sand size on the performance of putting green turf.

Materials and Methods

The 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 topdressing (50- and 100-lbs. / 1,000-ft^2 every 10 to 14 days from June through October), and cultivation (non-cultivated or core cultivated plus backfill in May and October). Controls (no mid-season topdressing) at each level of cultivation were also included for comparisons resulting in 14 total treatments (Table 1). The medium-coarse sand met USGA recommendations for construction; whereas the fine sand content of the medium-fine and fine-medium sands exceeded USGA recommendations and contained little to no coarse particles (Table 2).

Data collection included: clippings to determine the quantity and particle size distribution of sand collected during mowing; falling-head infiltration rate; surface hardness (Clegg Soil Impact Tester, 0.5-kg and 2.25-kg missiles); surface firmness (penetration depth); mat layer thickness, organic matter content (loss on ignition) and sand particle size distribution; volumetric water content (VWC) of the surface 0- to 38-mm and 0- to 76-mm depth zones; visual rating of turf color, density and quality; and normalized difference vegetation index (NDVI).

Results

Topdressing with medium-coarse sand increased the percentage of applied-sand collected during mowing compared to medium-fine and fine-medium sands. Additionally, the percentage of applied-sand collected in mower clippings was greater at 100 lbs./1,000-ft^2 topdressing than the 50 lbs./1,000-ft^2.

Infiltration rate was strongly affected by sand size and cultivation (Table 4a). Plots topdressed with medium-coarse and medium-fine sand had greater infiltration rates than plots topdressed with fine-medium sand. Infiltration rate was greater in core cultivated plots compared to non-cultivated. Additionally, the 3rd inch of water infiltration indicated that sand size had a greater effect on infiltration of non-cultivated plots than core cultivated plots (Table 4b). The effect of sand size on volumetric water content (VWC) at the 0- to 1.5-inch depth after infiltration depended on the cultivation factor. Without cultivation, the VWC of medium-coarse and medium-fine sand plots were 4 to 6% lower than fine-medium sand plots within 2-hours after infiltration. Core cultivation reduced the surface wetness of all plots but had the greatest effect on fine-medium sand plots, reducing VWC after infiltration by 8%. Surface VWC before and 1-hr after infiltration was influenced by the mid-season topdressing rate for only the medium-fine sand plots, where the 100 lbs. rate reduced VWC compared to the 50 lbs. rate (Table 4b).

A greater surface hardness (maximum deceleration, G_{max}) as measured by a 0.5-kg Clegg Soil Impact Tester was observed on non-topdressed control plots compared to topdressed plots at both levels of cultivation (orthogonal contrasts in Table 5a). This is probably due to the extremely shallow thatch layer of non-topdressed controls being easily compressed with a small deceleration of the Clegg missile; once the thatch layer is compressed the Clegg missile abruptly decelerates and reaches a large G_{max} as it interacts with the underlying rootzone. Conversely, the mat layer structure formed in topdressed plots is capable of absorb more of the missile energy resulting in a slower deceleration (lower G_{max}).

The effect of sand size on surface hardness depended on the level of core cultivation. Surface hardness of core cultivated plots was similar for all sand sizes; however, for non-cultivated plots, topdressing with medium-coarse and medium-fine sand produced greater surface hardness than plots topdressed with fine-medium sand (Table 5b). Surface hardness responses were associated with the VWC of respective plots; the lowest G_{max} values were observed on plots with the greatest VWC (non-cultivated, fine-medium sand).

Topdressing increased the mat layer depth and promoted organic matter accumulation (mass-content, kg/m^2) in the mat layer, while the diluting effect of adding sand to the mat layer reduced the organic matter concentration [% by weight] compared to non-topdressed controls (Table 6a). Similar, but muted responses to the pooled topdressing effect were observed on core cultivated plots.

Mid-season topdressing rate and cultivation were the factors that influenced development of the mat layer in topdressed plots (Table 6a). Plots topdressed at 100 lbs./1,000-ft^2 developed a thicker mat layer depth and greater organic matter accumulation (mass-content, kg/m2), while reducing the organic matter concentration [% by weight] compared to plots topdressed at 50 lbs./1,000-ft^2 (Table 6b). Core cultivated plots slightly reduced mat layer depth and decreased organic matter accumulation (mass-content, kg/m^2) compared to non-cultivated plots by 2018. There was a substantial reduction of the organic matter concentration (% by weight) in core cultivated plots compared to non-cultivated plots in 2017 and 2018.

The pooled topdressing effect (orthogonal contrasts) shifted the sand size distribution within the mat layer toward a finer size; core cultivation muted this shift in 2017 and obscured it (no statistical significance) by May 2018 (Table 7a).

Among topdressing treatments, topdressing size affected the sand size distribution within the mat layer, and the effect of sand size depended on the topdressing rate and cultivation factors (Table 7a). The sand size distribution within the mat became finer as the topdressing sand increased in fine sand content; this shift in fineness was intensified at the 100 lbs. topdressing rate for the fine-medium sand in 2017 (Table 7b). Fine-medium sand dramatically increased the portion of fine and very fine sand in the mat layer.

Plots that were core cultivated – and backfilled with medium-coarse sand – reduced the tendency to increase the fineness of sand in the mat layer of plots topdressed with sand containing more than 20% fine sand; however, the fine sand content was well above (9-10% more than) that of plots topdressed with medium-coarse sand (Table 7b).

The NDVI of creeping bentgrass turf was lower for plots topdressed at 100 lbs./1,000-ft^2 compared to 50 lbs./1,000 ft^2 throughout 2018 (Figure 1a). The NDVI of creeping bentgrass turf was also lower on core cultivated plots compared to non-cultivated plots throughout 2018 (Figure 1b).

Under non-cultivated conditions, topdressing reduced surface wetness (VWC at the 0 to 1.5-inch depth) compared to the non-topdressed control (Figure 2a). However, under core cultivated conditions, this drying effect of topdressing was only occasionally observed probably because the core cultivation treatment was highly effective at lowering VWC throughout the year (Figure 2b).

Topdressing rate effected surface wetness for plots topdressed with medium-fine sand; plots topdressed with medium-fine sand at 100 lbs./1,000 ft^2 occasionally (14 of 70 dates in 2018) had a lower VWC than plots that received 50 lbs./1,000 ft^2 (Figure 3b). Surface wetness of plots topdressed with either medium-coarse or fine-medium sand was not affected by topdressing rate (Table 3a and 3c).

The effect of sand size on surface wetness also depended on the cultivation factor during 2018. Without core cultivation, topdressing with either medium-coarse or medium-fine sand produced a substantially drier surface compared to plots topdressed with fine-medium sand (Figure 4a). However, these differences among sand sizes were less prominent when plots were core cultivated due to core cultivation being highly effective at reducing surface VWC (Figure 4b).

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

	Factors in the Experiment			
Treatment No.	Sand Size[†]	Topdressing Rate during Mid- Season[‡]	Cultivation[¶]	Annual Quantity of Sand Applied
		lbs. / 1,000 sq. ft.		lbs. / 1,000 sq. ft.
1	Medium-coarse	50	Non-cored	1,200
2	Medium-coarse	50	Core + Backfill	1,700
3	Medium-coarse	100	Non-cored	1,700
4	Medium-coarse	100	Core + Backfill	2,200
5	Medium-fine	50	Non-cored	1,200
6	Medium-fine	50	Core + Backfill	1,700
7	Medium-fine	100	Non-cored	1,700
8	Medium-fine	100	Core + Backfill	2,200
9	Fine-medium	50	Non-cored	1,200
10	Fine-medium	50	Core + Backfill	1,700
11	Fine-medium	100	Non-cored	1,700
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). 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 1½-inch depth was performed twice a year (10 May and 2 November) using ½-inch diameter hollow tines spaced to remove 10% of the surface area annually. Coring holes were backfilled with 600 lbs. per 1,000 sq. ft. of medium-coarse sand. At the time of coring, non-cultivated plots were topdressed with the respective sand size at 400 lbs. per 1,000 sq. ft. to fill the surface thatch and verdure layers to the same extent as on the cored and backfilled plots.

Table 2. Sand size distributions of the three topdressing sizes, mat layer and the underlying rootzone at the initiation of the trial; USGA construction specification provided for references.

	Particle Diameter (mm)/Size Class				
Topdressing Sand Size	2.0-1.0 V. Coarse	1.0-0.5 Coarse	0.5-0.25 Medium	0.25-0.15 Fine	0.15-0.05 V. Fine
	------------------------------ % retained (by weight) ------------------------------				
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
Mat Layer[†]	0.1	25.3	56.4	15.4	2.7
Rootzone	6.9	25.3	44.6	17.2	4.1
USGA construction specification	≤10	≥60		≤20	≤5

[†] Size distribution of sand in 45 core samples of the mat layer collected before the initiation of treatments in May 2016.

Table 3. Percentage of applied-sand in mower clippings collected from a 1.9-m^2 area one day after topdressing with three sand sizes applied at two rates on creeping bentgrass turf maintained at 2.8-mm during 2016 and 2017.

	Collection Date¶					
Source of Variation	7-Jul-16†	17-Aug-16†	28-Sep-16	18-Jul-17	22-Aug-17	29-Sep-17
	-------------------------------- probability of significant *F* test --------------------------------					
Sand Size (SS)	***	***	***	***	***	***
Topdressing Rate (TR)	**	**	**	*	**	**
SS*TR	ns	ns	ns	ns	ns	*
Core Cultivation (CC)	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 Effects						
Sand Size	----------------------- percentage of applied-sand in mower clippings‡ -----------------------					
Medium-coarse	4.9	6.9	1.7	3.7	3.7	3.6
Medium-fine	2.3	3.9	0.8	2.3	1.6	2.0
Fine-medium	2.3	2.2	0.7	2.4	1.2	1.9
LSD$_{0.05}$	0.5	0.6	0.1	0.5	0.5	0.5
Topdress Rate						
50 lbs./1,000-ft^2	2.9	3.9	1.0	2.4	1.9	2.2
100 lbs./1,000-ft^2	3.5	4.7	1.1	3.1	2.5	2.8
Cultivation						
Non-cultivated	3.0	4.1	1.0	2.9	2.2	2.7
Core Cultivated	3.4	4.5	1.1	2.7	2.2	2.2

* Significant at $p \leq 0.05$; ** significant at $p \leq 0.01$; *** significant at $p \leq 0.001$; ns: nonsignificant

¶ Clippings from each plot were collected the day after topdressing three times during 2016, 2017 and 2018 to determine the quantity and particle size distribution of sand collected during mowing. Clippings were separated from sand by combustion before sieving to determine sand size distribution.

† Mowing height was 0.125-inch on 17-Aug-16

‡ Weight of sand collected by mower ÷ weight of topdressing applied to mowing area x 100

Table 4a. Infiltration rate and volumetric water content at the 0- to 1.5-inch depth zone as affected by topdressing with three sand sizes applied at two rates on creeping bentgrass turf maintained at 2.8-mm during 2016 and 2017.

	Infiltration Rate[†]			Volumetric Water Content			
	1st inch	2nd inch	3rd inch	Before	Hours after 3rd Inch of Infiltration		
Source of Variation	of Water	of Water	of Water	Infiltration	0	1	2
Sand Size (SS)	***	***	***	***	***	***	***
Topdressing Rate (TR)	ns	ns	ns	**	**	ns	*
SS*TR	ns	ns	ns	*	ns	*	ns
Core Cultivation (CC)	***	***	***	***	***	***	***
SS*CC	ns	ns	*	***	*	**	*
TR*CC	ns	ns	ns	ns	ns	ns	ns
SS*TR*CC	ns	ns	ns	ns	ns	ns	ns
Main Effects							
Sand Size	-------------- inches/hour --------------			---------------------------- % (v/v) ----------------------------			
Medium-coarse	10.7	6.7	6.4	24	34	28	27
Medium-fine	8.3	6.1	5.8	24	35	29	27
Fine-medium	6.0	3.9	3.6	28	38	32	31
$LSD_{0.05}$	1.9	0.9	1.0	1.3	1.3	1.1	1.4
Topdress Rate							
50 lbs./1,000-ft^2	7.8	5.5	5.3	26	36	30	29
100 lbs./1,000-ft^2	8.8	5.6	5.2	24	35	29	28
Cultivation							
Non-cultivated	5.8	4.1	3.8	28	39	32	31
Core Cultivated	9.8	7.0	6.7	23	33	27	26

* Significant at p≤0.05; ** significant at p≤0.01; *** significant at p≤0.001; NS: nonsignificant

[†] A falling-head infiltration rate was measured three times per plot using one double-ring falling-head infiltrometer (20-inch diameter outer ring and 12-inch diameter inner ring) in August 2018. One-inch of water was applied to the inner and outer rings and the time required to infiltrate all water in the inner ring was recorded, after which the time to infiltrate a second- and then a third-inch of water in the inner ring were also recorded.

Table 4b. Infiltration rate and volumetric water content at the 0- to 1.5-inch depth zone of a creeping bentgrass turf affected by the sand size by topdressing rate and sand size by core cultivation interactions in August 2018.

Interacting Factors		Water Infiltration†	Volumetric Water Content			
				Hours after 3rd Inch of Infiltration		
Sand Size	Mid-season Topdressing Rate	3rd inch of Water	Before Infiltration	0	1	2
	lbs. / 1,000-ft^2	inches/hour	---------------------------- % (v/v)	----------------------------		
Medium-coarse	50	na	24	na	28	na
Medium-coarse	100	na	24	na	27	na
Medium-fine	50	na	26	na	30	na
Medium-fine	100	na	22	na	28	na
Fine-medium	50	na	28	na	32	na
Fine-medium	100	na	27	na	32	na
	LSD$_{0.05}$		1.8		1.5	
Cultivation	Sand Size					
Non-cultivated	Medium-coarse	5.1	25	37	30	29
Non-cultivated	Medium-fine	4.1	26	38	31	30
Non-cultivated	Fine-medium	2.3	32	42	36	35
Core Cultivated	Medium-coarse	7.8	22	32	26	25
Core Cultivated	Medium-fine	7.4	22	32	27	25
Core Cultivated	Fine-medium	4.9	24	34	28	27
	LSD$_{0.05}$	1.4	1.8	1.8	1.5	1.9

† Falling-head infiltration rate was measured three times per plot using one double-ring falling-head infiltrometer (20-inch diameter outer ring and 12-inch diameter inner ring) in August 2018. One-inch of water was applied to the inner and outer rings and the time required to infiltrate all water in the inner ring was recorded, after which the time to infiltrate a second- and then a third-inch of water in the inner ring were also recorded.

Table 5a. Surface hardness, firmness and volumetric water content responses to sand size, mid-season topdressing rate and cultivation of a creeping bentgrass turf on 16 Oct. 2018.

	Surface Hardness[†]			Volumetric Water Content (depth zone, inches)	
Orthogonal Contrasts	0.5-kg	2.25-kg	Firmness[‡]	0 to 1.5	0 to 3
	G$_{max}$		mm	%	
Non-cultivated:					
Topdressed vs.	12.7*	7.8^{ns}	2.9*	28*	22*
Non-topdressed	14.7	7.7	3.8	32	25
Core Cultivated:					
Topdressed vs.	14.2*	8.7^{ns}	2.3*	24*	20^{ns}
Non-topdressed	15.4	8.6	2.5	26	20
Source of Variation	----------------------- probability of significant *F* test -----------------------				
Sand Size (SS)	ns	ns	ns	***	***
Topdressing Rate (TR)	ns	*	***	***	*
SS*TR	ns	ns	ns	*	*
Core Cultivation (CC)	***	***	***	***	***
SS*CC	***	*	ns	***	***
TR*CC	ns	ns	ns	ns	ns
SS*TR*CC	ns	ns	ns	ns	ns
Main Effects			mm		
Sand Size	------ G$_{max}$ ------			------ % ------	
Medium-coarse	13.4	8.3	2.4	24.1	19.1
Medium-fine	13.6	8.4	2.4	24.9	21.0
Fine-medium	13.3	8.1	2.4	29.6	22.8
LSD$_{0.05}$	ns	ns	Ns	1.3	2.5
Topdress Rate					
50 lbs./1,000-ft^2	13.5	8.1	2.6	27.4	21.1
100 lbs./1,000-ft^2	13.4	8.4	2.2	25.0	20.8
LSD$_{0.05}$	ns	0.2	0.14	1.1	2
Cultivation					
Non-cultivated	12.7	7.8	2.5	28.5	22.5
Core Cultivated	14.2	8.7	2.3	23.9	19.5
LSD$_{0.05}$	0.2	0.2	0.14	1.1	2.0

[*] Denotes a statistic difference between the pooled topdressing response and non-topdressed control.

[†] Surface hardness was measured by dropping a Clegg Soil Impact Tester (0.5-kg and 2.25-kg missiles) in six different locations of each plot.

[‡] The penetration depth of a 5.5-mm diam. shaft extending from an electronic digital indicator (Starrett® Cat. No. F2750-1 EDP No. 65847) into the verdure at six locations of each plot was used to determine surface firmness.

Table 5b. Surface hardness and volumetric water content responses to cultivation as influenced by the size of topdressing sand size applied to a creeping bentgrass turf, measured on 16 Oct. 2018.

Interacting Factors		Surface Hardness[†]		Volumetric Water Content (depth zones, inches)	
Cultivation	Sand Size	0.5-kg	2.25-kg	0 to 1.5	0 to 3
		-------- G_{max} --------		---------- % ----------	
Non-cultivated	Medium-coarse	12.8	8.0	25	20
Non-cultivated	Medium-fine	13.1	8.1	27	21
Non-cultivated	Fine-medium	12.3	7.4	34	26
Core Cultivated	Medium-coarse	14.0	8.6	23	18
Core Cultivated	Medium-fine	14.4	8.7	23	21
Core Cultivated	Fine-medium	14.4	8.7	26	20
	$LSD_{0.05}$	0.4	0.4	2.0	3.5

[†] Surface hardness was measured by dropping a Clegg Soil Impact Tester (0.5-kg and 2.25-kg missiles) in six different locations of each plot.

Table 6a. Mat layer depth, organic matter and sand mass-content, and organic matter concentration by weight in May 2017 and 2018 as affected by sand size, topdressing rate and cultivation on a creeping bentgrass turf maintained at 2.8-mm.

	2017 Mat Layer[¶]				2018 Mat Layer			
		Mass-content				Mass-content		
Orthogonal Contrasts	Depth[†]	Organic Matter[‡]	Sand	Organic Matter Concentration	Depth	Organic Matter	Sand	Organic Matter Concentration
	mm	------- kg/m^2 -------		% (kg/kg)	mm	------- kg/m^2 -------		% (kg/kg)
Non-cultivated:								
Topdressed vs.	17.2*	0.98*	11.1*	6.7	20.4*	1.21*	15.4*	5.9
Non-topdressed	15.9	0.83	9.3	8.5*	13.2	0.92	7.5	8.6*
Core Cultivated:								
Topdressed vs.	16.9*	0.86*	14.2*	5.7	19.3*	0.96*	20.2*	4.6
Non-topdressed	15.0	0.80	13.9	6.8*	15.9	0.82	19.4	5.1*
Source of Variation	-- probability of significant *F* test --							
Sand Size (SS)	ns	ns	ns	ns	ns	ns	ns	ns
Topdress Rate (TR)	***	**	***	***	***	***	***	***
SS*TR	ns	ns	ns	ns	ns	ns	ns	ns
Core Cultivation (CC)	ns	ns	ns	***	*	***	***	***
SS*CC	ns	ns	ns	ns	ns	ns	ns	ns
TR*CC	ns	ns	ns	ns	ns	ns	ns	ns
SSS*TR*CC	ns	ns	ns	ns	ns	ns	ns	ns

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

[¶] Forty-five core samples (1-inch diam.) of the mat layer were collected from across the trial area in May 2016 before treatment initiation. Four core samples (3-inch diam.) of the mat layer were collected from each plot in May 2017 and 2018. The thickness, organic matter content (loss on ignition) and sand particle size distribution of core samples were measured

[†] Average mat layer depth was 6.3-mm at the initiation of treatments in May 2016.

[‡] Average organic matter mass-content of mat layer was 0.82-kg/m^2 at the initiation of treatments in May 2016.

Table 6b. Mat layer depth, organic matter and sand mass-content, and organic matter concentration by weight responses in May 2017 and 2018 to mid-season topdressing rate and cultivation main effects on a creeping bentgrass turf maintained at 2.8-mm.

	2017 Mat Layer[¶]				2018 Mat Layer			
		Mass-content				Mass-content		
Main effect	Depth[†]	Organic Matter[‡]	Sand	Organic Matter Concentration	Depth	Organic Matter	Sand	Organic Matter Concentration
	mm	------- kg/m^2 -------		% (kg/kg)	mm	------- kg/m^2 -------		% (kg/kg)
Topdress Rate								
50 lbs./1,000-ft^2	16.5	0.90	15.2	6.5	18.8	1.06	21.3	5.6
100 lbs./1,000-ft^2	17.7	0.94	12.9	6.0	20.9	1.11	18.2	5.0
$LSD_{0.05}$	0.6	0.03	0.7	0.2	0.9	0.05	0.7	0.2
Cultivation								
Non-cultivated	17.2	0.98	13.9	6.7	20.4	1.21	19.4	5.9
Core Cultivated	16.9	0.86	14.2	5.7	19.3	0.96	20.2	4.6
$LSD_{0.05}$	ns	ns	ns	0.2	0.9	0.05	0.7	0.2

[¶] Forty-five core samples (1-inch diam.) of the mat layer were collected from across the trial area in May 2016 before treatment initiation. Four core samples (3-inch diam.) of the mat layer were collected from each plot in May 2017 and 2018. The thickness, organic matter content (loss on ignition) and sand particle size distribution of core samples were measured.

[†] Average depth of the mat layer was 6.3-mm at the initiation of treatments in May 2016.

[‡] Average organic matter mass-content of the mat layer was 0.82-kg/m^2 at the initiation of treatments in May 2016.

Table 7a. Particle size distribution of sand within the mat layer of creeping bentgrass turf in May 2017 and 2018 as affected by sand size, topdressing rate and cultivation.

	2017 Sand Size Distribution[†]					2018 Sand Size Distribution				
Orthogonal Contrasts	Very Coarse	Coarse	Medium	Fine	Very Fine	Very Coarse	Coarse	Medium	Fine	Very Fine
Non-cultivated:	---------- % by weight ----------									
Topdressed vs.	3.4	20.1	46.7	23.9 *	5.9 *	2.1	18.3	50.9	23.6 *	5.1
Non-topdressed	4.8 *	25.3 *	46.0	19.9	4.0	4.7 *	26.2 *	46.0	19.3	3.8
Cultivated:										
Topdressed vs.	3.1	20.2	51.6	20.6 *	4.5	2.2	20.1	55.9	18.3	3.6
Non-topdressed	3.7	22.0 *	50.9	19.3	4.1	2.9	22.9	55.0	16.4	2.9
Source of Variation	---------- probability of significant *F* test ----------									
Sand Size (SS)	ns	***	***	***	***	ns	***	***	***	***
Topdress Rate (TR)	ns	*	ns	ns	***	ns	ns	ns	ns	ns
SS*TR	ns	ns	***	***	***	ns	ns	ns	ns	ns
Core Cultivation (CC)	ns	ns	***	***	***	ns	ns	*	***	**
SS*CC	ns	***	***	***	***	ns	**	*	**	**
TR*CC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SSS*TR*CC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

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

[†] Four core samples (3-inch diam.) of the mat layer were collected from each plot in May 2017 and 2018; organic matter was removed (loss on ignition) and sand particle size distribution measured. Very Coarse represents 1-2 mm; Coarse represents 0.5-1 mm; Medium represents 0.25-0.5 mm; Fine represents 0.25-0.15 mm; Very Fine represents 0.15-0.05 mm

Table 7b. Particle size distribution of sand within the mat layer of creeping bentgrass turf in May 2017 and 2018 as affected by the interaction of sand size and topdressing rate, and sand size and core cultivation on particle size distribution.

Interacting Factors		2017 Sand Size Distribution[†]					2018 Sand Size Distribution				
Sand Size	Topdressing Rate	Very Coarse	Coarse	Medium	Fine	Very Fine	Very Coarse	Coarse	Medium	Fine	Very Fine
	lbs./1,000-ft^2	% by weight									
Med.-coarse	50	3.2	25.6	49.9	17.9	3.3	2.1	22.8	56.7	15.9	2.5
Med.-coarse	100	3.6	25.8	50.5	16.9	3.2	2.9	28.1	54.1	13.0	1.9
Med.-fine	50	3.2	18.0	53.8	21.2	3.7	2.2	15.8	60.3	18.9	2.8
Med.-fine	100	2.9	16.6	55.7	21.2	3.6	2.1	15.4	61.2	18.8	2.5
Fine-med.	50	3.6	18.2	43.8	26.6	7.7	2.3	17.9	44.3	28.2	7.3
Fine-med.	100	3.1	16.4	41.1	29.7	9.6	1.5	15.0	43.8	30.8	8.8
	LSD$_{0.05}$	ns	ns	1.4	1.2	0.6	ns	ns	ns	ns	ns
Sand Size	Cultivation										
Med.-coarse	Non-cultivated	3.2	27.5	48.7	17.4	3.2	1.9	26.9	54.3	14.8	2.1
Med.-coarse	Core Cultivated	3.6	24.0	51.7	17.4	3.3	3.0	24.1	56.5	14.1	2.3
Med.-fine	Non-cultivated	3.1	16.3	53.7	22.9	4.0	2.4	13.6	60.1	20.9	3.0
Med.-fine	Core Cultivated	3.0	18.3	55.8	19.5	3.4	1.9	17.6	61.4	16.7	2.4
Fine-med.	Non-cultivated	4.0	16.5	37.6	31.4	10.5	2.0	14.5	38.4	35.0	10.1
Fine-med.	Core Cultivated	2.7	18.2	47.3	25.0	6.9	1.7	18.5	49.7	24.0	6.0
	LSD$_{0.05}$	ns	1.3	1.4	1.2	0.6	ns	1.5	1.7	1.8	1.5

[†] Four core samples (3-inch diam.) of the mat layer were collected from each plot in May 2017 and 2018; organic matter was removed (loss on ignition) and sand particle size distribution measured. Very Coarse represents 1-2 mm; Coarse represents 0.5-1 mm; Medium represents 0.25-0.5 mm; Fine represents 0.25-0.15 mm; Very Fine represents 0.15-0.05 mm.

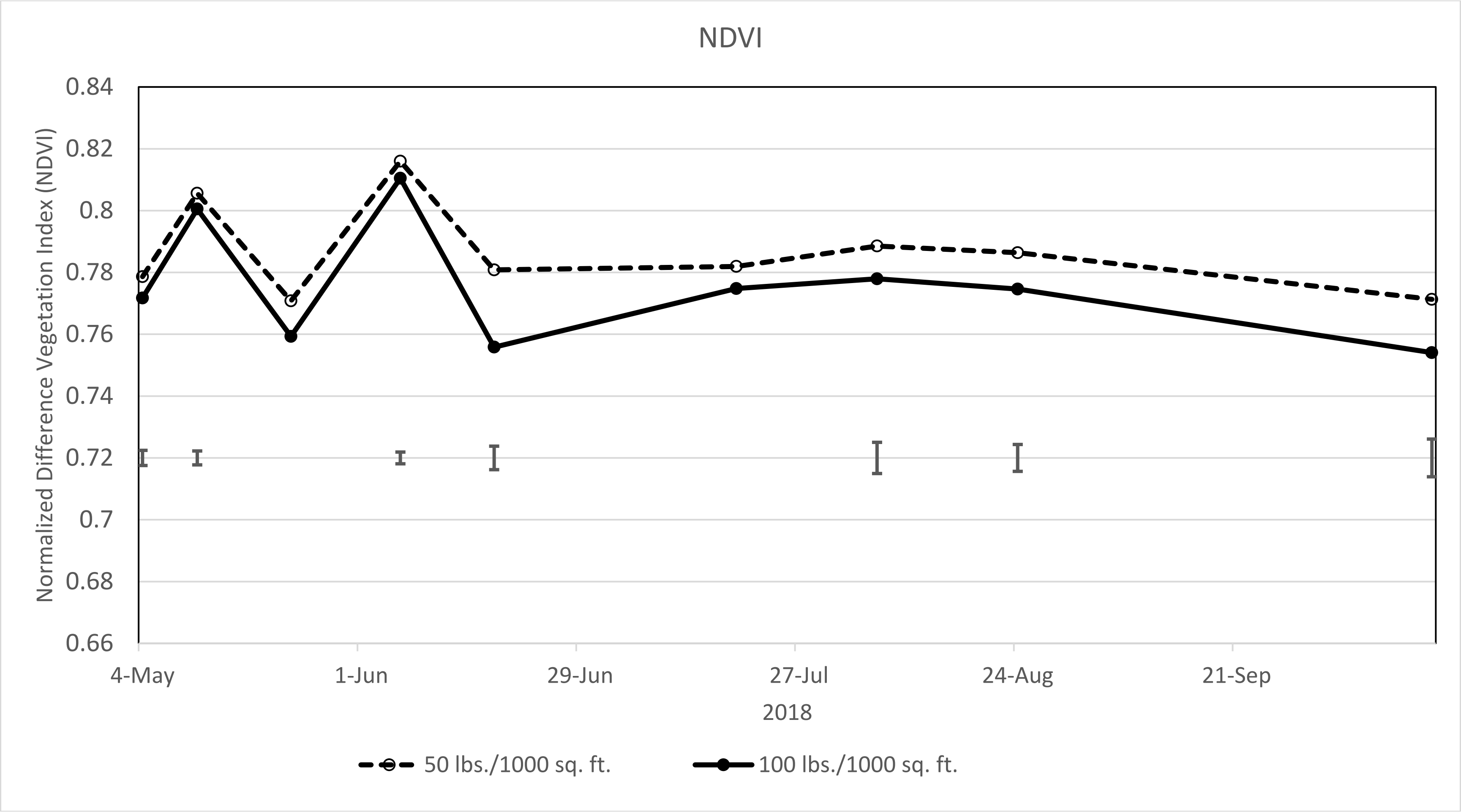

Figure 1a. Effect of topdressing rate on normalized difference vegetation index (NDVI) of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2018. NDVI measured using Multispectral Radiometers (CROPSCAN, Inc.) every 14 to 28 days. Core cultivation performed on 17 May 2018.

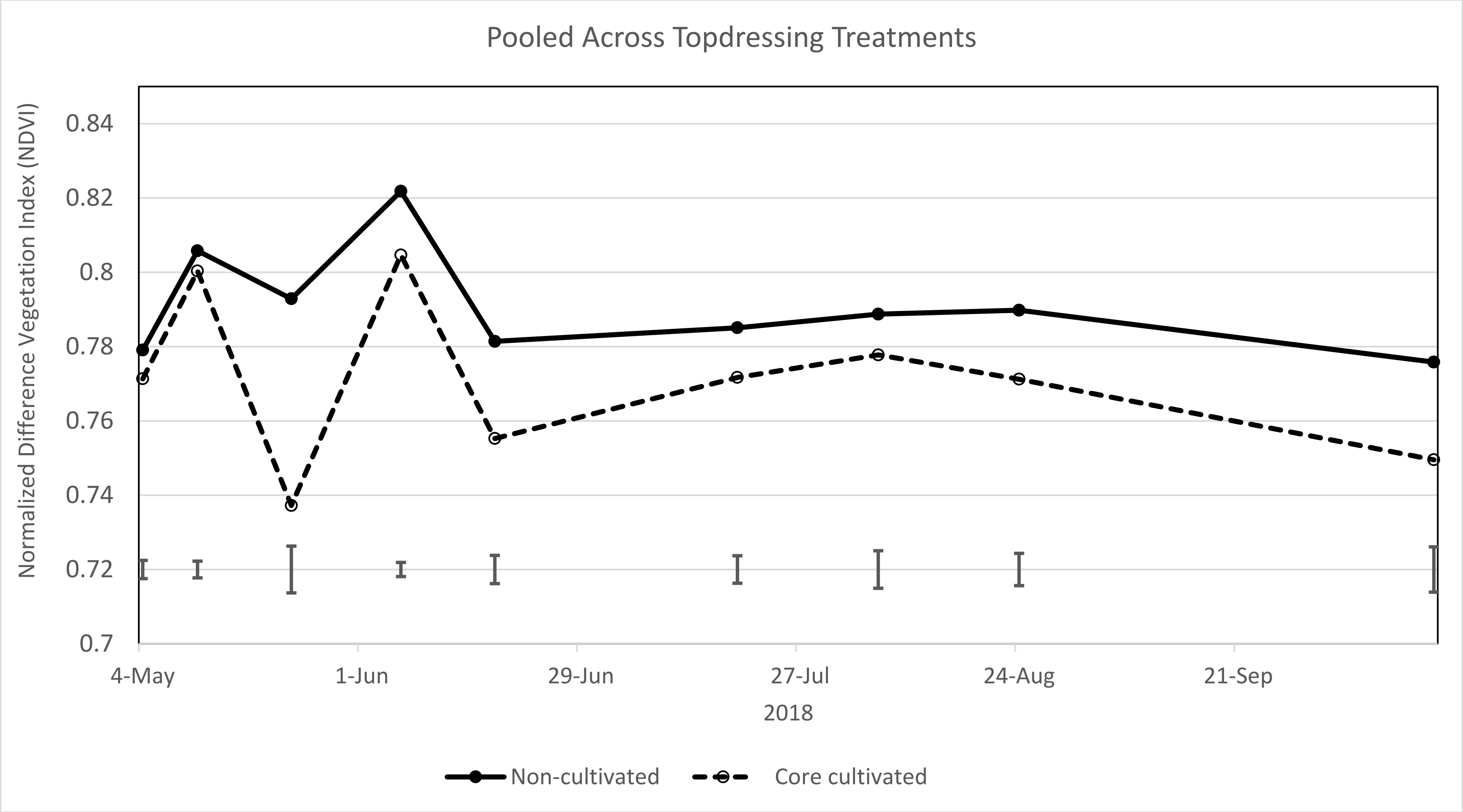

Figure 1b. Effect of core cultivation on normalized difference vegetation index (NDVI) of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2018. NDVI measured using Multispectral Radiometers (CROPSCAN, Inc.) every 14 to 28 days. Core cultivation performed on 17 May 2018.

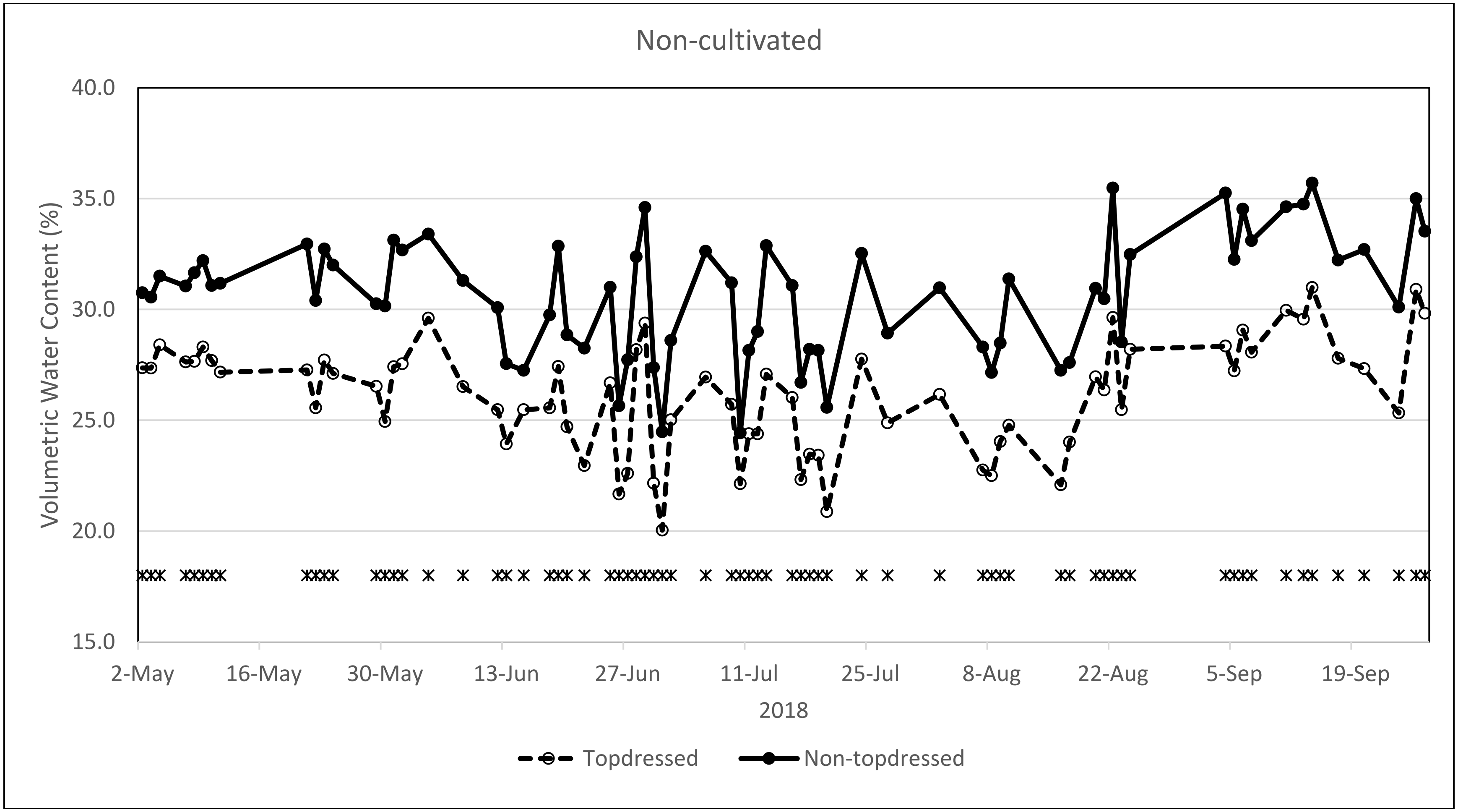

Figure 2a. The volumetric water content of the 0- to 1.5-inch depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm for the pooled topdressing effect compared to the non-topdressed control under non-cultivated conditions during 2018 in North Brunswick, NJ. Field Scout™ TDR 300 Soil Moisture Meter was used to measure volumetric water content,

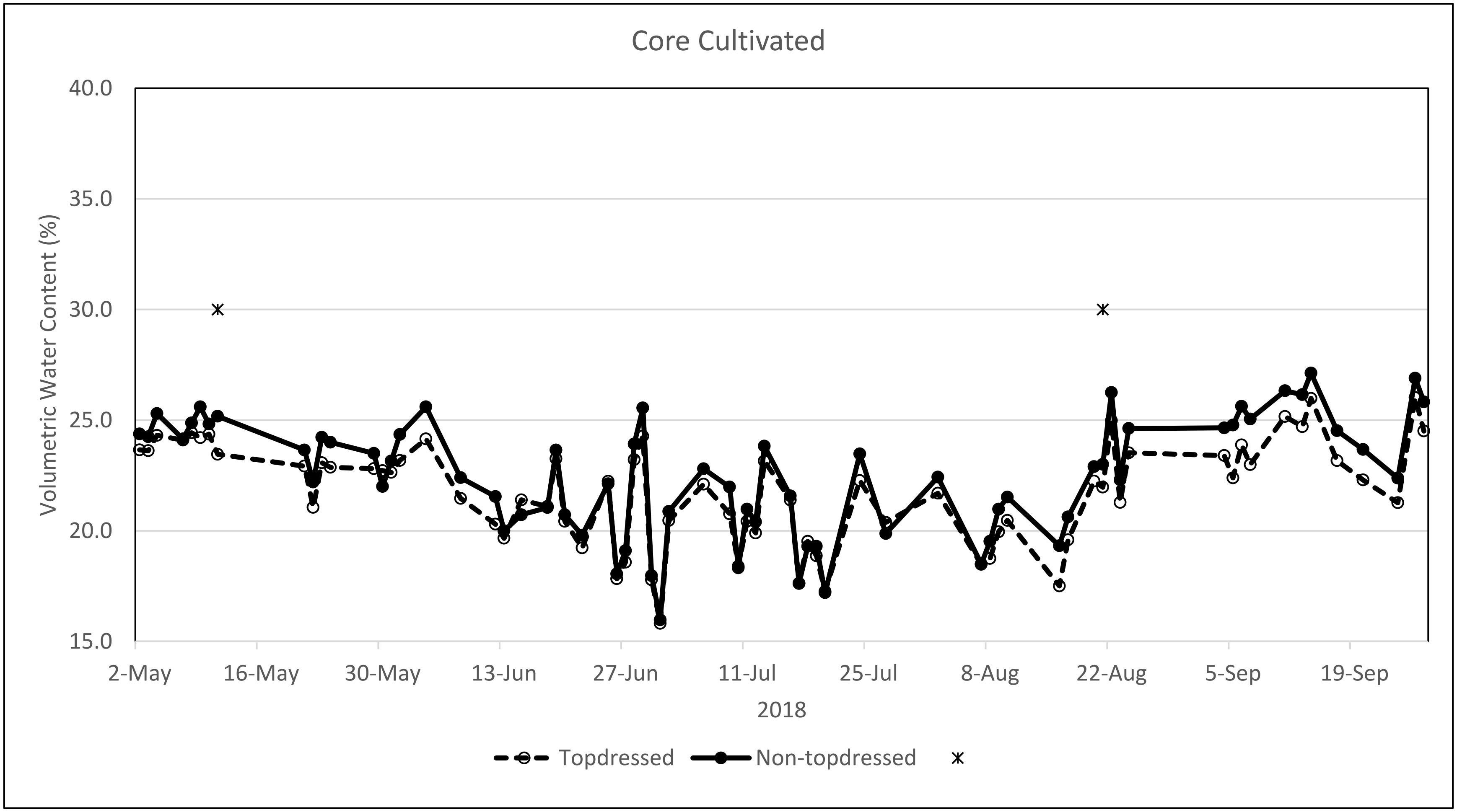

Figure 2b. The volumetric water content of the 0- to 1.5-inch depth zone of a ‘Shark’ creeping bentgrass turf maintained at 2.8-mm for the pooled topdressing effect compared to the non-topdressed control under core cultivated conditions during 2018 in North Brunswick, NJ. Field Scout™ TDR 300 Soil Moisture Meter was used to measure volumetric water content.

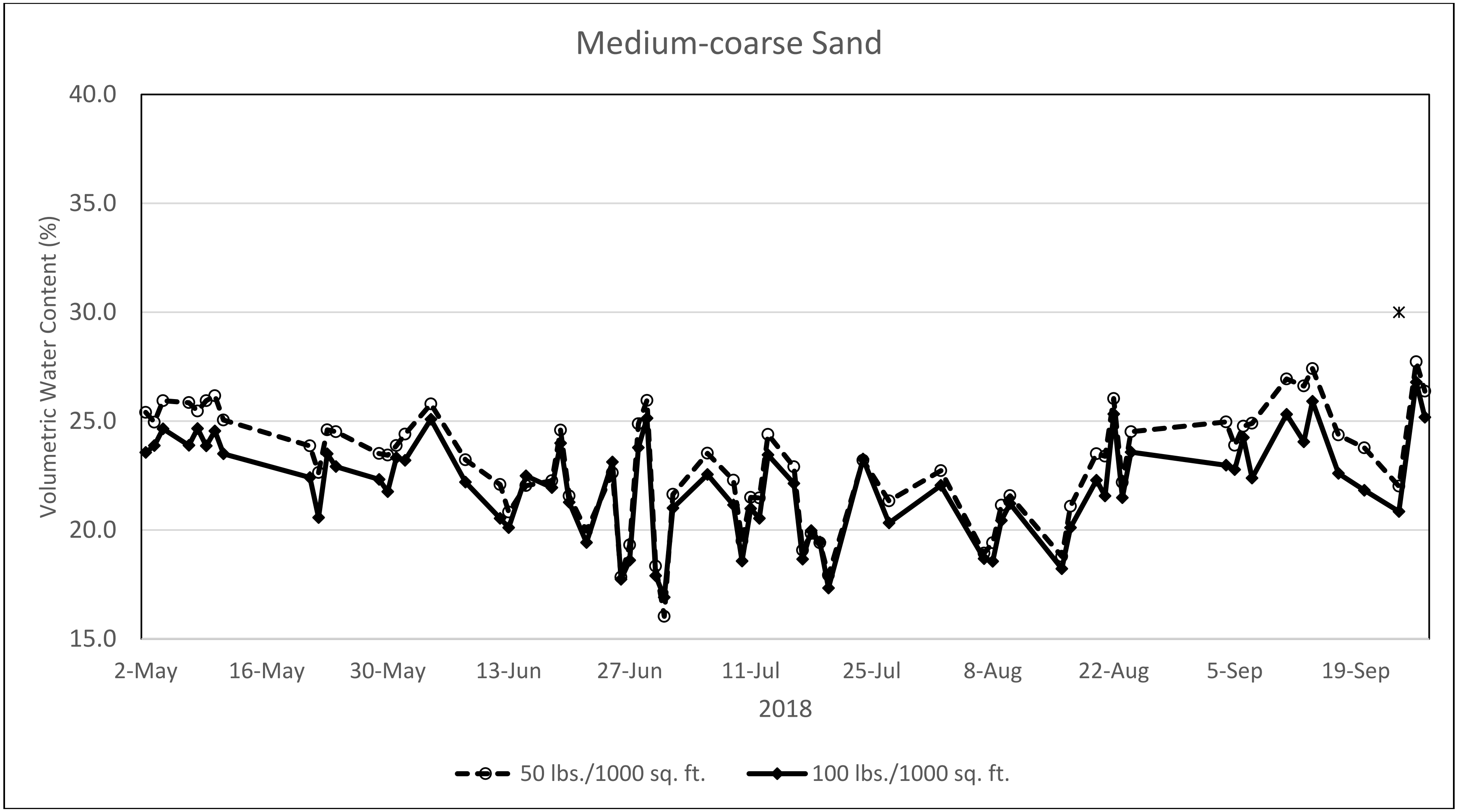

Figure 3a. The effect of topdressing rate with medium-course sand on volumetric water content at the 0- to 1.5-mm depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2018. Field Scout™ TDR 300 Soil Moisture Meter was used to measure volumetric water content

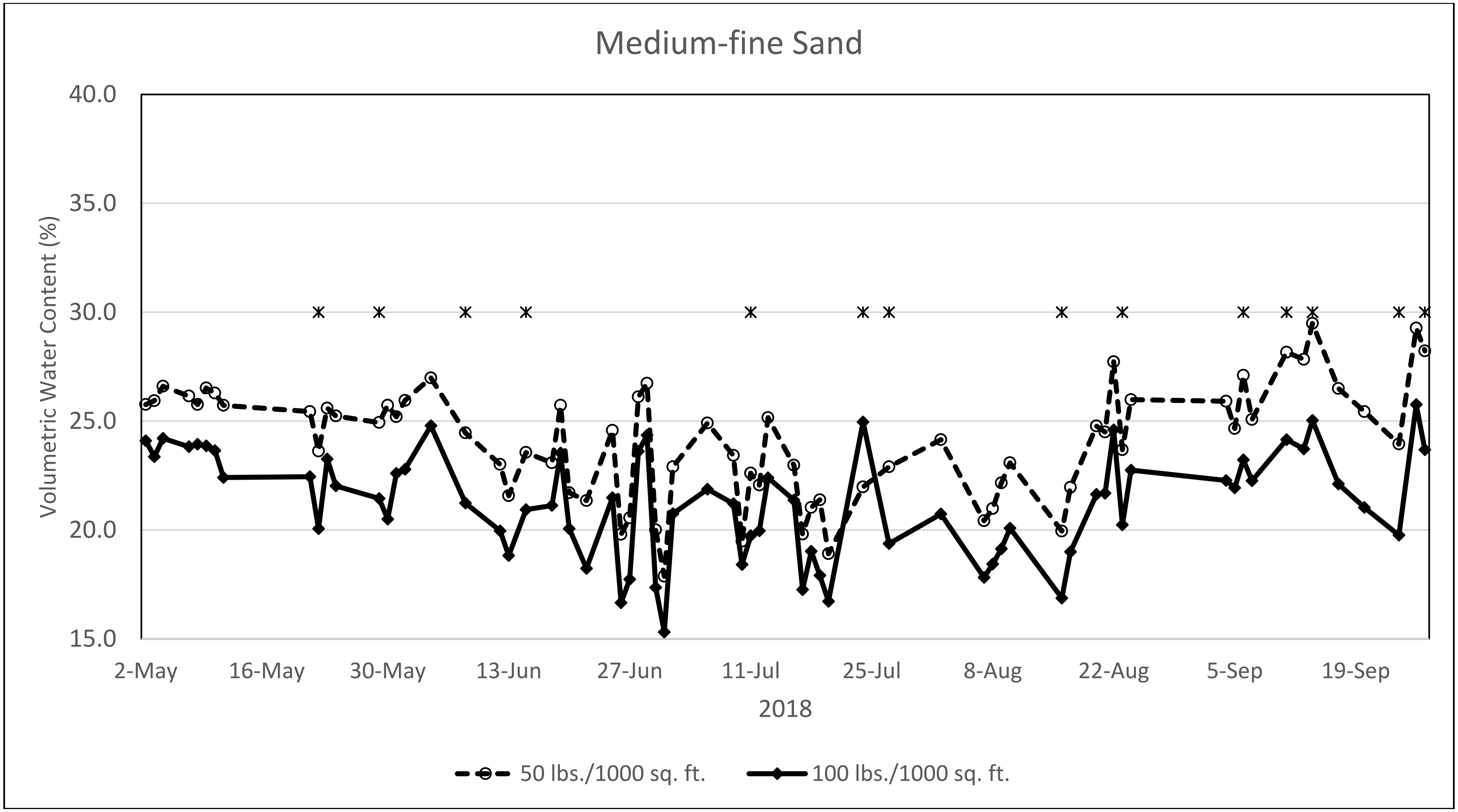

Figure 3b. The effect of topdressing rate with medium-fine sand on volumetric water content at the 0- to 1.5-inch depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2018. Field Scout™ TDR 300 Soil Moisture Meter was used to measure volumetric water content.

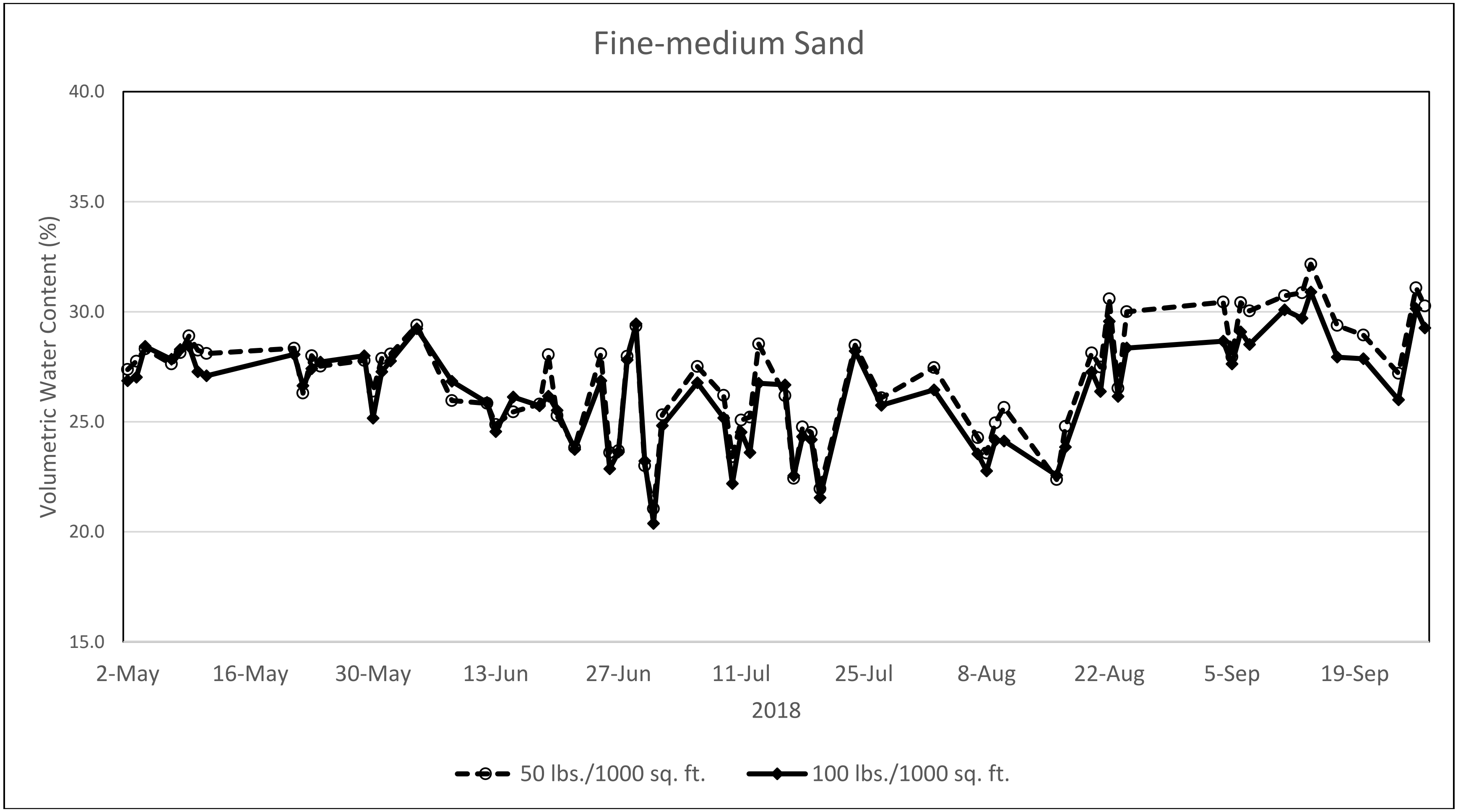

Figure 3c. The effect of topdressing rate with fine-medium sand on volumetric water content at the 0- to 1.5-inch depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2018. Field Scout™ TDR 300 Soil Moisture Meter was used to measure volumetric water content.

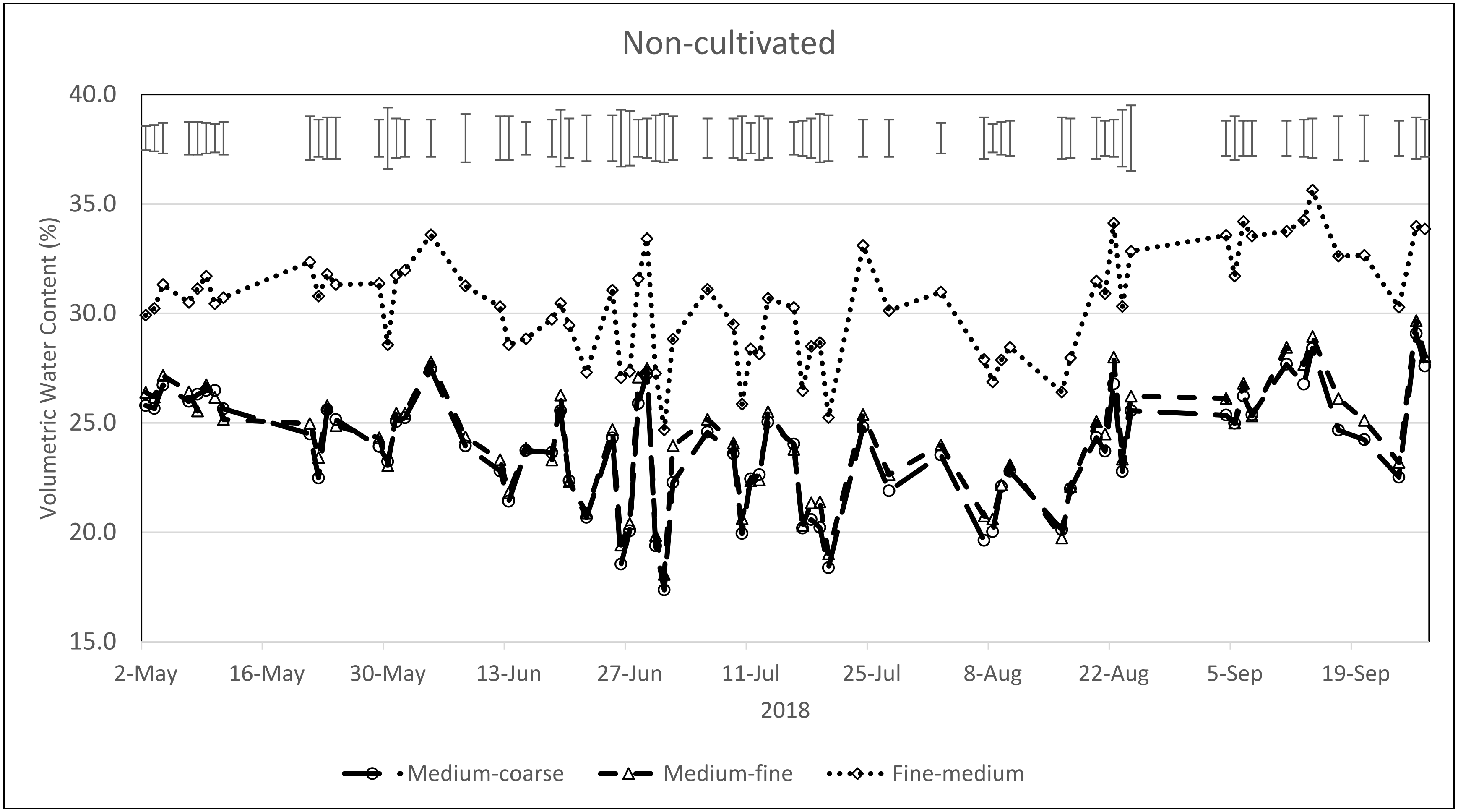

Figure 4a. The sand size effect under non-cultivated conditions on volumetric water content at the 0- to 1.5-inch depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2018. Field Scout™ TDR 300 Soil Moisture Meter was used to measure volumetric water content.

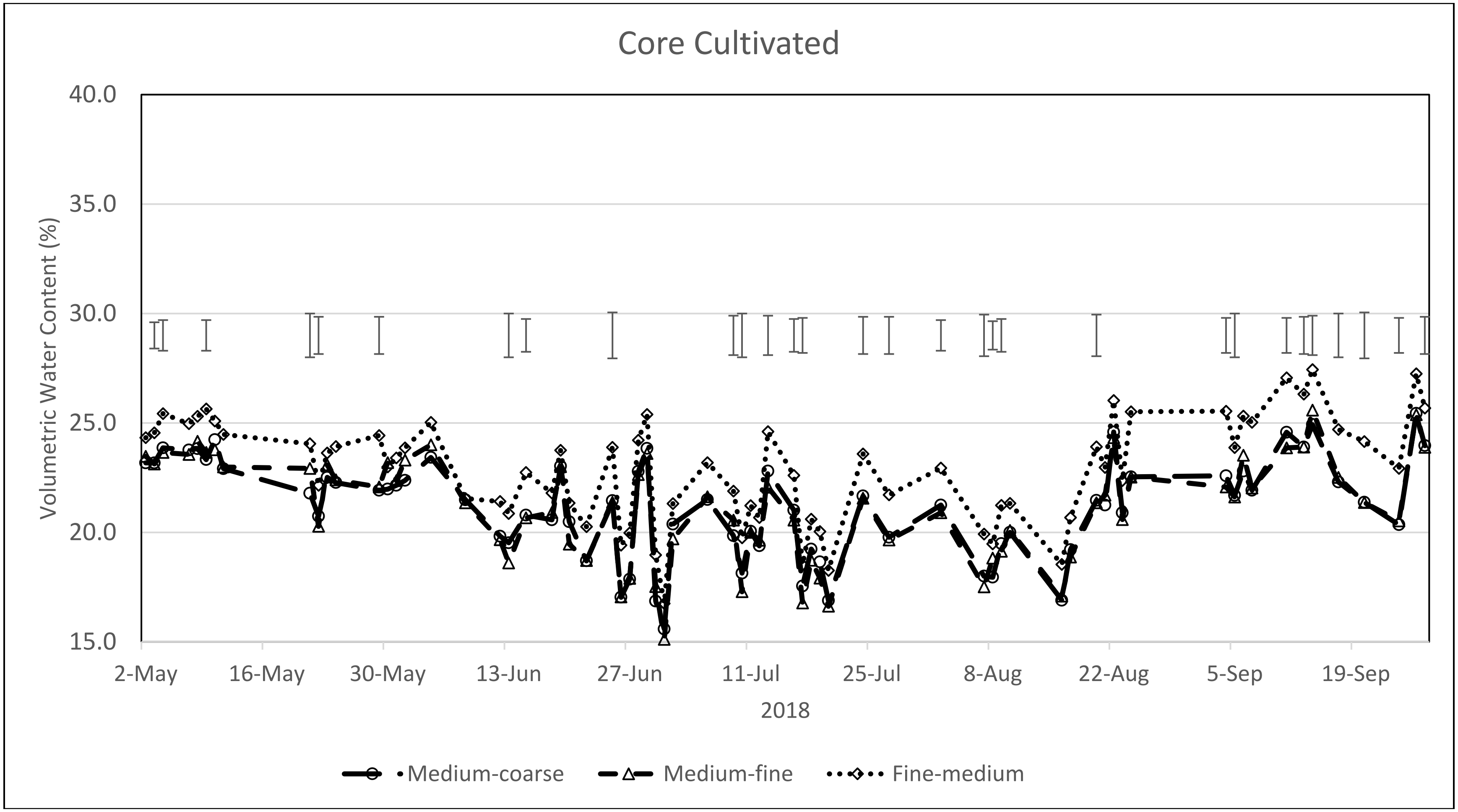

Figure 4b. The sand size effect under core cultivated conditions on volumetric water content at the 0- to 1.5-inch depth zone of a 'Shark' creeping bentgrass turf maintained at 2.8-mm in North Brunswick, NJ during 2018. Field Scout™ TDR 300 Soil Moisture Meter was used to measure volumetric water content.

USGA ID#: 2016-17-567

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

Project Leaders: K. McInnes and B. Wherley
Affiliation: Texas A&M University

Start Date: 2016
Project Duration: 3 years
Total Funding: $85,501

Summary Points:

- Infiltration rates of putting green surfaces were less than expected from the particle size distribution of the sand near the surface.
- Generally, infiltration rate decreased with decreasing mean particle size and increasing organic matter content, but some greens with large particles and moderate organic matter had low infiltration rates.
- Only one-third of the variability in infiltration rate on greens could be explained by a linear model with particle size and organic matter content as variables.
- One-half of the variability in water holding capacity in the surface 2 inches of the greens could be explained by a linear model with particle size and organic matter content as variables.
- One-third of the variability in apparent total porosity (maximum observed surface water content) could be explained by a linear model with particle size and organic matter content as variables.

Summary Text:
It is becoming common practice to topdress ultradwarf bermudagrass golf 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 sands to topdress golf greens.

Multiple putting greens on nine 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 (if available). Infiltration rates, apparent total porosity, and apparent capillary porosity of the putting greens are being measured.

A 15-cm diameter permeameter is being 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, 15 cm of water is added to the permeameter and allowed to infiltrate, followed by a second 15 cm depth of water being 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. After this second aliquot has infiltrated, the surface water content (0 to 2 inch and 0 to 6 inch) is electronically measured for one hour to estimate the effective capillary porosity.

Generally, greens with finer particles and greater OM were less permeable to water and held more water after drainage, as expected, but some greens with large particles and moderate organic matter had low infiltration rates.

The Krumbein and Monk (1943) equation has been used to estimate the saturated hydraulic conductivity *Ks*at from standard particle size analysis of sand. The estimation predicts *Ksat* of a sand to be proportional to the square of the geometric mean diameter *GMD2* of its particles and to an exponentiation of the sand's coefficient of uniformity *Cu*.

$$Ksat \propto GMD2 \cdot e\text{-}Cu \;.$$

Arya et al. (2010) measured the paricle size distributions and saturated hydraulic conductivity of several sands used on golf courses. For sands meeting USGA recommendation for particle size distribution and having similar *Cu*, their data showed that

$$Ksat \cong 11 + 670 \cdot GMD2,$$

where *Ksat* has units [in h-1] and *GMD2* has units [mm2]. This relationship is represented by the solid line in Figure 1. All the data collected by our research to date falls to the right-hand-side of this line (i.e., all have lower infiltration rates than expected from particle size of sand). This demonstrates that particle size of sand is not the only factor controlling infiltration rate. For example, only 10% of the variability in infiltration rate (*I*) on greens we measured could be explained by variation in particle size (*GMD2*), whereas 33% of the variability could be explained with the addition of organic matter content (*OM*) as a variable (Tables 1 and 2). That leaves 2/3 of the variability unexplained. We are collecting information on the use of wetting agents and will determine if that cofactor and the frequency and type of aeration help explain more of the observed variability in infiltration rates. Similar to the finding with infiltration rate, about 30% of the variability in apparent water filled porosity in the top 2 inches of the greens after 1-h drainage (capillary porosity at the tension produced by the depth of sand in the green) could be explained by a linear model with particle size (*GMD*) as the sole variable, while 44% could be explained with the addition of OM as a variable (Table 3).

References

Arya, L.M., J.L. Heitman, B.B. Thapa, D.C. Bowman. 2010. Predicting saturated hydraulic conductivity of golf course sand from particle-size distribution. Soil Sci. Soc. Am. J. 74:33-37.

Krumbein, W.C., G.D. Monk. 1943. Permeability as a function of the size parameters of unconsolidated sand. T. Am. I. Min. Met. Eng. 151:153-163.

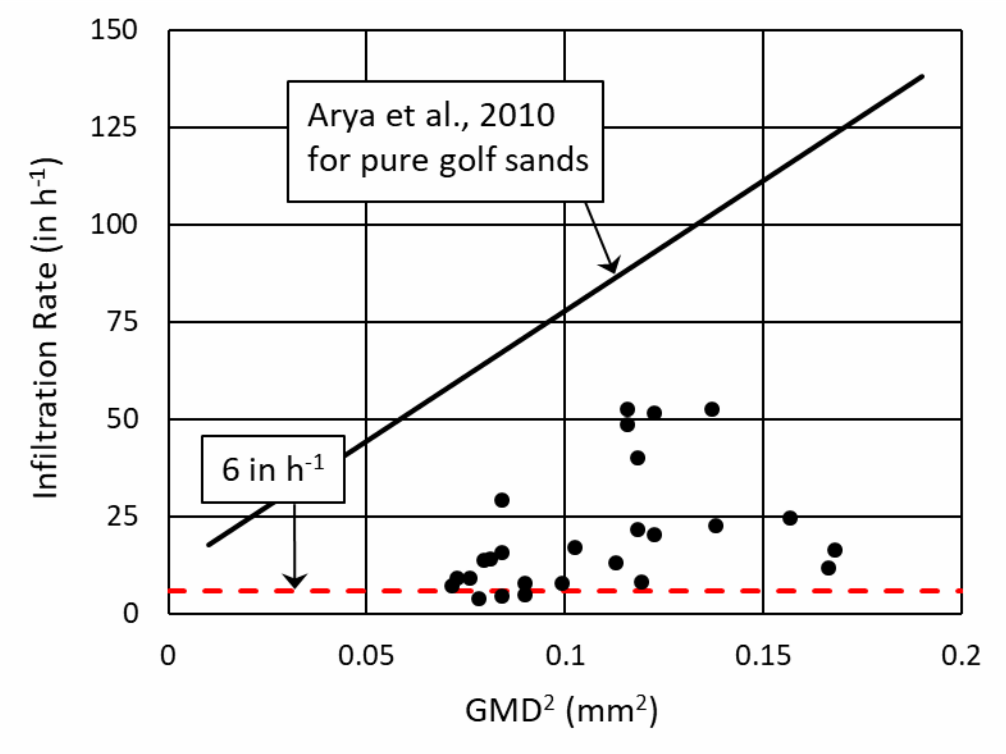

Figure 1. Infiltration rate of putting greens related to the geometric mean diameter GMD of sand grains in the surface 1 inch of material. Data points (solid round symbols) represent findings from this USGA Research Project. The solid black line represents the relationship derived for pure sand from Arya et al. (2010). The dashed red line represents the USGA recommended lower limit of saturated hyraulic conductivity for sand used in construction of a putting green.

Table 1. Linear regression coefficients of the model *I~GMD2*. *GMD2* (geometric mean diameter) was for the surface 1 inch of the putting greens sampled. *I* represents infiltration rate with water ponded on the surface.

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	2.74	10.68	0.257	0.7999
GMD2	166.64	90.24	-1.847	0.0783 ·

Significance code: '·' 0.1
Multiple R-squared: 0.1342, Adjusted R-squared: 0.09485

Table 2. Multiple linear regression coefficients of the model *I~GMD2+OM+GMD2:OM*. *GMD2* (geometric mean diameter2) and *OM* (organic matter content) were for the surface 1 inch of the putting greens sampled.

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	80.29	33.82	2.374	0.0277 *
GMD2	-708.0	315.5	-2.244	0.0363 *
OM	-7.018	2.724	-2.576	0.0180 *
GMD2:OM	78.50	26.67	2.944	0.0080 **

Significance codes: 0.001 '**', 0.01 '*'
Multiple R-squared: 0.42, Adjusted R-squared: 0.333

Table 3. Multiple linear regression coefficients of the model *WC~GMD+OM*. *GMD2* (geometric mean diameter) and *OM* (organic matter content) were for the surface 1 inch of the putting greens sampled.

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.398	0.0377	10.569	7.3e-10 ***
GMD	-0.855	0.2081	-4.108	5.02-4 ***
OM	-0.00485	.00177	-2.737	0.0124 *

Significance codes: '***' 0.0001, 0.001 '**', 0.01 '*'
Multiple R-squared: 0.485, Adjusted R-squared: 0.436

USGA ID: 2018-08-658

Project Title: Long-Term Dynamics and Management Requirements of Sand-Capped Fairways

Project Leaders: Benjamin Wherley, Kevin McInnes, Richard White, and Will Bowling
Affiliation: Texas A&M University, College Station, TX

Start Date: 2018
Project Duration: 3 years
Total Funding: $101,386

Summary Points:

- Subsoil sodicity (SAR) ranges from ~7 to 12 across treatments. SAR has increased to the greatest extent (SAR = 12) with no gypsum regimes, although only a slight decrease can be seen due to the 10 lbs./ 1000 sq. ft./ month application. The single spring application of 100 lbs. gypsum/ 1000 sq. ft. has been the most effective treatment at reducing subsoil sodicity in all cases (SAR = 7-8). Addition of monthly wetting agent applications did not noticeably enhance gypsum efficacy on reducing SAR of subsoil (Fig. 1)
- Water Droplet Penetration Times obtained at the 0.5" depth of 4 and 8" sand caps indicated no hydrophobicity within either sand cap treatment where wetting agent treatments are being applied. In the absence of wetting agents, moderate hydrophobicity is being noted at the surface of the 8" capping depth, likely due to the greater extent of drying following irrigation/rainfall relative to the 4" sand cap (Fig. 2).
- Surface infiltration rate measurements range from 2.4 to 2.9 mm/ second across the various secondary cultural management treatments, with slightly lower infiltration rates noted for the 4" relative to 8" sand cap. No significant treatment differences due to secondary cultural practices are occurring at the end of the initial season of testing.

Summary Text:

As golf course irrigation water quality continues to decline, sand-capping of golf course fairways is increasing. This study is evaluating long-term (years 4-6) changes in turf performance, soil physical properties, and cultural management requirements of sand-capped fairway plots originally established in 2014. The project is being conducted at the Texas A&M Turfgrass Field Laboratory, College Station, TX, on 4-year old 'Tifway' bermudagrass sand-capped fairway research plots which were constructed for a previously funded 2014-2017 USGA sand-capping research project. Plots are oriented along a south-to-north running 1.5% slope. Half of the 20,000 sq. ft. facility is sand-capped atop a fine sandy loam topsoil, while half is sand-capped atop a clay loam topsoil. Four replicated capping depths have been constructed on both subsoils, including 0= topdressed over time at a depth of 1" sand per year, 2", 4", and 8". A split-plot design is being utilized to assess sand-cap cultural management practices addressing surface organic matter accumulation as well as subsoil sodicity issues stemming from elevated Na and bicarbonates in the local water source. The fine sandy-loam subsoil study is being used to address subsoil sodicity management while the clay loam subsoil study is being used to evaluate secondary cultural practice regimes on surface organic matter management in sand-capped systems.

The fine sandy loam subsoil study focuses on subsoil sodicity and surface hydrophobicity management, specifically evaluating effects of wetting agent applications for mitigating surface hydrophobicity and gypsum application treatments for mitigating subsoil sodium accumulation, as well as the interaction of the two treatments on moving gypsum deeper into the profile. Within each capping depth, whole plots consist of wetting agent (Oars PS) applied at either 0 or 6 oz/ 1000 sq. ft., with gypsum (VerdeCal G applied at either 0 or 10 lbs./ 1000 sq. ft. monthly or as a single annual application at 100 lbs./1000 sq. ft) as the subplot treatment. Measurements including turf quality, soil volumetric water content, infiltration rates, water droplet penetration times, and subsoil (0-1") sodium adsorption ratio are being monitored within treatments across capping depths during the course of the season. Root biomass within sand and subsoil is being evaluated at the end of the project.

The clay loam subsoil study focuses on surface organic matter management, specifically focusing on secondary cultural management regimes for managing surface organic matter. Whole plots consist of sand cap depth (Topdressed, 2", 4", or 8"), with subplots consisting of either no secondary cultural management, verticutting, core aeration, verticutting + core aeration performed twice annually. Measurements including turf quality, percent green cover, surface hardness, and surface infiltration rates are being monitored during the course of the season. Percent organic matter for the 0-2" depth is being determined at the end of each season, and currently under combustion analysis for the initial season. At the end of the final year of the study, saturated hydraulic conductivity and water release curve data (water to air-filled porosity) will be developed for select treatments in order to better understand and characterize physical changes that have occurred over time with various treatments and cultural management inputs.

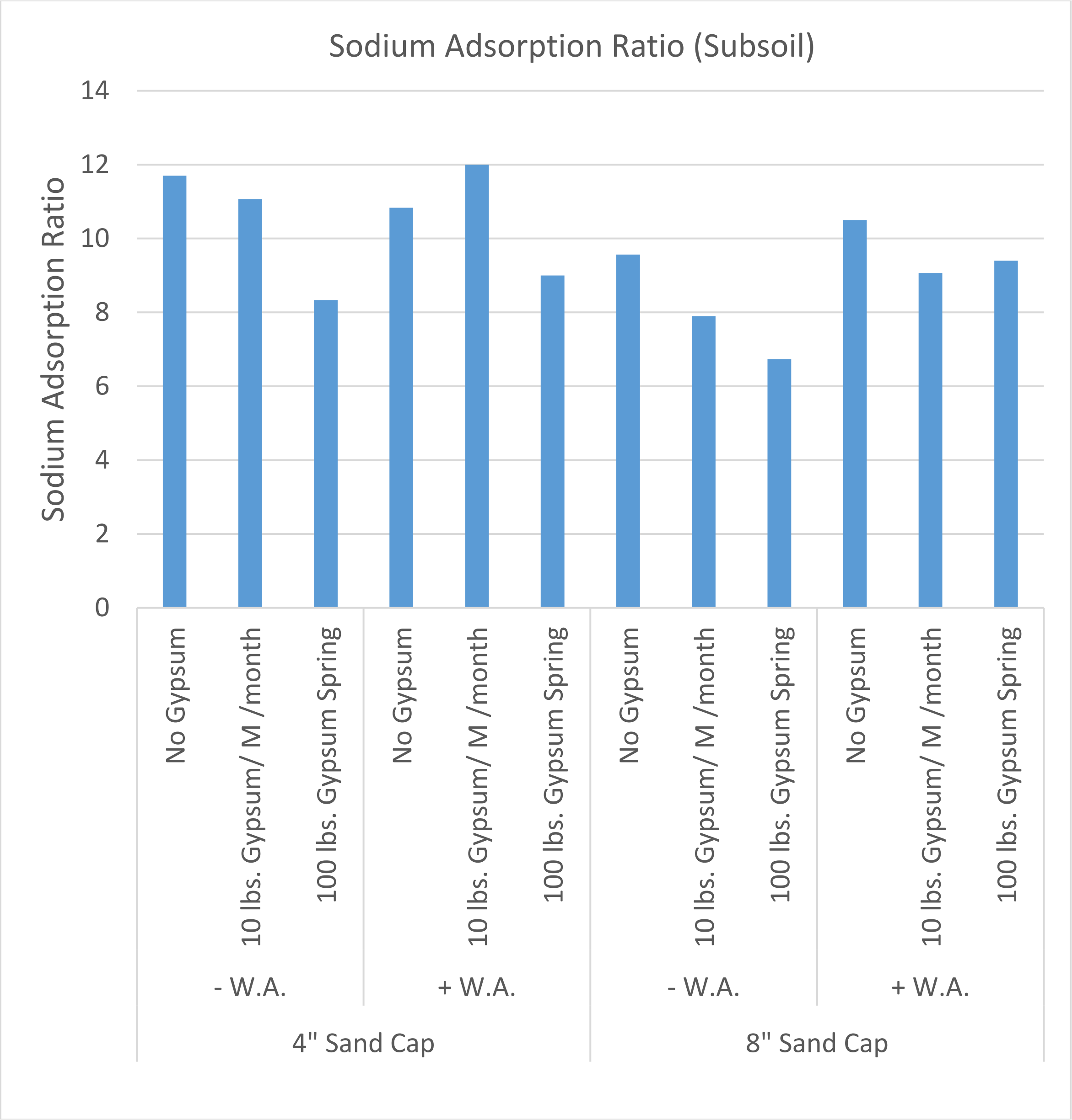

Figure 1. Sodium Adsorption Ratio of subsoil beneath sand cap as affected by gypsum treatments, wetting agent, and sand cap depth for the fine sandy loam subsoil study. Data are for August 2018, three months following initiation of treatment applications.

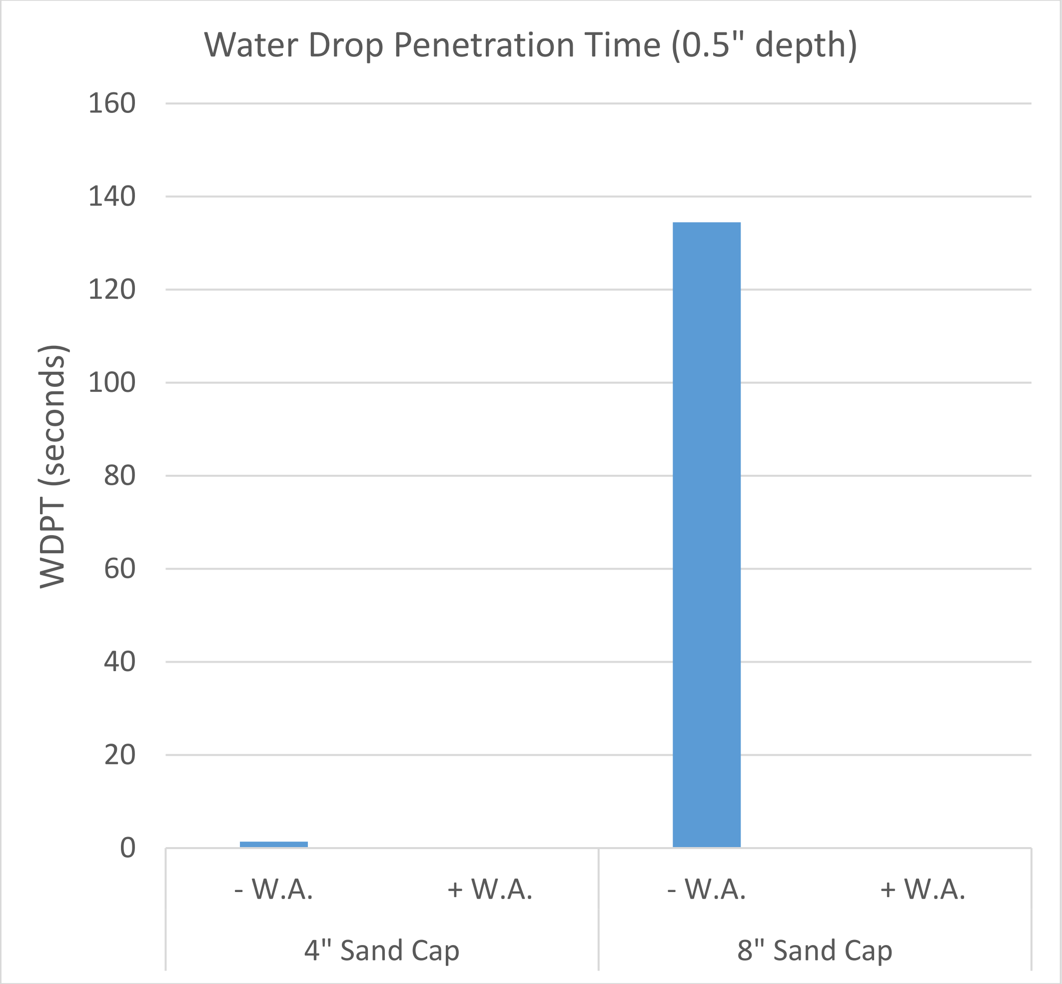

Figure 2. Water Drop Penetration Time for the 0.5” depth of the 4 and 8” sand cap treatments atop the fine sandy loam subsoil. Data are for the August 2018 rating date, 3 months after initiation of monthly wetting agent treatments.

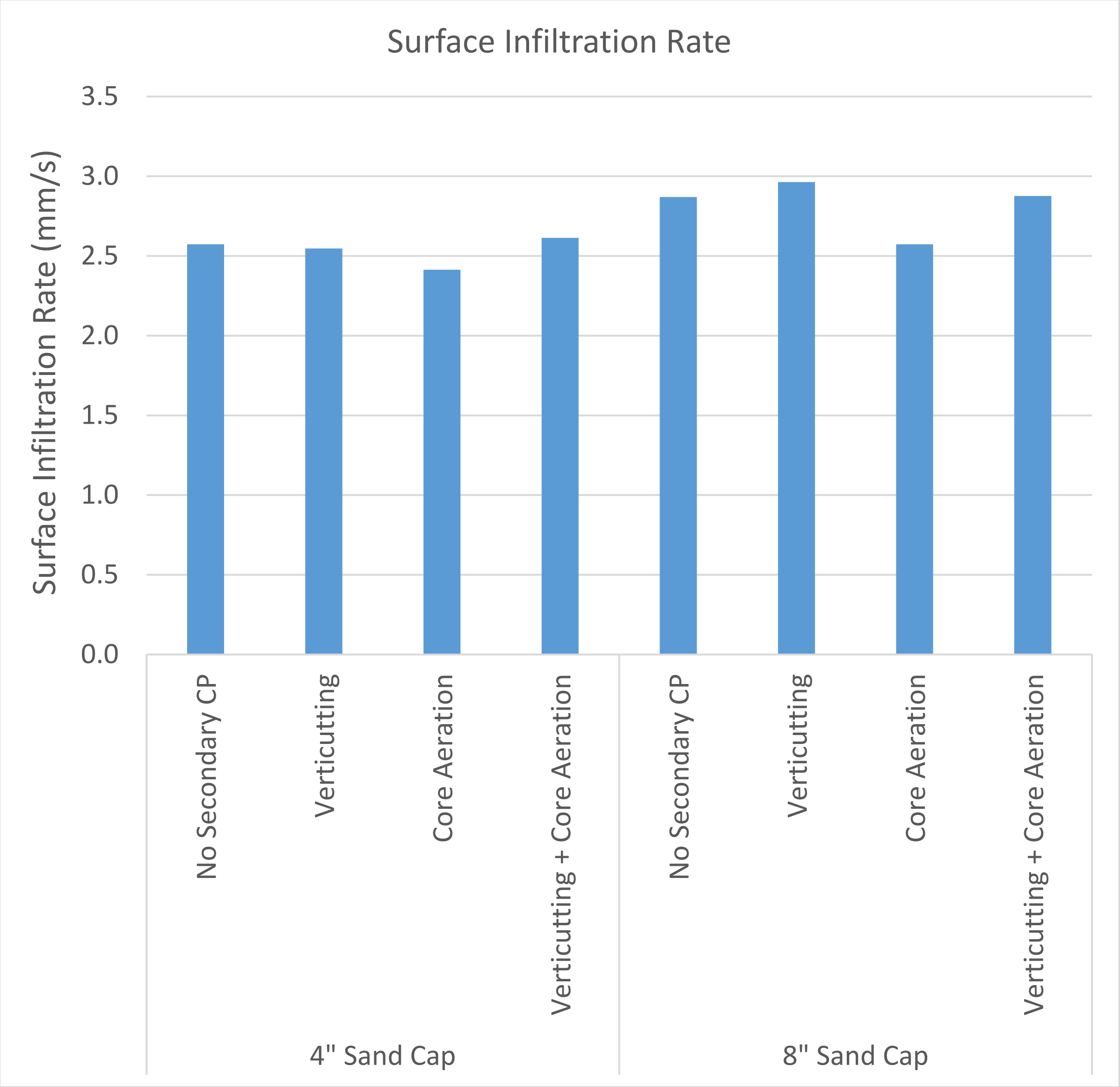

Figure 3. Sand Cap surface infiltration rates for the 4” and 8” sand caps as affected by secondary cultural practice regimes on the clay loam subsoil study. Secondary cultural practices are performed twice annually during the summer months. Data are for November 2018, the final rating date of the initial season of testing.

USGA ID: 2018-10-660

Title: Evaluation of Hollow Tine Core Aerification Recycling on Sand-Based Putting Greens Performance and Playability

Project leader Adam Thoms, Nick Christians, and Ben Pease
Affiliation Iowa State University

Objectives:

1. To compare the performance and playability of sand-based putting green plots that are either
    a. subjected to hollow tine aerification, all of the cores are removed, and topdressing is applied compared,
    b. putting green plots that subjected to hollow tine aerification, the cores are verticut, chopped cores are drug back in, excess organic matter is removed, and additional topdressing is added as needed, or
    c. putting green plots that are subjected to hollow tine aerification, cores are processed through the Core Recycler, and additional topdressing sand is added as needed.
2. Conduct an economical comparison for each of the three treatments listed in objective 1 and determine the amount of sand saved by recycling cores.

Start Date: 2018
Project Duration: 2 years
Total funding $10,000

Summary Points:

- Hollow tine core recycling with the Wiedenmann Core Recycler is being compared to traditional hollow tine aeration core removal and replacement with fresh sand and verticutting hollow tine cores and dragging back in the chopped up cores.
- A creeping bentgrass putting green meeting USGA spec rootzone was aerated on 2" by 2" spacing with 3/4" tines on 30 Aug. 2018 and treatments were applied. All treatments were fully recovered from aeration within two weeks of aeration, with no negative effects of recycling cores on putting green recovery.
- All plots experienced a reduction of soil organic matter from the aeration regardless of core or topdressing treatment. No differences were present between treatments for soil organic matter. This indicates no negative effects from returning hollow tine cores to the putting green after one year.
- Few differences were found between treatments for the variables measured. This indicates that in year one the Wiedenmann Core Recycler or verticutting hollow tine cores can provide a way to return sand into the putting green surface without negative effects of recycling on the rootzone characteristics and performance.

Summary Text:

Golf course superintendents struggle to find affordable topdressing sand for putting greens that offers characteristics that will benefit the rootzone after hollow tine aerification. This is especially problematic in areas where the cost of trucking is greater than the sand. Aerification is a critically important practice for golf course superintendents to maintain healthy putting greens and limit organic matter increases in sand-based rootzones. Topdressing with all new sand after aerification can be costly and often budgets restrict how much sand topdressing can be done. As a result many lower budget golf courses will skip a time period between hollow tine aerification and topdressing, or the superintendent will drag back in the cores to try to reduce the amount of sand needed for topdressing. Skipping aerification and topdressing has created layering problems in putting greens from a buildup of organic matter.

The majority of the organic matter in a hollow tine core is in the portion closest to the surface, so research is needed to see if the lower portion of the hollow tine core could be returned to the rootzone after aerification to help reduce topdressing costs. Hollow tine core cultivation and soil reincorporation into the thatch did not affect thatch amounts significantly but did increase bulk density (Danneberger and Turgeon, 1986; Hurto et al., 1980) and water holding capacity (Hurto et al., 1980). Rieke and Murphy (1989) provide a great review of cultivation methods and studies done to date, but do not mention any devices like the modern Core Recycler machine. Current research is lacking to provide data on how hollow tine core recycling will impact a creeping bentgrass putting green.

This study is investigating recycling hollow tine aerification cores as compared to traditional methods of complete removal of aerification cores and topdressing with new sand. Hollow tine core recycling is being compared by the Wiedenmann Core Recycler (which has brushes and rotating screens allowing sand to be separated from the organic matter) to verticutting hollow tine aerification cores on a putting green. These treatments were compared to hollow tine aerification with removal of all the cores. This research project is being conducted at the Iowa State University Horticulture Research Station in Ames, Iowa on a ‘Penncross’ creeping bentgrass (*Agrostis stolonifera* L.) putting green established over a rootzone that was constructed to meet USGA putting green specifications. The plots were maintained to optimize turfgrass health with proper fertilization and minimize turfgrass disease, weed, and insect pressure. The creeping bentgrass was mowed six times a week at 0.125” height of cut with a reel mower to simulate a golf course putting green. Additional water will be applied through irrigation to minimize turfgrass stress. The study was conducted in a randomized complete block design with three replications.

Before aerification, each plot was evaluated for organic matter in the rootzone, water infiltration, total soil pore space, percent turfgrass cover, green speed, surface hardness with the TruFirm. Hollow tine aerification was applied on a 2” by 2” spacing with ¾” tines on 30 August 2018. Plots were then subjected to one of the three treatments explained earlier. Additional topdressing sand conforming to USGA putting green specifications was added to the plots to ensure the aerification holes were filled. After treatments were applied plots were tracked weekly for recovery (percent green cover with digital image analysis), green speed, volumetric soil moisture, and surface hardness. After turfgrass recovery plots were tested for soil organic matter, water infiltration, and total porosity.

Data were analyzed in Proc Mixed in SAS. Means were separated at the 0.05 level of significance with Fishers LSD. Treatments will be repeated over two years. Soil organic matter levels did not differ between treatments after any rating date in 2018. Soil organic matter was 5% before treatments applied and the levels were reduced on every plot after aeration and core treatments were applied: 4.3% for the core recycler and traditional treatments and 4.05% for the verticutting and dragging of the cores treatment. Creeping bentgrass cover increased over time after aerification as expected and all treatments were fully recovered from aeration by week two. Percent green cover only differed between treatments on the first week after aeration when the traditional aeration methods had a higher percent green cover (88%) than the core recycler treatments (79%), but not the verticutting of the cores method (82%). No differences were found between treatments for soil moisture, green speed, green hardness, or water infiltration during year one. Higher levels of sand were found in the clippings from the core recycler treatments and the verticutting of the cores treatments as compared to the traditional removal and topdressing method on all four rating dates (data not shown). Additionally, an economic figure needs to be calculated for the savings in sand and cost between treatments for 2018.

Plots will be monitored this summer for indications of localized dry spot and ratings taken if necessary. Additionally, weekly volumetric soil moisture readings will be recorded to see if water-holding differences exist between treatments throughout the next growing season. The study will be repeated in 2019 on the same plots to see if changes happen to the rootzone with repeated treatment applications.

References

Danneberger, T.K. and A.J.Turgeon. 1986. Soil Cultivation and Incorporation Effects on the Edaphic Properties of Turfgrass Thatch. J. Am. Soc. Hort. Sci. 111:184-186.

Hurto, K.A., A.J. Turgeon and L.A. Spomer. 1980. Physical Characteristics of Thatch as a Turfgrass Growing Medium. Agron. J. 72:165-167.

Rieke, P.E. and J.A. Murphy. 1989. Advances in Turf Cultivation. The 6th Intl. Turf. Resc. Conf. Tokoyo, Japan. P. 49-54.

Figure 1. Wiedenmann Core Recycler used to separate sand from organic matter in the top portion of a hollow tine core.

Figure 2. Hollow tine aeration cores being completely removed with fresh topdressing sand to be added. This treatment is referred to as “Traditional” in the report.

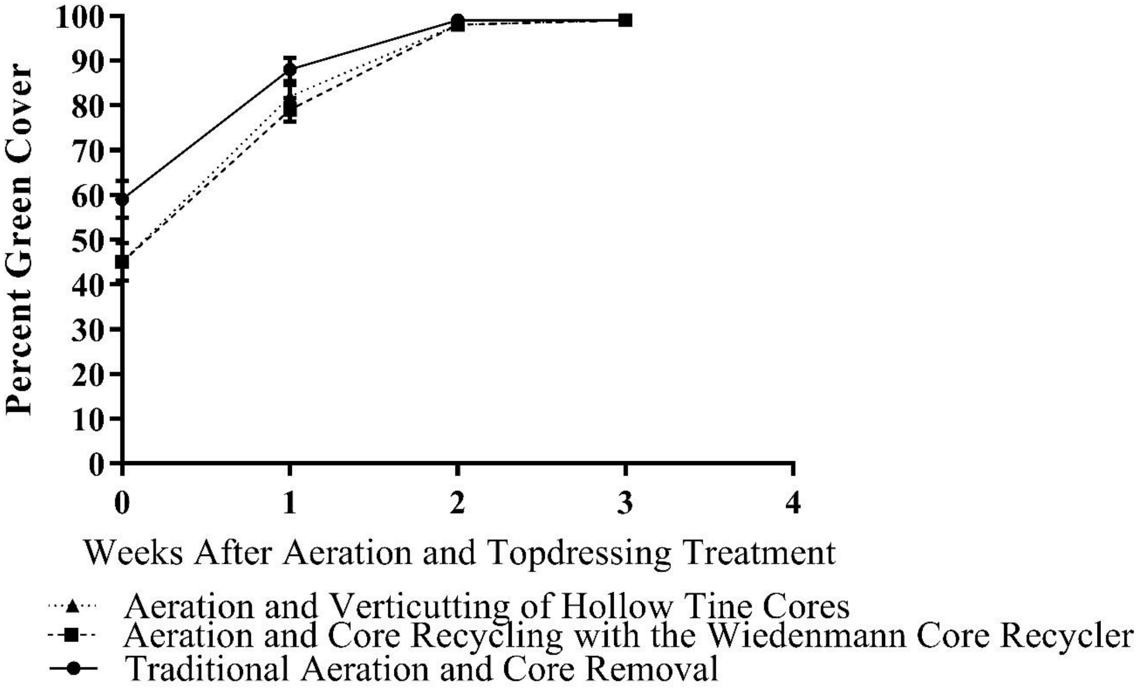

Figure 3. Creeping bentgrass putting green recovery as determined by percent green cover (from digital image analysis), for various aeration and topdressing treatment applied 30 Aug. 2018 in Ames, IA.

USGA ID#: 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:

1. Determine if Solvita® Soil CO_2-Burst and Soil Labile Amino N tests are correlated to bentgrass fairway turf quality and growth responses.
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 Points:

- First complete season of full treatment imposition.
- There is a preliminary suggestion that SLAN concentrations show promise in predicting some bentgrass fairway quality responses for the No-Trafficked plots.
- There was no positive relationship between Solivita soil test concentrations and bentgrass quality or growth responses with the Trafficked plots.

Summary Text:
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 tests measure 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. An estimate of the mineralization potential should help guide N fertilization.

Methods:
The study site is located in Storrs, CT, 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 into the 0 to 4-inch soil profile by rototilling prior to seeding. After compost incorporation, creeping bentgrass (‘13M’) was seeded into the study site and managed as a fairway. During the bentgrass grow-in period during the late fall of 2017, an organic fertilizer (Suståne all natural 5-2-4) was applied to the plots at the same rates as the initial incorporated compost rates. In addition to the organic treatments, a standard fertilizer regime treatment with 0.2 to 0.25 lbs N 1000ft^{-2} was applied approximately every 21 days as liquid urea. The fall of 2017 was used as the establishment period. Full implementation of the treatments and data collection commenced in 2018.

Beginning in the spring 2018, traffic was applied with a cart-traffic simulator three times a week during the growing season. Bentgrass response measurements (NDVI, percentage green cover, Dark Green Color Index

[DGCI], visual quality, visual color, visual density, and clippings yield) and soil samples were collected monthly from May through October from each plot. Data were not collected in November due to frequent heavy rains and occasional snow cover. Soil samples were analyzed using the Solvita® SCB and SLAN tests. Data were statistically analyzed using analysis of variance to determine treatment effects (fertilizer rates, traffic, and the fertilizer rate × traffic interaction) on the mean bentgrass quality and growth responses, and soil SCB and SLAN concentrations. Bentgrass responses were correlated to the Solvita® soil test concentrations to determine if any relationship exists between the variables using regression analyses. For those variables that suggested a positive correlation, binary logistic regression was applied to determine the probability of response to N fertilization in relation to a given soil test value, using the responses from the standard N fertilization practice as the comparison benchmark values.

Results to Date:

Traffic effects were significant for visual quality, visual color, visual density, percentage green cover, DGCI, and clipping yields; fertilizer treatment effects were significant for NDVI, visual quality, color, and density, percentage green cover and clipping yields (Table 1). Generally, responses from the low organic rates were significantly lower than the standard treatment for the visual measurements, whereas, NDVI from three of the four highest organic rates were significantly greater than the standard treatment.

When pooled across the entire growing season for the first year of treatment imposition, relative NDVI, relative visual quality, relative visual color, and relative visual density showed significant, but weak, logistic regression models to SLAN concentrations for the No-Traffic plots, but not for the Trafficked plots. When SLAN concentrations were ≥ 169, 216, 180, and 201 mg kg^{-1}, there was a $\geq 67\%$ chance that the bentgrass responses for NDVI, visual quality, visual color, and visual density would equal or exceed the response of the Standard fertilizer treatment (approximately 0.2 lbs N per 1000ft^2 every 21 days) in the No-Traffic plots (Fig. 1). To date, there is no significant correlation between the Trafficked plot variables for either soil test.

Future Expectations:

It is anticipated that with time, mineralization of the compost and yearly organic fertilizer applications will further widen the range of Solvita soil test concentrations, which should give a better model fit for the bentgrass fairway quality and growth responses. There were no significant fertilizer treatment or traffic differences in mean Solvita SLAN or SCB concentrations for the first year of treatment imposition, but it is expected that differences should become apparent in the 2nd and 3rd year of the study with more mineralization.

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.

Table 1. Mean Solvita soil test concentrations and bentgrass quality and growth responses, with analysis of variance *P* values.

	SLAN	CO_2-Burst	NDVI	Visual Quality	Visual Color	Visual Density	Cover	DGCI	Sum Clippings yield
Traffic	mg kg^{-1}	mg kg^{-1}					% green		g m^{-2}
No	178.6	132.6	0.720	5.8	5.8	6.0	96.2	0.443	56.5
Yes	177.7	131.9	0.719	5.1	5.5	5.6	97.5	0.435	23.2
Treatment[†]									
0	173.0	130.1	0.703	5.0*	5.1*	5.3*	94.4*	0.427	30.0
0.25	179.4	132.6	0.710	5.3*	5.4*	5.6*	95.3	0.433	32.2
0.50	174.5	131.2	0.717	5.4*	5.6	5.7	96.6	0.436	38.1
0.75	176.8	130.7	0.720	5.4*	5.5	5.8	96.9	0.438	39.5
1.00	177.0	132.8	0.720	5.5	5.8	5.8	96.9	0.440	35.5
1.25	177.6	135.6	0.723	5.6	5.8	5.9	97.4	0.440	46.8
1.50	179.7	133.9	0.727*	5.6	5.8	5.9	97.9	0.444	43.9
1.75	180.4	132.0	0.724	5.5	5.8	6.0	97.5	0.440	43.5
2.00	180.8	135.1	0.727*	5.7	5.9	5.9	98.0	0.446	45.5
2.25	185.2	132.6	0.729*	5.6	5.8	6.0	97.9	0.444	45.8
Standard	174.9	128.2	0.714	5.8	5.8	6.0	96.6	0.440	37.9
				AOV *P*-values					
Traffic	0.7893	0.4354	0.2135	0.0060	0.0101	<0.0001	<0.0001	<0.0001	<0.0001
Treatment	0.4040	0.2837	<0.0001	0.0005	<0.0001	<0.0001	0.0009	0.3669	0.0048
T × T	0.5366	0.5485	0.1130	0.2272	0.2711	0.8699	0.4911	0.8318	0.5049

* Significantly different from the Standard treatment ($P < 0.05$)

[†] Compost and organic fertilizer rates of available N (lbs per 1000ft^2); Standard treatment is liquid urea at approximately 0.2 lbs N per 10000ft^2 every 21 days.

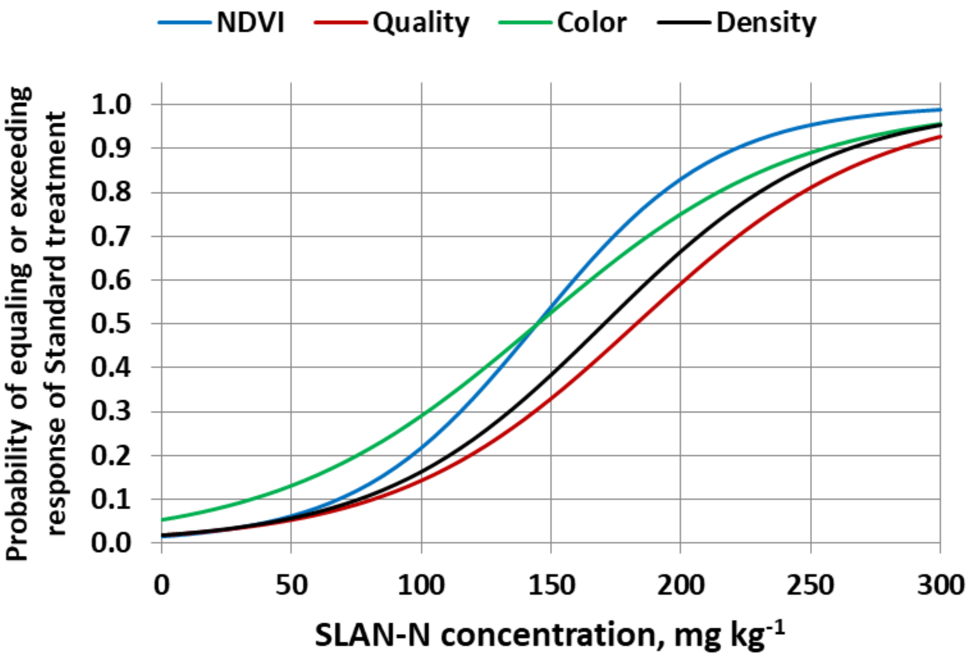

Figure 1. Probability curves of equaling or exceeding the NDVI, visual color, visual color, and visual density response of the Standard fertilizer treatment (approximately 0.2 lbs N per 1000ft^2 every 21 days) in relation to the Solvita SLAN-N concentrations for the No-Traffic plots.

USGA ID#: 2015-35-550

Project Title: National Evaluation of Turfgrass Water Use and Drought Resistance

Project Leader: Kevin Morris
Affiliation: National Turfgrass Evaluation Program (NTEP)

Start Date: 2016
Project Duration: 5 years
Total Funding: $500,000

Summary Points:

- Thirty-five total entries in the Cool-Season Water Use and Drought Resistance trial were planted in fall 2016/spring 2017. Five locations measure water used over a 100-day period under a rain exclusion shelter, and five locations induce drought by restricting ET_o replacement.
- Drought treatments were initiated at six of the ten locations in 2017, and at all ten locations in 2018, with differences in drought response noted among entries. In some instances, two-fold differences in water used were recorded among entries.
- The 40% ET_o replacement level resulted in >95% grass kill at the Riverside, CA location in 2017, while the 40% ET_o replacement level at Las Cruces, NM resulted in acceptable performance by some entries.
- Statistical differences among entries were smaller than expected, and small changes in trial protocol and statistical analysis were instituted as a result.
- A warm-season water use/drought trial with seventeen entries was planted at ten locations in summer 2018.

Summary Text:

As water restrictions become 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. This project addresses the need to identify turfgrass cultivars that deliver high quality turf while using significantly less water. Established at multiple locations nationwide, this project 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 a prescribed level of 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 ten 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 (40, 60 and 80% ET_o 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), initiated drought treatments in 2018.

The six cool-season trial locations that initiated 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).

Significant differences in the amount of water needed to maintain 50% green cover (the prescribed level) were noted at each of the rain exclusion sites in 2017. In some cases, more than a two-fold difference was noted in water used among entries. For instance, at West Lafayette, IN, 'BarRobusto' was the lowest water using tall fescue (47 mm) while 'MRSL TF15' required the most water (89 mm) to remain at least 50% green. Unfortunately, these differences were not statistically significant. Similar results were observed at Fayetteville, AR and College Park, MD with little statistical difference noted among entries, even though a 2x variation in actual water used among some entries was recorded at these sites.

The Griffin, GA rain exclusion shelter site differed from other sites, noting larger statistical differences in entry water use, however only for tall fescue. Tall fescue entries at Griffin, GA varied in water used from as little as 76.3 mm to 211.7 mm for the 100-day period, a 277% difference. As expected, at almost all locations, the entry with the lowest water used was a tall fescue, with the exception being Fayetteville, AR, where the best Kentucky bluegrass entry, 'BAR PP 110358', used less water (38 mm) than the best tall fescue entry, 'RS 4' (46.7 mm).

Due to little or no statistical differences noted at the rain exclusion sites in 2017, a few tweaks were made to trial protocol and analysis. After consulting with our trial cooperators, the percent green threshold for re-watering was changed to 65% (from 50%) for 2018. Cooperators felt this change would more accurately reflect a homeowner's desire to maintain a consistent green lawn, as 50% showed too much brown (loss of color) and in some cases, did not allow for recovery from water lost in the plant and soil profile. Also, a change to the statistical analysis procedure was suggested to better reflect performance. We will implement these changes for 2018 data, which is currently being received and processed.

The ET_o-based site at Riverside, CA saw >95% grass loss in the 40% ET_o replacement treatment in 2017. The 40% ET_o replacement plots recovered in spring 2018 but also saw significant stress during the 120-day deficit irrigation period at this location in 2018. Most all entries suffered significantly under the 40% ET_o replacement regime, but as the 60% ET_o replacement level also saw some significant grass loss, statistical differences were noted among some entries in 2017. Data from 2018 is now being analyzed, but it is possible that a few entries will provide minimally acceptable turf at locations similar to Riverside, CA, throughout a 100-120 day period utilizing the 60% ET_o replacement regime.

The Las Cruces, NM site differs from Riverside, CA in that summer rains are fairly common (and happened in 2017), helping aid turf in performance and survival. Our protocol does require accounting for rainfall in the ET_o replacement, which most likely contributed to better performance of the 40% ET_o level. In 2017, significant differences in drought resistance were noted among entries at Las Cruces, as well as differences in recovery from drought. Data from the 40% ET_o level in 2017 showed some entries delivering acceptable turf quality and performance throughout the trial period, although statistical significance was small among entries. It will be interesting to note the same trend when 2018 data is analyzed, especially considering the changes in statistical analysis we have instituted.

The warm-season version of this trial was established in summer 2018, at ten trial locations (five measuring water use under a shelter, five using ET_o -based replacement irrigation). This trial consists of seventeen entries: eleven bermudagrasses, five zoysiagrasses and two buffalograsses. The rain exclusion shelters and deficit irrigation infrastructure have been installed with drought treatments initiating in 2019. Deficit irrigation levels will initially be set at 30, 45 and 60% ET_o replacement. The percent green cover threshold level for the warm-season entries will be determined in consultation with our cooperators and advisory committee.

Figure 1. Cool-season grass entry differences under deficit irrigation in Las Cruces, NM.

Figure 2. Cool-season entries under 40% ET replacement in Riverside, CA.

Figure 3. Cool-season entries under a rain-exclusion shelter in Griffin, GA.

Figure 4. Cool-season entries under a rain-exclusion shelter in Griffin, GA.

USGA ID#: 2016-08-558

Title: Tree to Grass Water Use Ratios: Significance to the Golf Course Industry

Project Leaders: T. J. Wynne and D.A. Devitt
Affiliation: School of Life Sciences, University of Nevada, Las Vegas

Objectives:
Our study aimed to determine possible water use tradeoffs in urban landscapes based on comparing water use of turfgrass on an area basis equivalent to the basal canopy area of the trees. We hypothesized that these ratios will vary based on turfgrass species, with cool season tall fescue using significantly more water than warm season historical low fertility bermudagrass. We also hypothesized that based on morphological parameters, such as tree height, trunk diameter, basal canopy area, canopy volume and leaf area, monthly and yearly actual evapotranspiration of tree species can be estimated.

Start Date: 2016
Project Duration: 3 years
Total Funding: $87,508

Summary Points:

- Nine out of the ten tree species used less water than the turfgrass species, only L. indica used more water on a basal canopy area basis (cm).
- All of the trees revealed a 2 month lag offset in ET relative to ET_{ref} indicating that trees had higher water use rates during late summer/early fall compared to peak periods of high temperatures and environmental demand (June and July).
- ET of Trees and grass were correlated with ET_{ref} (trees $R^2$0.57-0.89, p<0.001, grasses R^2 0.61-0.77, p<.001).
- Tree ET could be predicted based on the equation; ET(L)=12070.34-150.82*Trunk Diameter-84.64*Basal Canopy Area+37.09*Area of Sun Leaf, R^2=0.58, p<0.001).
- Based on the results of our experiment, tradeoffs between turfgrass and trees would favor the replacement of turfgrass by trees. If an area 185 m^2 were planted to low fertility bermudagrass and irrigated at ET only in the case of the L. indica water use would the number of trees equivalent to the grass water use actually fit into this area.

Summary Text:
Water demand in the southwestern United States continues to rise, especially in the Las Vegas Valley, where the population now exceeds 2 million people. It is estimated that 60 percent of all the water used in the valley is used in the residential sector, with about 70% of that water used outdoors to irrigate urban landscapes (Devitt 2008). These landscapes are dominated by trees and turfgrass and although the water use of turfgrass species is well studied, little is known about the water use of landscape trees. Therefore, landscape professionals know little about the water use tradeoffs between grasses and trees in urban landscapes.

Methods
We conducted a tree to grass water use ratio study focusing on ten common landscape tree species grown in the Las Valley: Mesquite (*Prosopis alba*), Ash (Modesto and Arizona) (*Fraxinus velutina* 'Modesto' and *Fraxinus velutina* 'Arizona'), Desert Willow (*Chilopsis linearis)*, Oak (*Quercus virginiana* 'Heritage'), Palo Verde (*Parkinsonia floridum*), Vitex (*Vitex agnus-castus*), Locust (*Gleditsia tricanthos*),

Elm (*Ulmus parvifolia*), and Crepe Myrtle (*Lagerstroemia indica*) and four turf grass species: bermudagrass (*Cynodon dactylon* var. Tifway*)*, bentgrass (*Agrostis stolonifera* var. TI Creeping*)*, tall fescue (*Festuca arundinacea* var. Monarch*)* and ryegrass (*Lolium perenne* var. Palmer Prelude) and historical low fertility bermudagrass (Devitt et al. 1992). We estimated water use by closing hydrologic balances on mature trees planted in the ground within basins and turf grass in lysimeters. We also estimated transpiration of trees using Granier probes and estimated conductive tissue with a novel dye injection system. We compared water use of all ten tree species with the four turf grass species and developed models that predict the tree water use based on reference ET and morphological characteristics such as tree height, canopy volume, basal canopy area, Leaf Area Index (LAI) and leaf area.

Total Water Use

Total evapotranspiration for trees and grass were compared for the two-year period, revealing a very clear separation between the two groups (Figure 1). The trees used significantly less water than the grasses, even lower than low fertility *C. dactylon*, with one exception: *L. indica*. So 9 out of the 10 species of trees commonly planted in Southern Nevada used less water than the grasses. Only *F. arundinacea* and *C. dactylon* were compared due to the *L. perenne* and *A. stolonifera* dying during both summers and therefore having incomplete yearly data. The one-way ANOVA results based on log transformed two year total ET (cm) standardized on basal canopy area showed *F. arundinacea* and *C. dactylon* used significantly more water than all the trees except *L. indica*. ($p<0.03$). Low fertility *C. dactylon* ET was significantly higher than *P. alba, U. parvifolia, P. floridum, V. agnus-castus, Q. virginiana,* and *C. linearis.* Also, *L. indica* used significantly more water than all other tree species ($p<0.03$) on a basal canopy area basis. Interestingly, in Year 1, *Fraxinus velutina* 'Modesto' used more water than *P. grandiflora* ($p<0.003$) even though it was a significantly smaller tree and that it used significantly more water than another *Fraxinus species; velutina* 'Arizona'.

ET vs. Transpiration

Sap flow data showed transpiration was significantly less during summer months than evapotranspiration occurring with the hydrological balance revealing a clear seasonal oscillation pattern (Figure 2). During the winter months, the sap flow and the hydrological balance had very similar values. This was due to the lower irrigations driven by the lower evaporation and transpiration rates during these months. The effect was more pronounced in the *L. indica*, probably because more water was supplied to those trees and they had the smallest canopy volume leading to greater percentage of the basin area exposed for greater evaporation. Regressions between T and ET were poor for all of the trees except for the Arizona and Modesto Ash trees, which had average R^2 values >0.40 ($p<0.001$), suggesting that it would be difficult to use transpiration estimates to predict ET and accurately schedule irrigations under the conditions of our experiment. Four of the ten tree species had multi-trunks, which forced us to scale up estimates based on a single gage in a single trunk. In all but V. agnus-castus ET exceeded T, with E as a percent of ET averaging 45$\pm$ 23%.

Tree to grass Water Use Ratios

The tree to grass ratios typically fell below the 1:1 ratio line except for a few instances. *L. indica* had the highest ET (cm) of all trees, leading to tree to grass ratios > 1:1 during most months (Figure 3). Low Fertility *C. dactylon* (bermudagrass) used less water than the other four experimental turf grasses, leading to tree grass ratios closer to one. *L. indica* used significantly more water than low fertility *C. dactylon* (n=3, $p<0.008$). When comparing Low Fertility *C. dactylon* to *Q. virginiana,* the tree used significantly less water than the grass based on one year totals (n=3, $p<0.001$). The spike in December and January of 2016 resulted from reduced irrigation on the grasses to bring storage values down.

Irrigation to the trees was also reduced to avoid deep drainage during the low ET period. The winter irrigation adjustment was not needed during the second year.

Discussion

Nine out of the ten trees used less water than the four turfgrass species in our study and even less than the historical low fertility cynodon dactlyon. Only in the case of the L. indica (crepe myrtle) was the tree and grass water use similar based on basal canopy area. L. indica was the only tropical tree species in the study and it was the smallest of all ten species. We believe its higher water use was somehow related to its evolutionary origin, especially when compared to trees such as desert willow that are native to the desert southwest. Because of L. indica's smaller stature it allowed more solar radiation to strike the canopy and the soil surface and also allowed for more air turbulence around the canopy leading to higher transpiration and evaporation rates. In the earlier Devitt study (1995) immature trees were planted and irrigated with a leaching fraction as high as 25% demonstrating that water use went up as more water was made available. Differences between the two studies are related to the size of the trees, spacing between trees and the amount of irrigation applied. Our study does not validate or invalidate the previous study since the experimental conditions were significantly different. However, we do believe scaling up from immature trees to mature trees is problematic.

This research was conducted to assess trade-offs in the urban landscape between trees and grass. If a landscape area the size of 185 m^2 (2000 sq. ft.) was planted to tall fescue (*Festuca arundinacea)* our research would suggest it would lose about 345,000 liters of water per year via ET as opposed to low fertility bermudagrass (*Cynodon dactylon*) which would lose about 197,000 liters. Based on these amounts of water lost by these two turfgrass species, we asked the question how many trees of each species would this be equivalent to and how many of these trees could fit into the 185 m^2 area (Table 1).

Only in the case of L. indica could the number of trees needed to be equal to the water use of low fertility bermudagrass or high fertility tall fescue actually fit into the 185 m^2 area, with F. velutina 'Modesto" almost fitting into the area based on the comparison with low fertility bermudagrass. These results would be in agreement with research showing turfgrass areas having higher water use than tree dominated areas (Balogun et al. 2009, Kotani and Sugita, 2005 and Offerle et al. 2006). Clearly the comparison in our study was more favorable when low fertility bermudagrass was contrasted with the tree ET values, indicating tradeoffs are significantly different based on turfgrass type (C3 vs C4, low vs. high fertility) and that significantly larger turfgrass area trade-offs would exist with low fertility bermudagrass. Based on the experimental conditions of this study, the two highest water using trees were two of the smaller trees (basal canopy areas and canopy volumes). Rather than recommending one species over another, the decision should be based on landscape area available and the target goal for water applied to the area. Decisions should then be made based on landscape design, realizing tradeoff s exist between how much water is required to grow a warm season vs. cool season turfgrass vs. different ornamental landscape trees. The other option would be to simply remove trees/grass from a percentage of the landscaped area and redesign the irrigation system to capture the water savings. However, this would still require ET estimates for the selected grasses and trees to make sure that they were being properly irrigated and that the conservation goal was attained.

In the desert southwest many golf courses have reduced water requirements by reducing turfgrass in the fairways and roughs, thereby isolating some trees to separate landscaped irrigated areas. However many other mature trees still remain within turfgrass irrigated areas. Such a situation would suggest two different irrigation strategies for trees; 1) bumping irrigation amounts to identified turfgrass areas based on the number of trees growing in close proximity to the turfgrass irrigated area and 2) irrigating isolated landscape areas based on assessing environmental demand (ET_{ref}) and tree morphology using the approach taken in this study as a first approximation. Peters et al. (2010) also found differences in tree transpiration rates based on species, which they largely explained based on canopy structure and growing season length.

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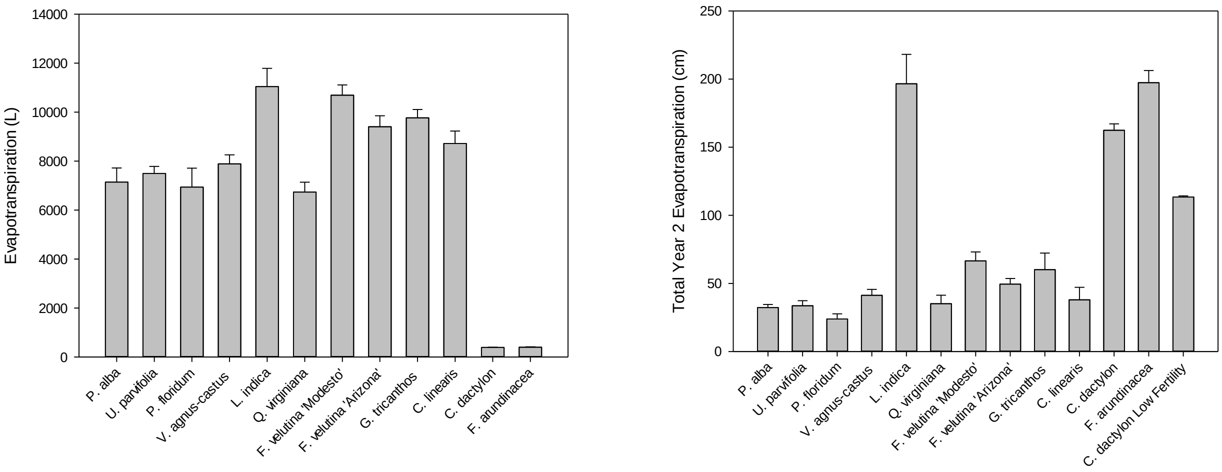

2nd Year Water use Per Plant or Lysimeter, Not Scaled to Water per Area

Grasses Generally Use More Water Than Trees per Basal Canopy Area

2017-2018. Means with one standard deviation.

Figure 1. Evapotranspiration (ET) standardized by area for both trees and grass. *L. perenne* and *A. stolonifera* were excluded due to the lack of summer time values. (Means with 1 SE). ET in liters is not normalized to area, and simply refers to the area of the lysimeter for the grass.

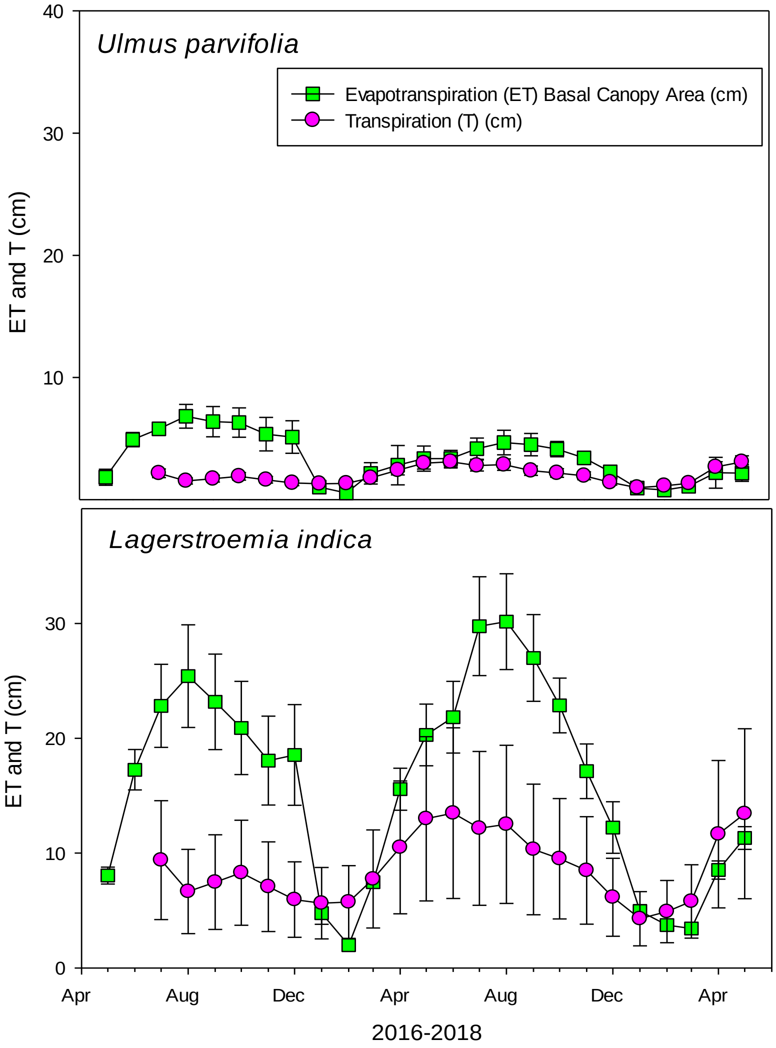

Figure 2. Sapflow Transpiration and ET determined by Hydrological balance. a) Points are the mean (n=3), error bars show 1 standard error, single trunk tree. b) Points are the mean (n=3), error bars show 1 standard error, trees have 1-4 trunks. (Sapflow was adjusted by multiplying sapflow by trunk size and number).

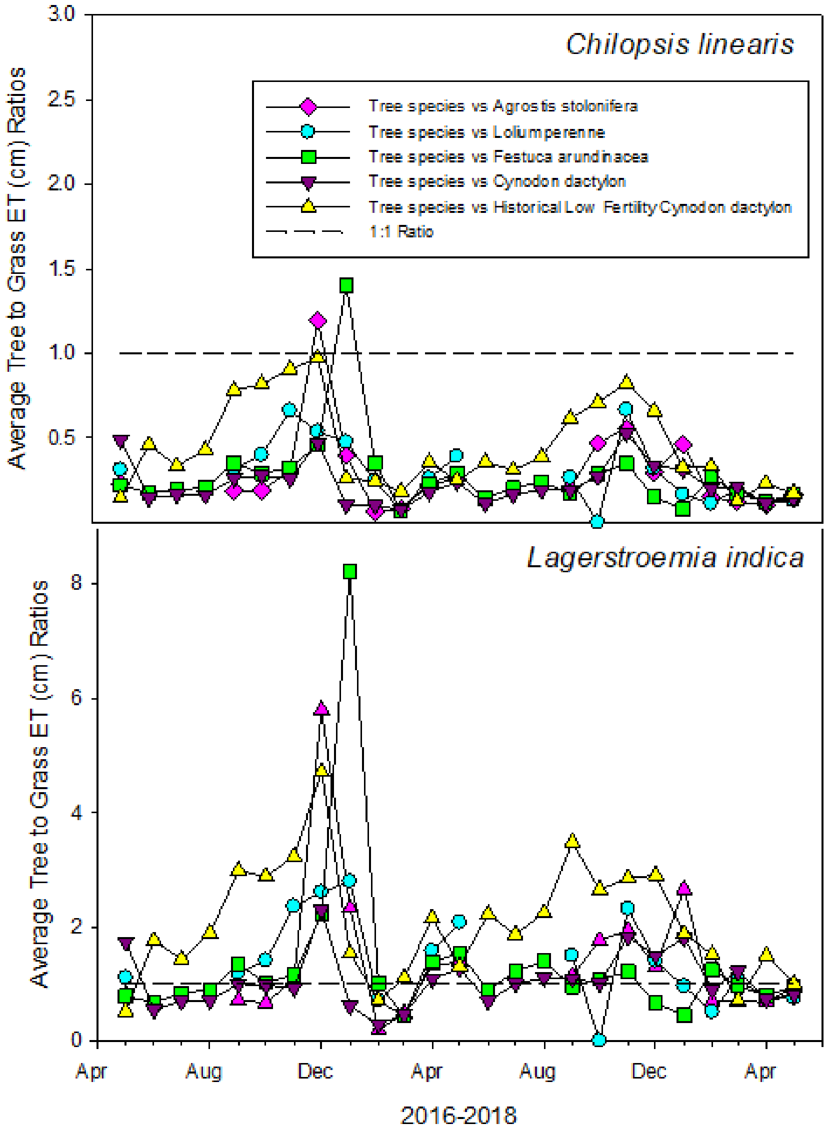

Figure 3. Tree to grass ratios for one desert adapted tree (*C. linearis*) and one tropical tree (*L. indica*).

Table 1. Comparison of tree numbers that physically fit into an area of 185 m^2 (based on basal canopy area) and the number of trees that would need to fit into this area based on the difference in water use between the different tree species and low fertility bermudagrass and high fertility tall fescue.

Species	Trees to fit area	Trees needed based on bermudagrass ET	Trees needed based on tall fescue ET
C. linearis	7.5	17.4	30.4
F. velutina 'Arizona'	9.7	24.1	42.1
F. velutina 'Modesto'	11.1	13.4	23.5
G. tricanthos	10.4	18.0	31.5
L. indica	32.5	17.6	30.9
P. alba	8.3	20.1	35.3
P. floridum	6.2	17.2	30.2
Q.virginana	9.0	18.6	32.5
U. parvifolia	8.1	17.4	30.4
V. agnus-castus	9.4	22.4	39.2

USGA ID#: 2017-01-611

Project Title: Effects of deficit irrigation and rootzone depth on water use and drought resistance of warm-season fairways.

Project Leaders: 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

Summary Points:

- Field plots for a warm-season fairway deficit irrigation study show differences between cultivars regarding drought resistance and irrigation water requirements.
- Restricted rootzones may increase the irrigation water requirements of location differently for each cultivar.
- A final design for an automated golf cart trafficker and irrigation system has been developed with construction scheduled to begin in December 2018.

Summary Text:

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.

Methods

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. Plots have been mowed three times per week at 0.5-inches during the growing season.
During summer 2018, cultivar main plots were split into four irrigation levels (25, 50, 75, and 100% of ET_o x 0.7 or ET_c). Irrigation was hand-applied once per week using a nearby weather station to estimate reference ET. To assess how cultivar performance varies under the presence of restrictive rootzones, lysimeters (8-in and 12-in) were installed within the same plots (Fig. 1). Measurements of turf performance were conducted weekly using turf quality ratings (NTEP methods) and NDVI (Rapid Scan, Holland Scientific). During winter 2017-18, access tubes were installed for measurement of soil moisture using a soil profile sensor (PR2, Delta-T Devices). Volumetric water content was measured at 3, 4, 8, 12, and 16-inch depths twice per week. Differences in moisture content between measurement dates will be used to estimate ET rates over the course of a typical irrigation interval.

A second experiment is being conducted to study the effects of traffic on irrigation water requirements of common fairway turfgrasses. Small plots were established in summer 2018 from plugs (TifTuf, U-3, Latitude 36, Celebration, Tifway, OKC 1403, and OKC 1221) or sod (Meyer) as a randomized complete block design having three replications. The plots are unique in that they were planted as a pie wedge around a central point. A small–scale center pivot irrigation system has been designed such that it creates a radial gradient irrigation system (RaGIS) moving from near the center (wet) to the outer edge (dry) (Fig. 2). The pivoting arm is also designed to simulate golf cart traffic associated with the turning of wheels.

To Be Completed: For experiment 1, a complete data analysis will occur during winter 2018-19. Preliminary results are reported below. For the RaGIS, construction and installation is scheduled to begin in late fall semester with completion scheduled for February 2019. A suite of NDVI sensors and infrared thermometers will be installed on the irrigation arm, while buried soil moisture sensors will monitor volumetric water content at a 3 to 4-inch depth.

Early Results

Results from experiment 1 were limited due to above average rainfall in August. However, significant differences in drought resistance were apparent during late July (Fig. 3). Specifically, Meyer and OSU 1403 each showed drought stress at the 25% ET_c levels, while other cultivars showed no indication of stress at these levels (under unrestricted rooting). When rootzones were restricted, drought stress was more severe but again this was most visible for Meyer and OSU 1403. These early results suggest drought resistance in other cultivars may include either dehydration tolerance or lower water use rates.

Future Expectations

An additional year of data will be collected for experiment 1. Results will be compared between years and compiled for submission of a manuscript to a peer-reviewed journal. Irrigation and traffic treatments for the RaGIS system are planned for June 2019 and will be repeated in summer 2020.

Figure 1. An overview of the fairway deficit irrigation plots in July 2018 showing discolored circles where restricted rootzones occurred.

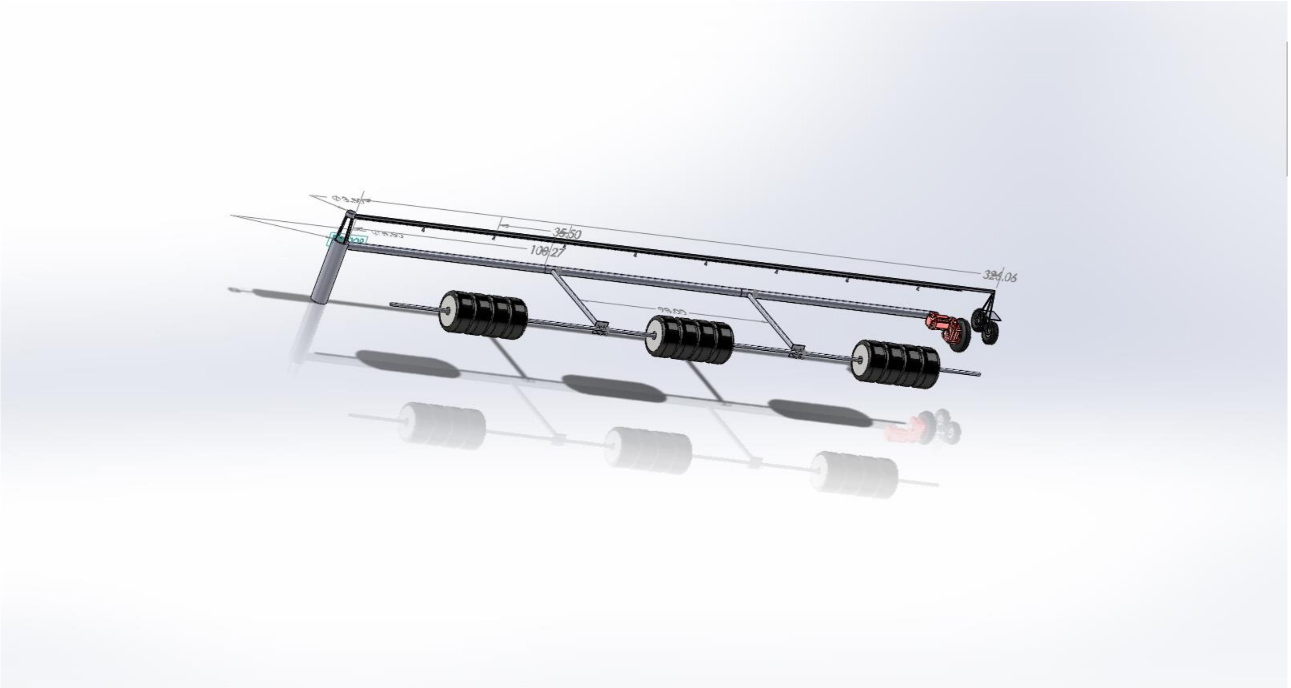

Figure 2. Final design for the proposed radial gradient irrigation system and trafficker.

Figure 3. Effects of severe deficit irrigation on restricted rootzone areas of an experimental bermudagrass showing poor drought resistance: 8-inch rootzone (left), 12-inch rootzone (middle), and unrestricted rootzone (right).

USGA ID: 2015-16-531

Title: Evaluating Small Unmanned Aerial Systems for Detecting Drought Stress on Turfgrass

Project Leaders: Mu Hong[1], Dale J. Bremer[1], and Deon van der Merwe[2]
Affiliation: [1]Horticulture and Natural Resources Dept., Kansas State University; and [2]Dept. of Farm Animal Health, University of Utrecht

Objectives:

1. Evaluate the ability to detect early drought stress utilizing sUAS technology combined with ultra-high remote sensing.
2. Compare sUAS remote sensing measurements with traditional, ground-based techniques.

Start Date: 2015
Project Duration: 3 years
Total Funding: 60,000

Summary Points:

- Declines in VWC in irrigation-deficit treatments were consistently detected by the NIR band and six VIs from sUAS, and NDVI and the red band from the handheld device with an active optical sensor, before drought stress was evident in VQ and PGC.
- These bands and indices predicted drought stress at least one week before symptoms appeared in VQ and PGC in 2016 and 2017.
- The NIR band and GreenBlue VI from sUAS were the most sensitive and the only ones to consistently detect drought stress early during the three years compared to other bands or VIs.
- The one year of Tc measurements acquired by sUAS were comparable to the best spectral parameters in predicting drought stress before drought symptoms appeared.
- Using ultra-high resolution remote sensing with sUAS can detect drought stress as well as or better than handheld devices before it is visible to the human eye and may prove viable for irrigation management on turfgrass.
- Results from this research have been widely presented at multiple international conferences, statewide turfgrass conferences and field days, university departmental seminars, and published or discussed in research reports, abstracts, a newsletter, and interviews in a trade journal (Golfdom) and an online webinar.

Summary Text:

Recent advances in small unmanned aircraft system (sUAS) may provide a rapid and accurate method for turfgrass research and management with less labor. Our research was conducted over three summers (29 June to 31 Aug 2015; 1 July to 29 Aug 2016; 9 June to 31 Aug 2017) on creeping bentgrass mown at fairway height (16 mm) under an automated rainout shelter. Turfgrass was irrigated across a gradient from well-watered to severe deficit [100% to 15% evapotranspiration (ET) replacement]. Airborne measurements of spectral reflectance were collected with a modified digital camera (Canon PowerShot S100, maxmax.com). The modified camera measured in three broadband reflectances [near infrared (NIR, 680-780 nm) and green and blue bands (overlapped, 400-580 nm)], from which eight vegetation indices (VIs) were derived. In 2017 only, airborne measurements of canopy temperature (Tc) were also obtained with a thermal camera (FLIR VUE PRO R 336). Traditional, ground-based measurements included volumetric water content (VWC; 7.5 cm depth; FieldScout TDR 300), visual quality (VQ), percentage green cover (PGC) with digital image analysis, and spectral reflectance parameters from handheld devices [FieldScout 1000 (passive optical sensor); and Holland Scientific RapidScan CS-45 (active optical sensor)].

Spectral and thermal images revealed striking differences among irrigation treatments as the dry downs progressed (Figs. 1 and 2). Relatively slow declines in turfgrass visual quality during early drought stress development allowed for detection of early drought stress with remote sensing. For example, spectral reflectance measurements in the near infrared (NIR) band and the GreenBlue VI [(Green - Blue) / (Green + Blue)] consistently detected drought stress in turfgrass before it was visible in VQ. Figure 3 illustrates how the NIR band and GreenBlue VI detected lower VWC in 15% and 30% ET treatments on 7 July, despite no differences in VQ or PGC, and predicted declines in VQ and PGC in 15% and 30% ET plots one week later on 15 July. In 2016 and 2017, five additional VIs (NDVI Enhanced1, NDVI Enhanced2, NDVI Enhanced3, Blue NDVI, and NIR Blueratio) acquired from sUAS, in addition to the NIR broadband and GreenBlue VI, detected drought stress 7-16 days before it became evident in VQ, as did the NDVIRS and red narrowband from the handheld active optical sensor (RapidScan). However, the NIR and GreenBlue VI were the most consistent spectral reflectance parameters from sUAS data to distinguish deficit-irrigation treatment effects before they appeared in VQ and PGC throughout the three-year study. From the on-ground reflectance measurements, NDVIRS and red reflectance from the active optical sensor (RapidScan) were best at predicting drought stress.

Airborne measurements of Tc from sUAS did not begin until one week after irrigation treatments began (15 June) due to technical issues. By then, Tc was already greater in 15% and 30% than in 100% ET plots, matching patterns of lower VWC in 15% and 30% ET plots on 15 June, and remained so throughout the study (Table 1). However, on the same day (15 June) there were no differences in VQ among treatments despite higher Tc in 15% and 30% than 100% ET plots. In fact, VQ didn't decrease in 15% and 30% ET plots until 1 July, which suggests Tc detected drought stress 16 days before it became visible. This was also true for spectral reflectance measurements of NIR and GreenBlue obtained aerially (Table 2). Five additional VIs from sUAS measurements, and NDVI and red reflectance from the handheld active (RapidScan), but not the handheld passive (FieldScout) optical sensor, also detected differences between 100% ET and 15% ET, but not 30% ET plots 16 days before symptoms appeared (Table 2). Therefore, Tc, NIR, and GreenBlue VI from sUAS were the most sensitive at detecting early drought stress in the lower irrigation levels compared with the other spectral reflectance bands and VIs from the sUAS and handheld sensors. Thus, the ability of Tc to detect early drought stress is comparable to the best spectral parameters (i.e. NIR and GreenBlue VI) on a companion flight.

Regarding drought detection 16 days before symptoms became evident in 2017: It is possible that drought symptoms became visible before 1 July because VQ was not evaluated on days between sUAS flights (e.g., between 20 June and 1 July). Thus, it is not certain that spectral reflectance parameters detected drought stress symptoms a full 16 days early. However, spectral reflectance parameters and Tc clearly detected drought stress before it was visible, as discussed above. Additional research is warranted to refine the window of time between initial drought stress detection by sUAS remote sensing and the appearance of drought stress symptoms.

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Table 1. Irrigation main effect by date on canopy temperature (Tc), visual quality (VQ), percentage green cover (PGC), and volumetric water content (VWC), in 'Declaration' creeping bentgrass in 2017 (P <0.05).

Treatment†	7 June	15-Jun	20-Jun	1-Jul	10-Jul	25-Jul	4-Aug	31-Aug
Average air temperature for the same hour Tc was measured (°C)								
		33.5	32.9	28.3	35.5	34.1	23.5	26.6
Tc (°C)								
100%	na‡	40.4A	37.4A	42.6A	39.1A	40.8A	39.3A	39.4A
80%	na	40.9ABC	37.7AB	43.0AB	39.7A	41.5A	39.5A	41.1AB
65%	na	40.8AB	37.5A	42.8A	39.9A	41.2A	39.3A	40.4A
50%	na	40.9ABC	37.9AB	43.2AB	40.2A	43.5AB	40.6AB	43.3B
30%	na	41.4BC	38.8BC	44.4BC	42.5B	47.2BC	43.1BC	47.2C
15%	na	41.4C	39.3C	44.9C	44.6C	49.7C	45.3C	47.2C
VQ								
100%	7.1	7.3	7.6	8.1A	8.6A	7.9A	8.3A	7.4A
80%	8	8	8.8	8.6A	8.9A	8.5A	8.5A	5.6BC
65%	7.3	7.6	7.9	7.8A	7.6AB	7.3A	7.8A	6.5AB
50%	8.3	7.9	8.4	8A	7.3B	5.6B	6B	4.5CD
30%	7.8	8	7.9	6.1B	5.1C	4C	4.5BC	3.4DE
15%	7.1	6.6	6.9	5.6B	4.3C	3.1C	3.4C	2.8E
PGC (%)								
100%	82.5	90.5AB	91.2A	98A	97.7AB	96.4A	98.8A	89.3A
80%	90.8	95.6A	95.8A	99A	99.1A	97.5A	99.5A	67AB
65%	87.5	92.5A	94.1A	98.2A	97.6AB	95.7A	98.3A	85.5A
50%	90.9	94.9A	95.6A	98.5A	98.4AB	88.3A	96.8A	64.9AB
30%	92	93.8A	92.5A	90.7B	72.9CB	49.3B	57.3B	26.4C
15%	83	84.5B	83.1B	85.2B	53C	36.8B	35.1B	38.2CB
VWC (%)								
100%	45.4	45.2A	42.8A	41.7A	47.6A	42.5A	46.3A	38.8A
80%	45.3	43.8A	42.3A	41.4A	46.9A	40.9A	43.9AB	34.4B
65%	44.9	40.7A	38.5B	39.2A	47A	38.6A	44.5AB	34.9AB
50%	45.2	40.9A	39.8AB	39.3A	44A	33.3B	41.4BC	28.1C
30%	46.1	34.3B	27.9C	27.4B	34.2B	24.7C	37.1CD	22D
15%	44.5	29.4C	24.9C	22.9C	27C	20.9C	33.4D	18D

† Percentage of evapotranspiration (ET) replacement.

‡ Airborne canopy temperature wasn't available on June 7.

Table 2. Analysis of irrigation main effects on visual quality (VQ), canopy thermal infrared temperature (Tc), spectral reflectance data acquired from the small unmanned aerial system (sUAS), and the RapidScan handheld optical sensor (NDVIRS and red)], for 'Declaration' creeping bentgrass on 15 June.

Treatment†	VQ	VWC	Tc (℃)	GreenBlue§	NDVI Enhanced1¶	NDVI Enhanced2#	NIR	Blue NDVI††	NIR Blueratio‡‡	NDVI §§ RS	Red
100%	7.3	45.2A	40.4A*	-0.093A***	-0.055A**	0.284A**	201AB***	-0.019A**	-7.79A**	0.78A*	4.5A*
80%	8	43.8A	40.9ABC	-0.093A	-0.049A	0.289A	203A	-0.008A	-3.43A	0.81A	4.0A
65%	7.6	40.7A	40.8AB	-0.096AB	-0.056A	0.283A	199BC	-0.018A	-7.45A	0.78A	4.6A
50%	7.9	40.9A	40.9ABC	-0.099B	-0.055A	0.284A	199BC	-0.015A	-5.99A	0.80A	4.3A
30%	8	34.3B	41.38BC	-0.101B	-0.056A	0.282A	197C	-0.016A	-6.23A	0.79A	4.4A
15%	6.6	29.4C	41.43C	-0.110C	-0.073B	0.267B	191D	-0.038B	-15.13B	0.75B	5.3B

*Treatment means were significantly different at *P* <0.05 probability level, indicated by different letters; no letter presented when P>0.05.

** Treatment means were significantly different at *P* <0.01 probability level, indicated by different letters.

*** Treatment means were significantly different at *P* ≤0.001 probability level, indicated by different letters.

† Percentage of evapotranspiration (ET) replacement.

‡ Visual quality based on a 1 to 9 scale, with 1 = dead, 6 = minimally acceptable, and 9 = uniform, green, dense turfgrass.

§ GreenBlue= (G-B)/(G+B); G, green spectral reflectance, and B, blue spectral reflectance are between 400-580 nm.

¶ NDVI Enhanced1= (NIR+G-2B)/(NIR+G+2B). NIR, near infrared spectral reflectance, peaks within 680-780 nm.

NDVI Enhanced2= (NIR+G-B)/(NIR+G+B).

†† Blue NDVI= (NIR-B)/(NIR+B).

‡‡ NIR Blueratio= NIR-B.

§§ NDVIRS = (NIRRS-red)/(NIRRS+red); NIRRS peaks at 780nm, near infrared spectral reflectance; Red peaks at 670nm.

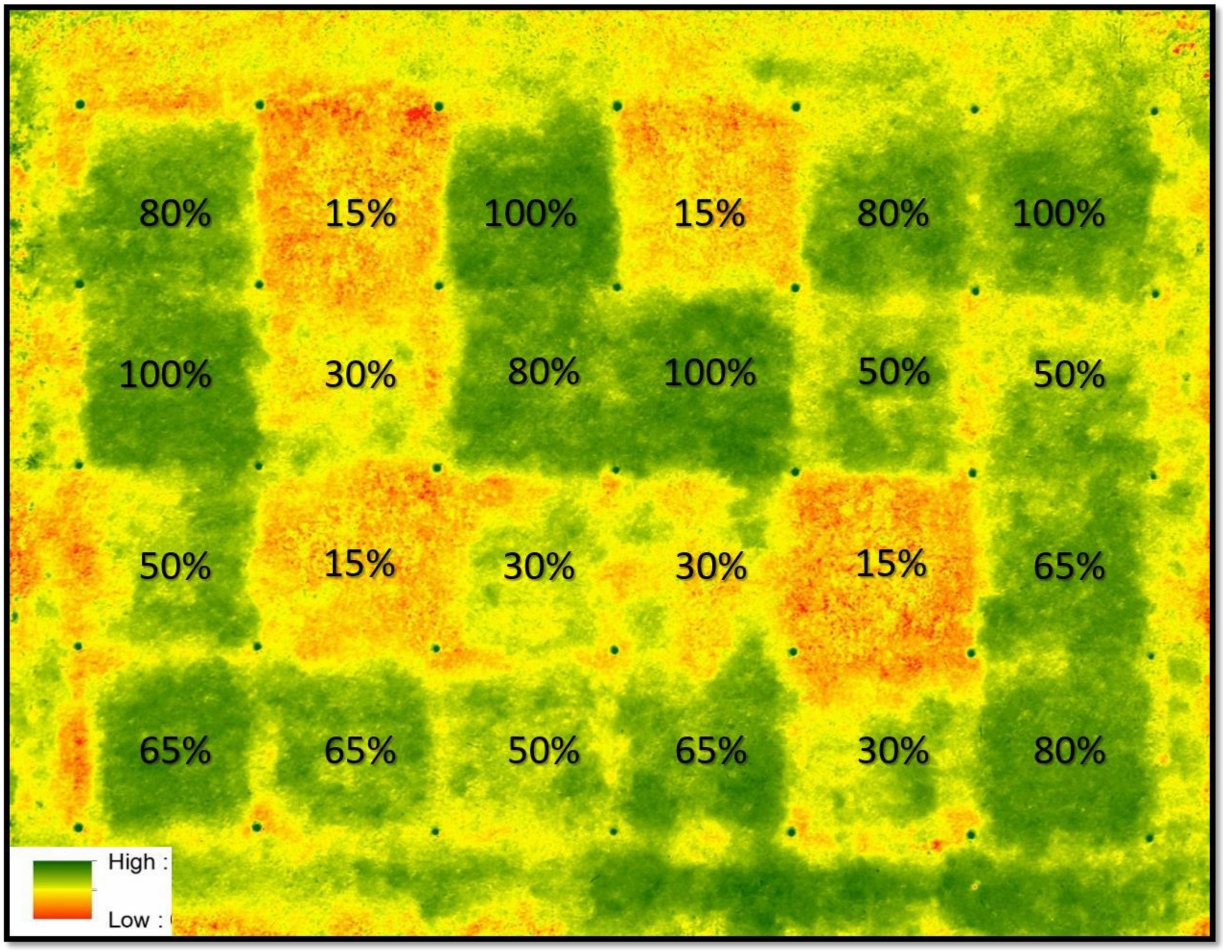


Figure 1. Color-enhanced image of plots in the near-infrared (NIR) band on 31 August 2015. Percentages denote evapotranspiration (ET) replacement irrigation treatments. Dark green (high) indicates more turf biomass. Image created in ArcGIS.

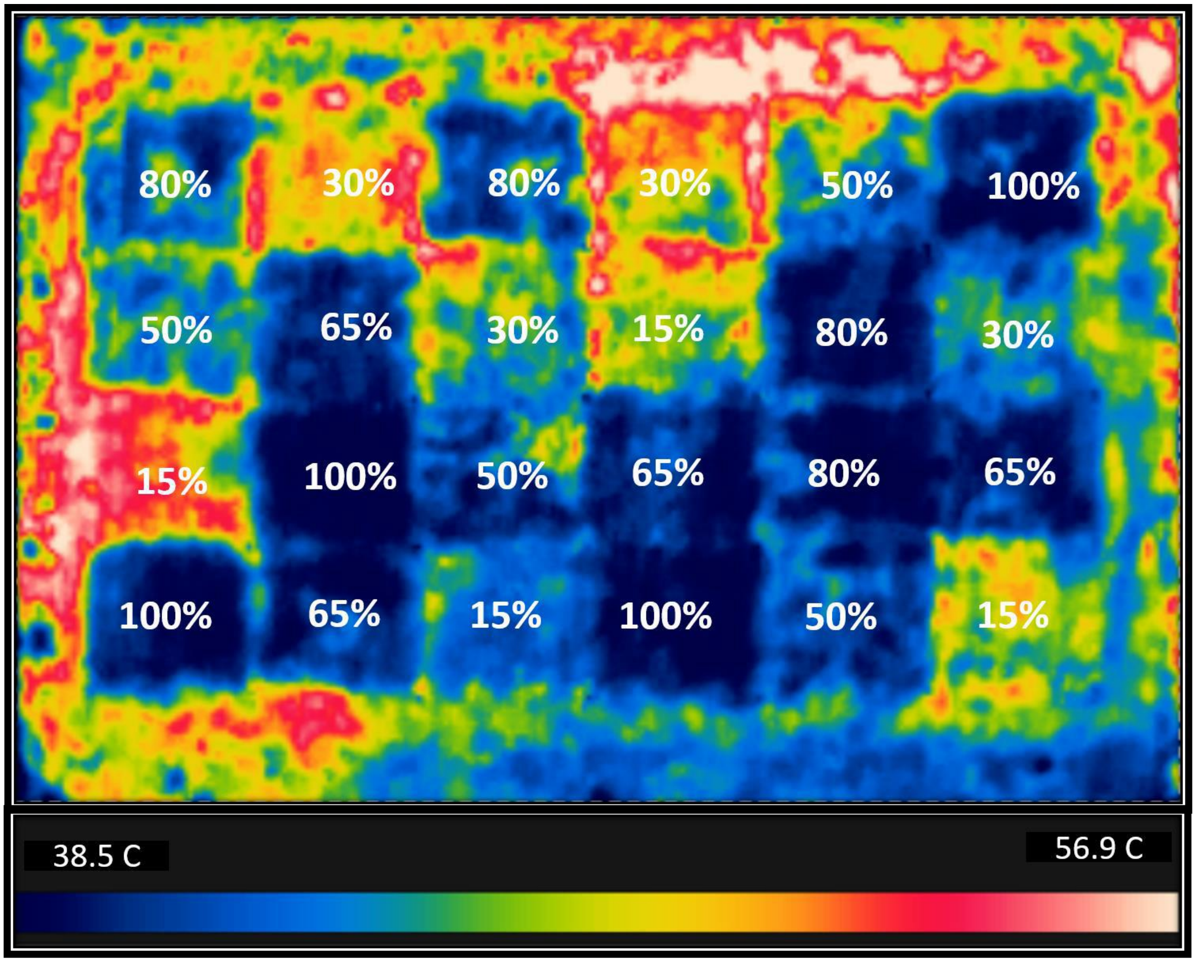


Figure 2. Color-enhance thermal image of plots on 31 August 2017. Percentages denote evapotranspiration (ET) replacement irrigation treatments. Image created in FLIR Tools.

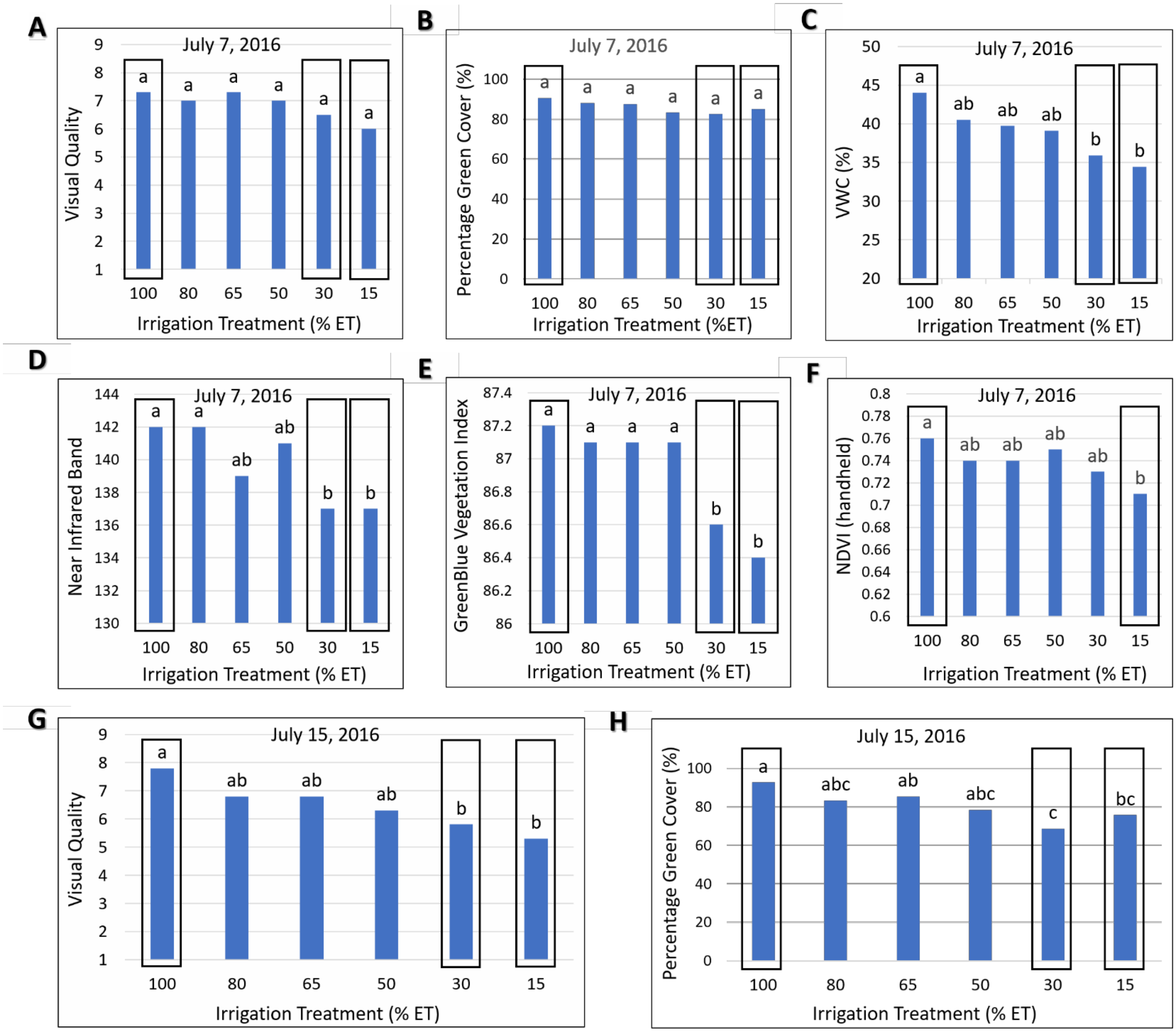


Figure 3. Measurements on 7 July, 2016 of turf visual quality (A), percentage green cover (B), volumetric soil water content (VWC, C), near infrared from modified Canon S100 on sUAS (D), GreenBlue vegetation index from modified Canon S100 on sUAS (GreenBlue, E), normalized difference vegetation index (NDVI) with handheld radiometer (F), and 8-days later on 15 July, visual quality (G) and percentage green cover (H). Bars with the same letter within each figure indicate no significant differences ($P<0.05$).

USGA ID#: 2018-04-654

Title: Enhancing Water Conservation through Remote Sensing Technology on Golf Courses

Project Leaders: Dr. Joseph Young[1], Dr. Sanjit Deb[1], Dr. Glen Ritchie[1], Dr. Wenxuan Guo[1], Eduardo Escamilla[1], Juan Cantu[1], and Dr. David McCall[2]
Affiliation [1]Texas Tech University and [2]Virginia Tech University

Objectives:

1. Determine optimum canopy temperature for warm- and cool-season grasses used on golf courses.
2. Ground-truth spectral sensory data from a UAV to specifically recognize water-deficit stress.
3. Optimize the best technology for ease of transfer to the golf industry and quantify water savings.

Start Date: 2018
Project Duration: 3 years
Total Funding: $95,618

Summary Points:

- The shorter leaf canopy maintained may limit drought-specific vegetation indices (970 nm) from more effectively identifying drought stress.
- Current data may point to soil compaction as a factor indicating stress on these fairways.
- Increasing frequency of flights in 2019 will provide a broader range of images under different environmental conditions to more clearly distinguish stressors.
- Overlaying ground measured parameters on top of NDVI-calculated images will begin to demonstrate soil or turf parameters leading to stress signals from images.

Summary Text:

Water conservation strategies continue to be developed and tested throughout the golf industry. Agricultural producers have effectively incorporated remote sensing technology into maximizing yield while reducing inputs or targeting inputs to areas of greatest demand. Utilizing remote sensing data to improve turf management procedures is in its infancy, but there are many current research studies working to demonstrate the benefits of site-specific management practices or pesticide applications. The overall goal of this project is to test various spectral sensors collecting images of golf course fairways to improve recognition of drought stress signatures on cool- and warm-season turf species.

Methodology

UAV Flights and Data Compilation. Weather conditions provided challenges in completing more frequent flights, but full flight data were obtained from two holes of a warm-season golf course (Rawls Golf Course n = 5) and three holes of a cool-season golf course (Amarillo Country Club n = 3). A complete flight included collecting geo-referenced imagery from four sensors [Red/Green/Blue (RGB); Red Edge (RE); NIR850 nm; and NIR970 nm). All images were compiled and stitched into a single image per golf course fairway flown and analyzed in Blue Marble Global Mapper GIS software. Analysis consisted of NDVI calculations using RE/NIR850/NIR970 sensor with RGB images.

Ground-truth Data with Flight. A GPS grid-point map was developed in Google Earth Path add-on within Google Earth. Soil samples will be obtained at each intersection (soil physical properties) along with consistent measurement of soil compaction (0-5 cm and 5-10 cm), NDVI, and relative volumetric water content (VWC) with TDR at 3 inch (7.6 cm) depth (All instruments from Spectrum Technologies). Instrument data collection is targeted within 1-2 days of flight to overlay with analyzed drone images to validate stress in fairway/rough locations.

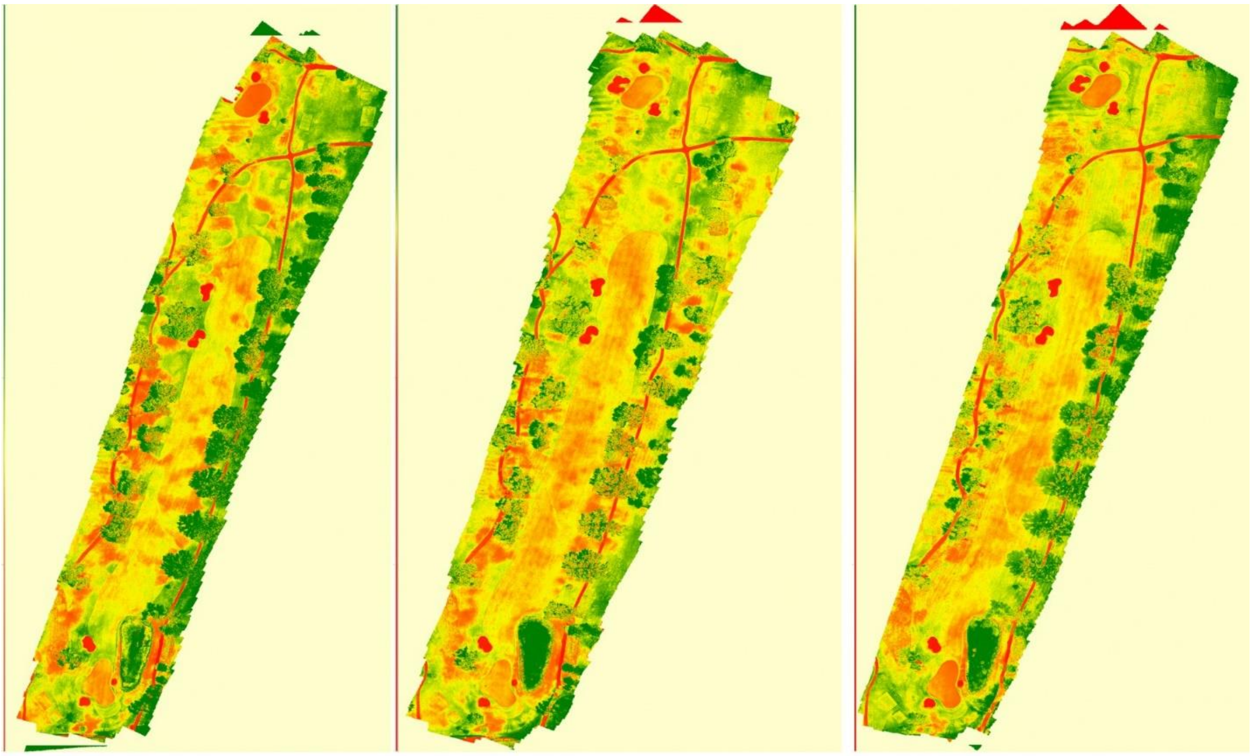
Calibration of Soil Moisture Sensor. Soil was obtained from golf tees (sand-based) and fairways (native soil) for laboratory calibration of the Toro soil moisture sensors. A circular soil column with one TurfGuard sensor inserted in it was placed in a pressure plate extractor. Continuous VWC measurements with the sensor were then obtained, and gravimetric-based soil water content were determined under different matric potential values, ranging from saturation (zero bar) to permanent wilting point (-15 bar).

Results to Date/Future Expectations

UAV Flights and Data Compilation. Flight images from both locations have been stitched and analyzed using an NDVI formula. The analyzed images depict change in stress from flight to flight as environmental conditions became more oppressive. However, many of the calculated images do not clearly distinguish the four sensors flown at each location. We are looking to increase flight numbers in 2019 to attempt a minimum of one flight per month January to December. Due to similarity in sensors, only two sensors will be flown each flight to more effectively use time and expand number of holes to be flown. We hope collecting imagery over this extended period will allow us to better validate drought response from other stress factors.

Ground-truth Data with Flight. Ground measurements were obtained in close proximity to 1-2 flights at each location. There was a lag in time and knowledge of creating the GPS coordinates initially and then effectively finding coordinate intersections for measurements. An example map from hole 9 at Amarillo Country Club provides preliminary data of NDVI, compaction, and relative VWC. Based on visual analysis of these preliminary maps, soil compaction may be a primary indicator of higher stress zones on the fairways. Our methods and grid point creation have been solidified at this point, so we anticipate much greater data collection in 2019 to better understand ground variability that may be indicating stress from drone imagery. Soil samples from the same coordinate intersections will be obtained this winter prior to heavier golf season to minimize interruption of play during soil collection. Maps similar to those presented and overlaying maps of GPS-coordinate data on top of the geo-referenced images from the drone will allow us to more specifically identify stress factors from constructed NDVI images.

Calibration of Soil Moisture Sensor. The sensor readings and gravimetric-based VWC measurements were completed for both soil types (two golf courses) over the range of VWC-matric potential relationship levels studied. The experiment was repeated three times for both soils. The linear calibration equations of TurfGuard sensors are being developed for both soil types at two golf courses. Additionally, a variety of calibration equations widely used for dielectric soil moisture sensors are being analyzed, particularly are being fitted using a least–squares optimization approach to obtain soil-specific equation's empirical parameters or coefficients. Of significant note, manufacture's calibration and standard values of these parameter values provided by the manufacturers are usually unsatisfactory for many soils such as clay-rich soils at the golf courses selected for this study, which required specific calibrations. The TurfGuard sensor readings and gravimetric-based VWC data were also compared with the outputs from other calibrated widely-used dielectric soil moisture sensors such as Hydra Probe II (Stevens Water Monitoring System, Inc.). Understanding this information will assist us in determining if the sensor could effectively help golf course superintendents schedule irrigation more efficiently than previous methods.



6/4/2018 7/14/2018 8/15/2018

Figure 1. NDVI analyzed images from NIR 850 nm sensor progressing through flights from Amarillo Country Club Hole 9. There is a progression of increasing stress as summer months continue on this cool-season grass fairway. Zooming in on some regions show stress that corresponds with some compaction from ground-truth measurements.

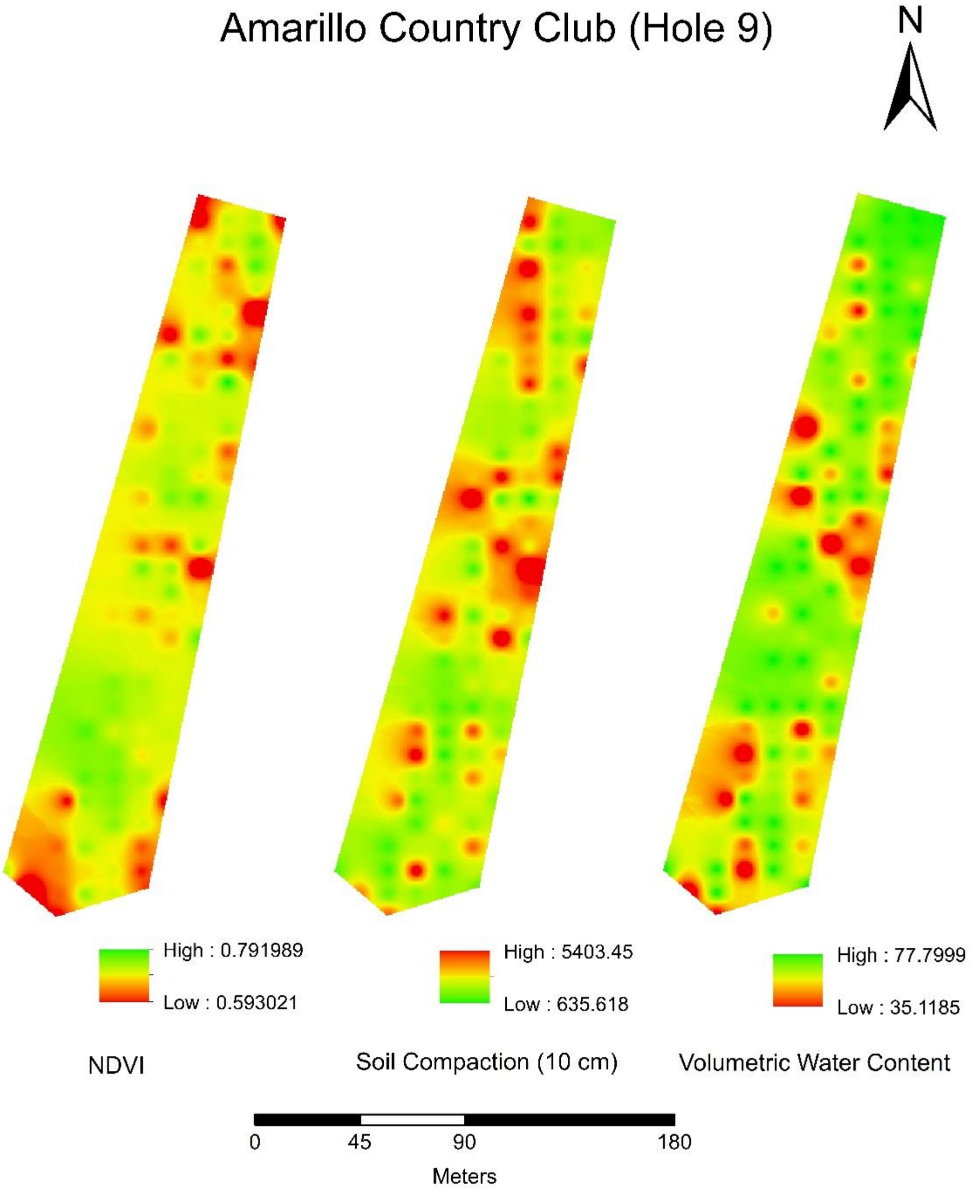


Figure 2. Generated maps from GPS gridded points of ground based measurements obtained in 2018 including: NDVI, soil compaction, and relative volumetric water content. These values will be collected more frequently in close proximity to flights in 2019 to validate analyzed drone sensor imagery.

Figure 3. Unmanned aerial system taking off from a tee box in preparation for a flight at Amarillo Country Club.

USGA ID#: 2017-17-627

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

Project Leader: Lawrence Hipps
Affiliation: Utah State University

Objectives:

1. Conduct eddy covariance measurements of evapotranspiration (ET) and energy balance of a golf course over multiple years to document daily and seasonal water use values. Use findings to test currently used simplistic approaches such as reference ET.
2. Use remote sensing based models to estimate ET, and validate their performance against ground- based measurements.
3. Combine measurements with theoretical knowledge to determine the response of ET to variations in weather and climate. Use this knowledge to develop a physically based model to estimate ET for the periods between satellite overpasses.

Start Date: 2017
Project Duration: 3 Years
Total Funding: $89,862

Summary Points

- Measurements of ET are being made at a golf course to quantify the turf water use on a daily to seasonal basis.
- The Triangle Method remote sensing model is being tested for this site to estimate ET values at each Landsat overpass. Preliminary results show that it is producing reasonably accurate estimates.
- The utility of adding MODIS satellite images to the model is being investigated. If this can be shown to work, it would allow up to eight times as many ET estimates to made from the model.
- Development of a biophysical model to simulate ET for periods between satellite overpasses is ongoing. It is hypothesized that this approach will improve the current rather crude methods currently used.

Summary Text:

Measurements

The research site is the Eagle Lake Golf Course near Layton, UT, about 25 miles north of Salt Lake City. The region is a mixture of urban, residential, and some agriculture. The golf course is very cooperative, and was so enthused they asked us to add a weather station to run all year. Key research measurements include the radiation energy available and the transport (flux) of heat and water vapor (ET) from the surface. Fluxes of heat and water are determined from the eddy covariance technique, which is the gold standard. An image of the station is shown in Figure 1.

In 2017, secondary irrigation water resulted in salt deposits on the lens of the water vapor sensor. Even with numerous cleanings, some data were not usable, and we are using known gap filling methods to recover ET values. In 2018, sprinklers were modified to nearly eliminate this problem, allowing good ET measurements from spring to fall. Various additional corrections result in hourly, daily and seasonal water use for the site.

ET Estimates from Remote Sensing Models

Landsat overpasses occur at approximately 2 week intervals, and were checked to verify they were cloud free and usable. The *Triangle Method Model* is used to determine ET for each overpass. Images are obtained for a much larger region surrounding the golf course. Different bands of the image allow estimation of normalized surface temperature (T*) and fractional vegetation cover (Fr) for each 30 meter pixel of surface. For each element, values of temperature and Fr are plotted and the resulting cloud of points resembles a distorted triangle. Documenting the “cold” and “hot” edges, allows one to determine the fraction of available energy used in evaporation, or *evaporative fraction* (EF). A diagram showing how the calculation is made for each location is shown in Figure 2.

An example of a triangle for the Landsat overpass on 9 July 2018 is shown below in Figure 3, including the cold and warm edges. The lobes on the lower right corner of the points, are artifacts of thermal properties of impervious urban surfaces, and are not truly part of the triangle. Hence, they were not considered in fitting the warm edge.

Incorporating the available radiation energy allows the actual ET for each pixel to be calculated. For each overpass, a map of both the EF and ET can be generated for the region described by the triangle. The distribution of EF values resulting from the analysis of the image for that day, as well as a blow up of the golf course and bordering areas is shown in Figure 4. The white areas on the edges of the golf course represent either buildings or paved surfaces. Notice that there is some spatial variability present in the EF even inside the golf course. The larger EF values are associated with larger ET.

The same procedure was used to generate both EF and actual ET values for 10 cloud-free overpasses. Figure 5 depicts the measured and model ET values for the golf course site for all 10 cases. These show model vs. measured ET at time of the over pass. Units are Watts per sq. meter or energy used in evaporation. These can easily be converted to inches of water per time. Agreement is good, and within the 10 -15% uncertainty of the ET measurements much of the time. Model estimates do appear low at the highest ET values. This is being investigated.

Addition of MODIS Satellite

MODIS satellite platform has similar wavebands as Landsat, at coarser resolution (250 m and 1 km). But data are possible about every other day. The thermal data for 1 km can be downscaled to 30 m using a published algorithm, that checks itself every time there is a Landsat overpass. We will be investigating whether these coarser spatial images can still be used for a golf course.

Future Work

- Use more cases of Landsat images to test the triangle model. Test the ability to estimate ET with MODIS data, that are potentially available 3 – 4 days per week.
- Generate daily, weekly and seasonal ET values for the site. Examine how much they respond to variations in summer climate.
- Test the accuracy of the commonly used Reference ET model. This is an empirical “black box” approach. Preliminary analyses suggests it has problems matching measurements.
- The Penman Monteith ET model will be combined with a stomatal conductance model to allow ET to be simulated at hourly intervals. This will be tested to determine its accuracy. And ability to fill in ET values between overpasses. This is necessary in order for the approach to be used for other sites without eddy covariance measurements

Figure 1. Image of eddy covariance station. The upwind distance "sensed" is about 350 m.

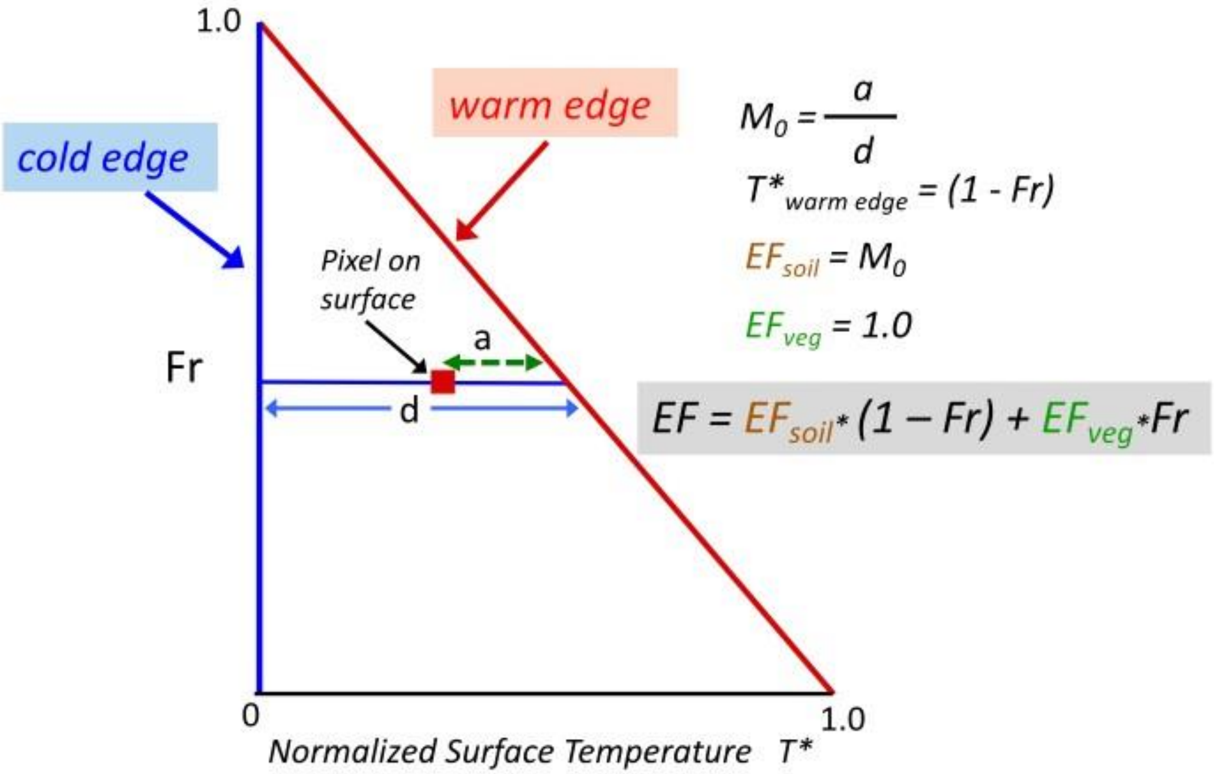


Figure 2. Diagram of how the EF determined from location of any pixel.

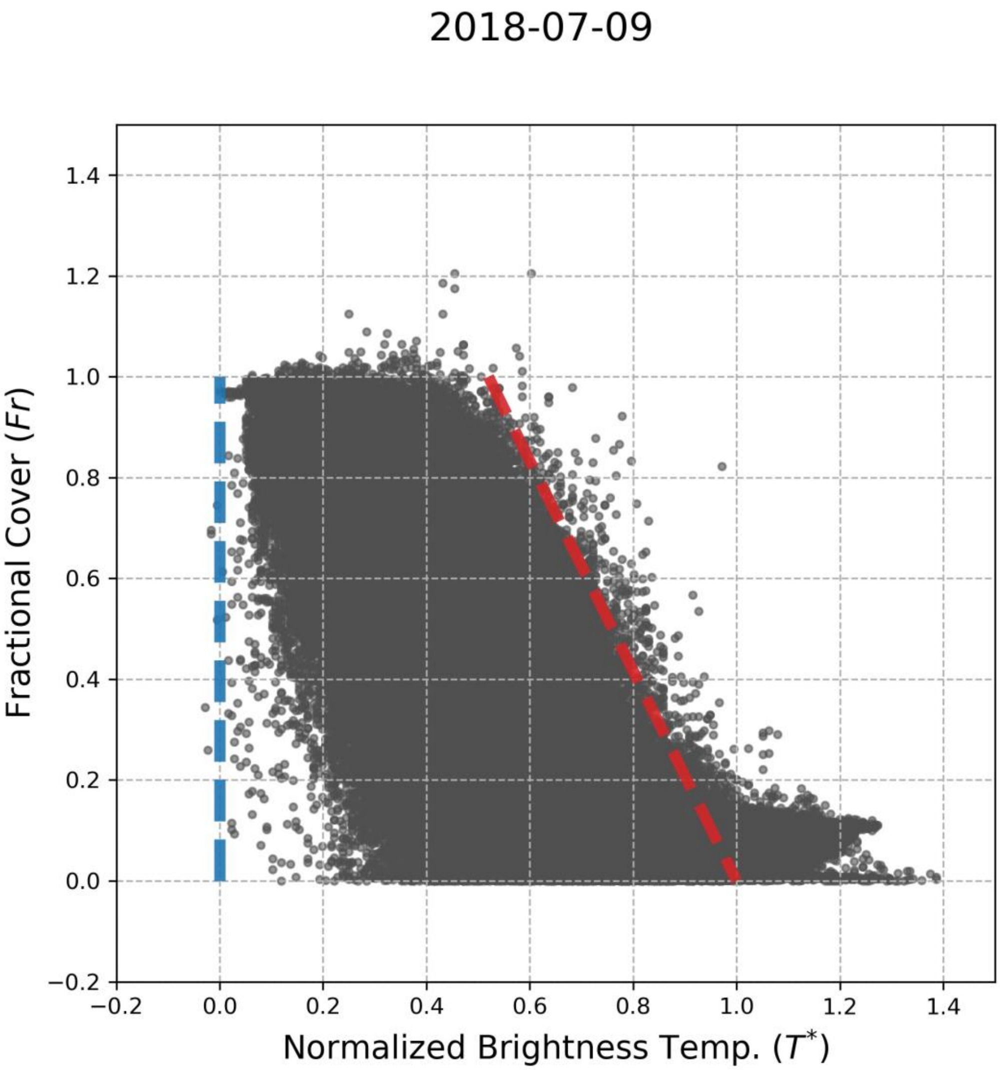


Figure 3. Example triangle for 9 July 2018.

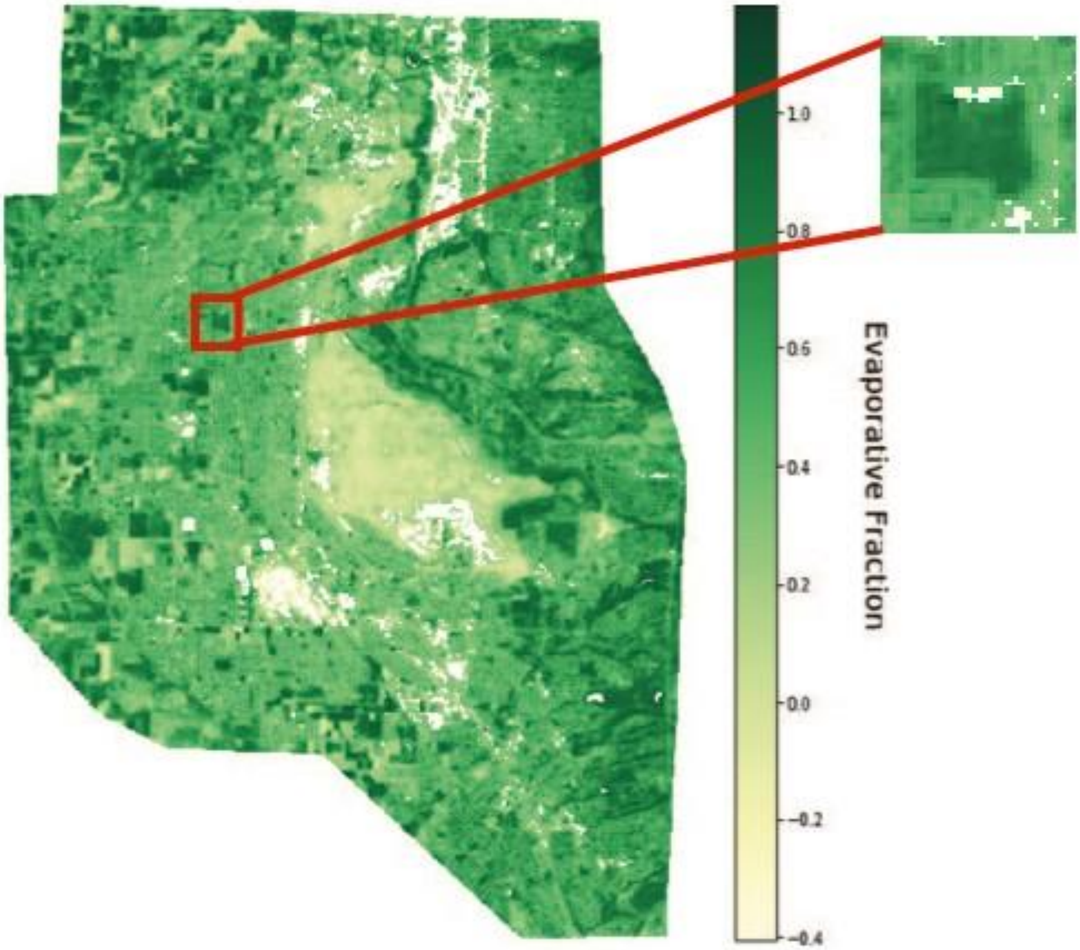


Figure 4. Evaporative fraction distribution in region, with blow up of golf course area.

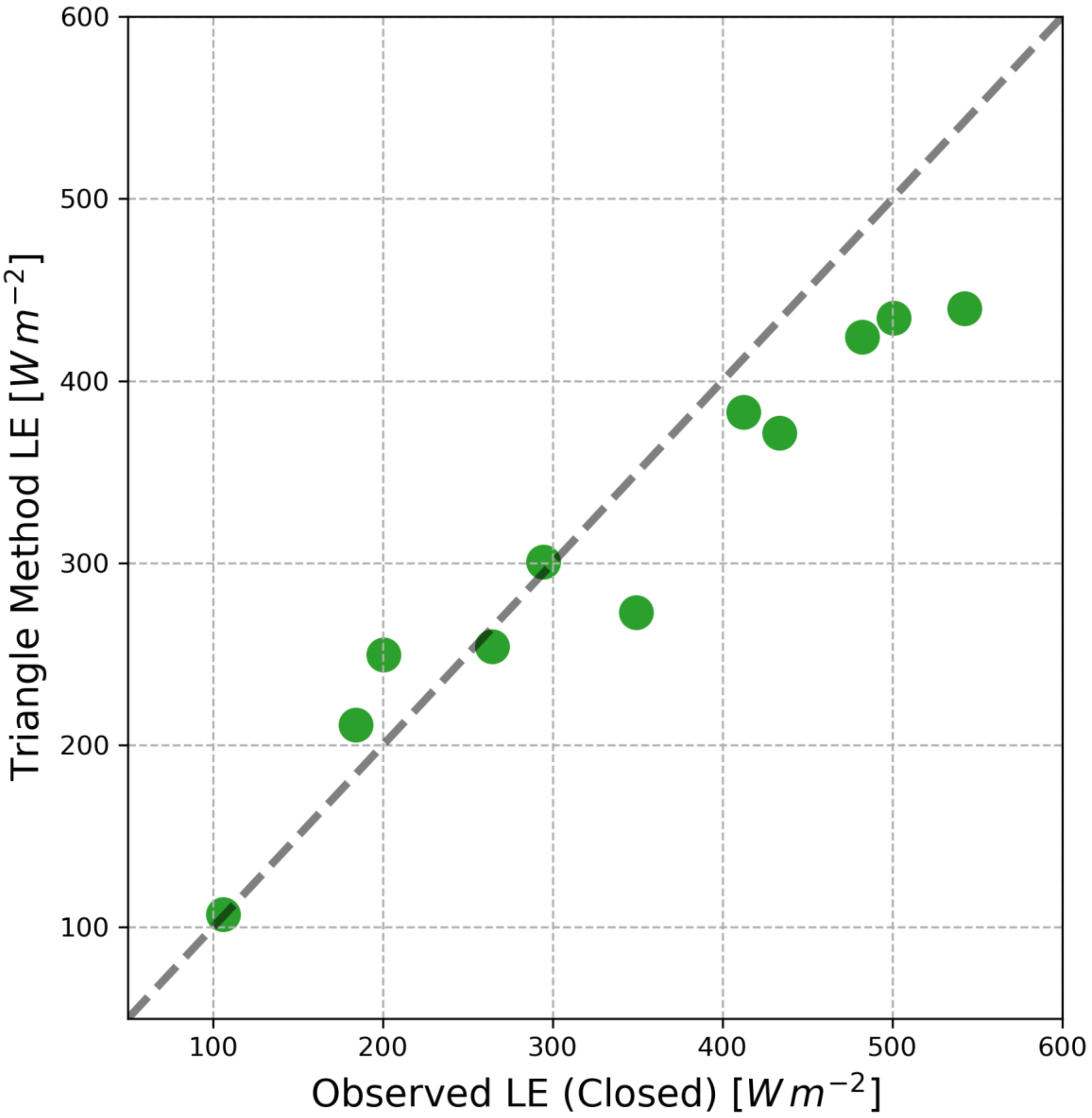


Figure 5. Model vs. measured actual ET values at the golf course site for 10 overpass cases.

USGA ID#: 2017-36-646

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

Project Leader: Priti Saxena, Robert Green, Eudell Vis and Valerie Mellano
Affiliation: California State Polytechnic University, Pomona, CA

Objectives:

1. Analyze the performance of SMS systems to apply less irrigation and result in water savings by bypassing irrigation events when soil moisture is adequate.
2. Evaluate SMS capability to maintain bermudagrass quality.
3. Compare SMS performances against standard irrigation scheduling.
4. Evaluate turfgrass quality, density and color.

Start Date: 2017
Project Duration: 3 years
Total Funding: $45,000

Summary Points:

- Soil moisture sensors (from Toro, Rain Bird and Tucor) were installed in the Bermudagrass plots fall 2017 and Spring 2018 to measure the moisture content in the root zone and effectively reduce the number of irrigation cycles.
- Irrigation amount is based on ETcrop, previous 2-d CIMIS ETo (adjusted for precipitation), monthly warm-season turfgrass Kc, full run time multiplier (RTM) based on individual plot irrigation system distribution uniformity, low quarter (DULQ), and individual plot precipitation rate.
- The first year study concluded that soil moisture sensors are effective in conserving water than control while maintaining acceptable turfgrass quality**.**

Summary Text:

In an effort to increase water conservation in California, water application based on Soil moisture sensors (SMS) provide an excellent irrigation management tool; with the potential to conserve water and reduce daily water use. Reducing a minute or two of irrigation application per valve on a golf course could significantly save on water and energy cost. A superintendent's ability to control irrigation scheduling by assessing soil moisture accurately and quickly at the root zone, would help in water conservation and save thousands of dollars over a growing season (GCSAA Environmental Survey data, 2009).

Automated soil moisture sensor systems contribute significantly to maintaining adequate moisture in root zone by overriding irrigation scheduling or bypassing unnecessary irrigation cycles (Cardenas-Lailhacar, 2007). To maintain such moisture levels in fine texture soil, the accurate monitoring of moisture content is imperative along with the use of SMS. Additionally, healthy turfgrass is the result of a balance between soil not too wet or not too dry by applying the appropriate amount of irrigation. The goal of this study is 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.

Hybrid bermudagrass [*C. dactylon* (L.) Pers. × *C. transvaalensis* (Burtt-Davy)] GN-1 plots (each 10 ft. × 10 ft. [3m × 3m]) were sodded in 2002 and separated by 3 ft. (0.91 m) in all directions at Center for

Turf, Irrigation and Landscape Technology (CTILT), California State Polytechnic University, Pomona, CA. Soil moisture sensors from three different sources (Toro, Rain Bird and tucor) were installed and compared to a control treatment (no SMS). The control plots were irrigated based on the ET value collected from CIMIS station #78. Irrigation amount is based on ETcrop, previous 7-d CIMIS ETo (adjusted for precipitation), monthly warm-season turfgrass Kc, full run time multiplier (RTM) based on individual plot irrigation system distribution uniformity, low quarter (DULQ), and individual plot precipitation rate. Plots are individually scheduled once per week. Total weekly irrigation run time will be equally divided over five irrigation days per week.

Each plot is individually zoned and has a rotating nozzle sprinkler at each of the four corners. The experiment were laid in complete randomize design with three replication. Bermudagrass plots were maintained at the height of ½" and mowed twice a week. The clippings were collected to measure the dry weight, weekly. The plots were double cut in opposing directions using a Tru- Cut walk behind reel mower. 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. The plots were verticutted and Urea was applied @ 1 lb N/100ft2 in fall 2018.

Collection of data includes runtime for each plot and treatment average (by week, month, season), irrigation applied for each plot, amount of saved applied irrigation (actual amount and as a percentage of no SMS control treatment), visual turfgrass quality, density and color ratings, clipping yield and soil salinity (bulk electrical conductivity). The run time of soil moisture sensors were lesser than that of control plots and conserving water. The results will provide irrigation applied for all the treatments, along with water savings for the SMS treatments during three years of study. The SMS response comparisons will also be reported. The bermudagrass turfgrass quality ratings are acceptable for a fairway in Southern California. Results should show if SMS were effective to reduce water usage while maintaining acceptable fairway turfgrass quality.

References

Cardenas-Lailhacar, B. and M.D. Dukes. 2007. Turfgrass Irrigation Controlled by Soil Moisture Sensor Systems. Proceedings of the 28th Annual International Irrigation Show, San Diego, CA. December 9-11, 2007. Irrigation Association, Falls Church, VA, CD-ROM.

GCSAA. 2009. Golf Course Environmental Profile Vol. 2. Water use and conservation practices on U.S. golf courses. http://www.eifg.org/programs/ EIFG_GCEP_Summary_Vol_2.pdf.

Figure 1. Each plot is individually zoned and has a rotating nozzle sprinkler at each of the four corners.

Figure 2. The experiment was laid in complete randomize design with three replications. Bermudagrass plots were maintained at the height of 0.5 inches and mowed twice a week.

USGA ID#: 2017-37-647

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

Project Leaders: Chase Straw[1], Josh Friell[2], and Brian Horgan[1]
Affiliation: [1]University of Minnesota, [2]The Toro Company

Objectives:

1. Quantify response of turf and course conditions to changes in plant available water.
2. Quantify changes in water consumption between soil moisture sensor-based, evapotranspiration (ET)-based, and traditional irrigation scheduling.

Start Date: 2017
Project Duration: 4 years
Total Funding: $204,875

Summary Points:

- Three course surveys were completed with the PS6000 under varying soil moisture conditions to gain an understanding of soil moisture variability at the study site.
- Nine fairways were identified for use in the study (randomized complete block design; three treatments and three replications).
- Irrigation zones were delineated, and then soil moisture classes within each zone were calculated, on fairways receiving the soil moisture sensor-based treatment.
- In-ground soil moisture sensors were installed within each soil moisture class on the fairways receiving the soil moisture sensor-based treatment.
- One dry down was conducted on the fairways receiving the soil moisture sensor-based treatment.
- One catch can irrigation audit was conducted on fairways receiving the soil moisture sensor-based treatment.

Summary Text:

The purpose of this research is to demonstrate that adoption of currently available soil moisture sensor and mapping technologies can provide golf course superintendents with appropriate, actionable information that can result in significant water and cost savings relative to evapotranspiration-based and traditional irrigation scheduling methods. Additionally, since this is the first on-course application of soil moisture sensor and mapping technologies, we expect that the knowledge gained will assist in creating practical protocols for their use in implementing site-specific irrigation.

Progress to Date

The study is taking place at Brackett's Crossing Country Club in Lakeville, MN. Three course surveys were conducted between May and June 2018 using the Toro Precision Sense 6000 (PS6000) to simultaneously measure thousands of georeferenced soil moisture (i.e. % volumetric water content), penetration resistance (i.e. soil compaction), and normalized difference vegetation index (NDVI; i.e. turfgrass quality) data points. The surveys were representative of values following a rainfall, a ~five-day dry down after rainfall, and an irrigation event. The survey conducted ~five days after a rainfall was given the highest consideration in future decisions, since soil moisture at the time of this data collection was likely the best representation of field capacity [soil moisture at field capacity has a stable pattern of spatial variation that can be strongly correlated with other stable soil properties (e.g. particle-size; Carrow et al., 2010)]. Nine fairways (eight par 4's and one par 5) were selected for use in the study and placed into similar groups of three based on soil moisture descriptive statistics and spatial maps of variability (raster maps with 1 x 1 m pixels interpolated via ordinary kriging; all spatial methods and analyses to date were conducted in ArcMap). Each grouping of three fairways is considered a replication in the study (i.e. randomized complete block design with three replications; Figure 1). One of three irrigation treatments will be applied in 2019 and 2020 to fairways within each group:

1. Soil moisture sensor-based irrigation scheduling,
2. ET-based irrigation scheduling, or
3. Traditional irrigation scheduling.

The remainder of 2018 focused on creating irrigation management zones, installing in-ground soil moisture sensors, determining upper and lower soil moisture limits, and auditing the irrigation system within the three fairways that will receive soil moisture sensor-based irrigation treatments. A GPS on the PS6000 was used to georeference irrigation head locations within these fairways. Irrigation management zones were delineated around each irrigation head using Thiessen polygons. Soil moisture raster maps from the aforementioned course surveys were used to determine average soil moisture values within each irrigation management zone. Irrigation management zones were classified into one of three soil moisture classes ("low", "moderate", or "high" soil moisture) using Jenks natural breaks (Figure 2).

Toro TurfGuard in-ground soil moisture sensors were installed late August or early September 2018. One sensor was placed in each soil moisture class within each replication (Figure 3). Placement was made within the largest cluster of a classification, or where we believed to be most representative (taking into account location effects, such as slope and shade). During in-ground soil moisture sensor installation, highest consideration was given to the soil classification maps created ~five days following a rainfall, since it was likely the best representation of field capacity. Sensors were installed so that the top and bottom tines were at soil depths of 5 and 18 cm, respectively. Soil moisture is measured from the in-ground sensors every 5 minutes and can be monitored at any time using Toro SiteVision software.

Next, in order to initiate dry downs, the superintendent was asked to completely turn off irrigation within fairways receiving the soil moisture sensor-based treatment. The goal of dry downs are to determine upper and lower soil moisture limits for each in-ground sensor. Soil moisture values at each sensor corresponding to field capacity (defined in this study as the stable value following a saturating irrigation or precipitation event after excess water has drained) and permanent wilting point (defined in this study as the value at which wilt becomes apparent, NDVI values begin to decline significantly, or the superintendent feels that we have reached his comfort limit) will be used to calculate plant available water (field capacity minus permanent wilting point). Once treatments are initiated, plant available water will be used to determine a threshold that triggers irrigation within each soil moisture class. NDVI will be measured during dry downs with the PS6000 and a drone (using aerial imagery of RGB and NIR). Due to rainfall the weeks following in-ground soil moisture sensor installation, only one preliminary dry down was conducted in 2018 (September 5-14; Table 1).

Finally, one catch can irrigation audit was conducted on October 17, 2018 on fairways receiving the soil moisture sensor-based treatment. The purpose of the catch can audits are to quantitatively define the relationship between the programmed water application and the true depth of irrigation applied, as well as visualize irrigation distribution uniformity in comparison to soil moisture variability (Figure 4). This information will be used to identify the influence of run-time on soil moisture values within soil moisture classes after an irrigation event, in order to adjust the command of irrigation heads (as needed).

Future Expectations

We are currently in the process of conducting an in-depth overview and further analyses of data collected 2018. Once the ground has thawed in 2019, we will continue repeating dry downs until the research team (including the superintendent) is comfortable with the soil moisture values identified for field capacity, permanent wilting point, and plant available water. Additionally, once irrigation resumes, we will conduct one more catch can irrigation audit to account for any fluctuations in the irrigation system that may have occurred during the previous audit.

We will then apply the knowledge gained to compare soil moisture sensor-based, ET-based, and traditional irrigation scheduling methods for the remainder of the 2019 growing season, as well as all of the 2020 growing season. For the three fairways receiving the soil moisture sensor-based treatment, the valve-in-head sprinkler control will be used to schedule individual heads in each soil moisture class to run together (e.g. all heads that are located in the low soil moisture class will run together; all heads in the moderate soil moisture class will run together; etc.). Irrigation will only be allowed within a soil moisture class once the plant available water 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 moisture to 75% of total plant available water. For the three fairways receiving the ET-based scheduling treatment, we will take a deficit irrigation approach and apply 70% of reference ET every three days. Finally, for the three fairways receiving the traditional irrigation treatment, we will ask the superintendents to irrigate as they usually would, taking into account any information that would typically be used.

Once irrigation scheduling treatments are initiated, total depth of irrigation applied will be recorded for each treatment, where totals will be quantified and compared on an area basis. Soil moisture variability will be monitored periodically with the PS6000. Simple corrections to irrigation heads (clogged nozzle, head doesn’t rotate properly, etc.) will be made throughout the study on all fairways, as necessary. NDVI will be measured regularly by a drone (and to a lesser extend the PS6000) to evaluate turfgrass quality between treatments. 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 technology to properly place in-ground soil moisture sensors, golf courses can realize even greater savings.

Literature Cited

Carrow, R.N., J.M Krum, I. Flitcroft, and V. Cline. 2010. Precision turfgrass management: challenges and field applications for mapping turfgrass soil and stress. Precis. Agric. 11:115-134.

Table 1. Field capacity, permanent wilting point, and plant available water calculated during a preliminary dry down from September 5-14, 2018 on each fairway receiving the soil moisture sensor-based treatment.[a]

Fairway (rep)	Field capacity[b]	Permanent wilting point[c]	Plant available water[d]
	———% volumetric water content———		
8 (1)	57	35	22
15 (2)	52	22	30
17 (3)	50	34	16

[a] Values in the table are indicative of an entire fairway. Values will be determined for each in-ground soil moisture sensor (i.e. each soil moisture class) within all fairways once the irrigation system has been programmed to irrigate by soil moisture class and additional dry downs have been conducted (spring 2019).

[b] Field capacity is defined in this study as the stable value following a saturating irrigation or precipitation event after excess water has drained. Field capacity values in the table were determined by identifying the highest % volumetric water content value of the three in-ground soil moisture sensors in each fairway on September 5 (~24 hours after rainfall on September 4).

[c] Permanent wilting point is defined in this study as the value at which wilt becomes apparent, NDVI values begin to decline significantly, or the superintendent feels that we have reached his comfort limit. The superintendent had reached his comfort level on September 14, which triggered irrigation for this preliminary dry down. Values in the table were determined by identifying the lowest % volumetric water content value of the three in-ground soil moisture sensors in each fairway on September 14.

[d] Plant available water is field capacity minus permanent wilting point.

Figure 1. The nine fairways selected for use in the study. Fairways were placed into similar groups of three based on soil moisture (% volumetric water content; VWC) descriptive statistics and spatial maps of variability. Each grouping of three fairways is considered a replication in the study (i.e. randomized complete block design with three replications). Maps of soil moisture in the figure are from the June 6, 2018 survey, where data were collected ~five days after a rainfall event.

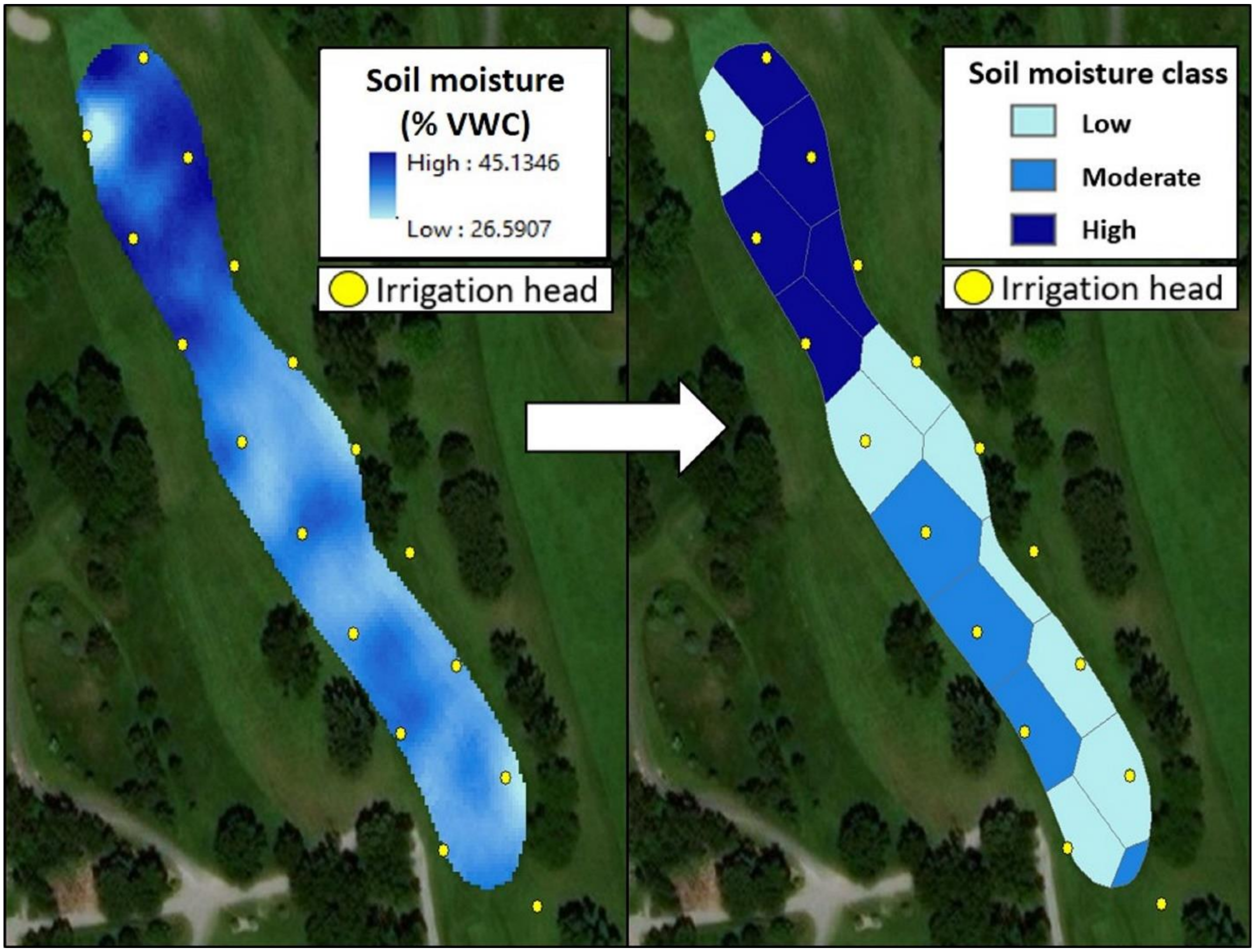


Figure 2. Soil moisture map [left; % volumetric water content (VWC)] and soil moisture classes within delineated management zones (right) on one fairway receiving the soil moisture sensor-based treatment.

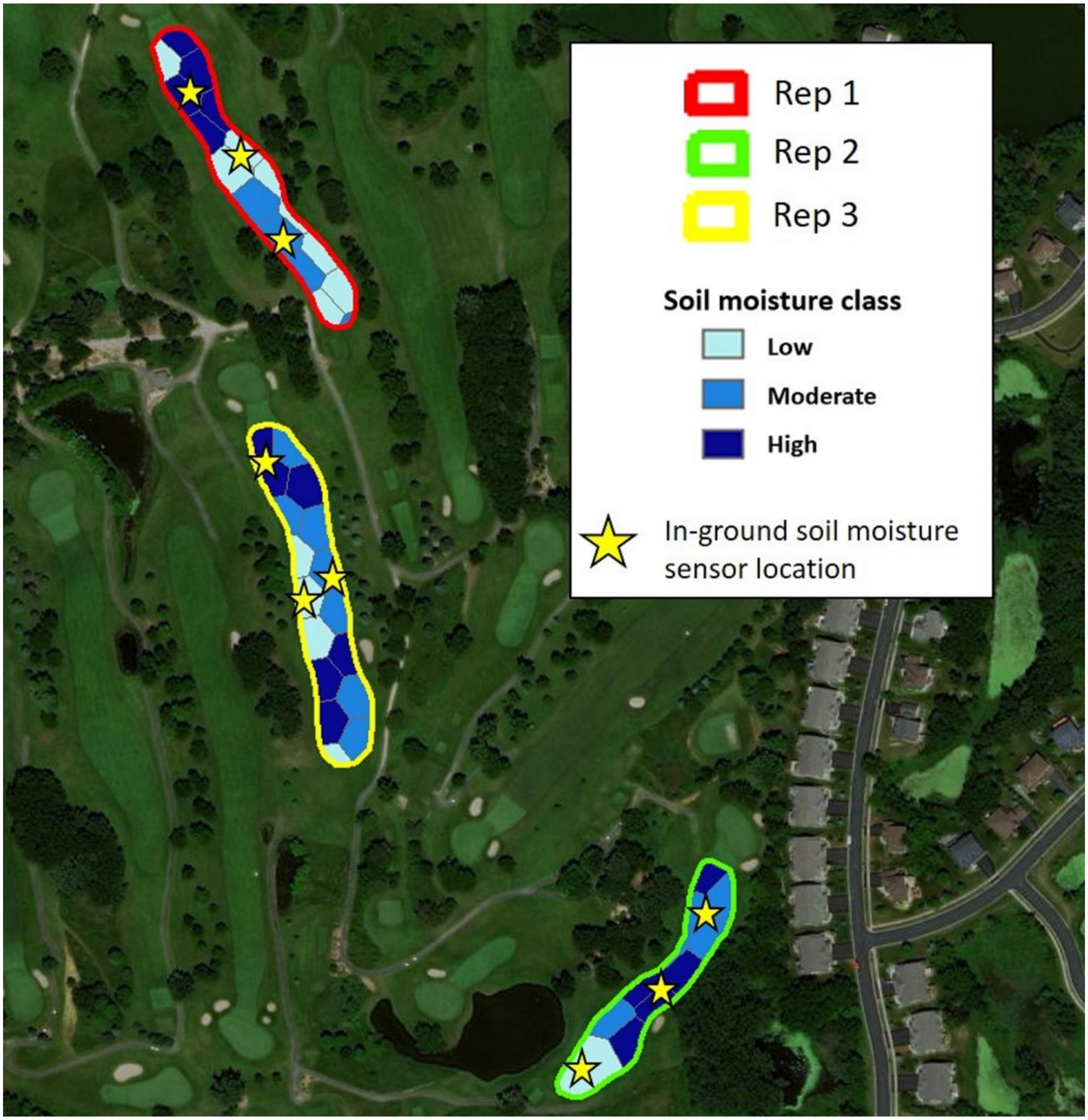


Figure 3. In-ground soil moisture sensor locations within each soil moisture class on the fairways receiving the soil moisture sensor-based treatment.

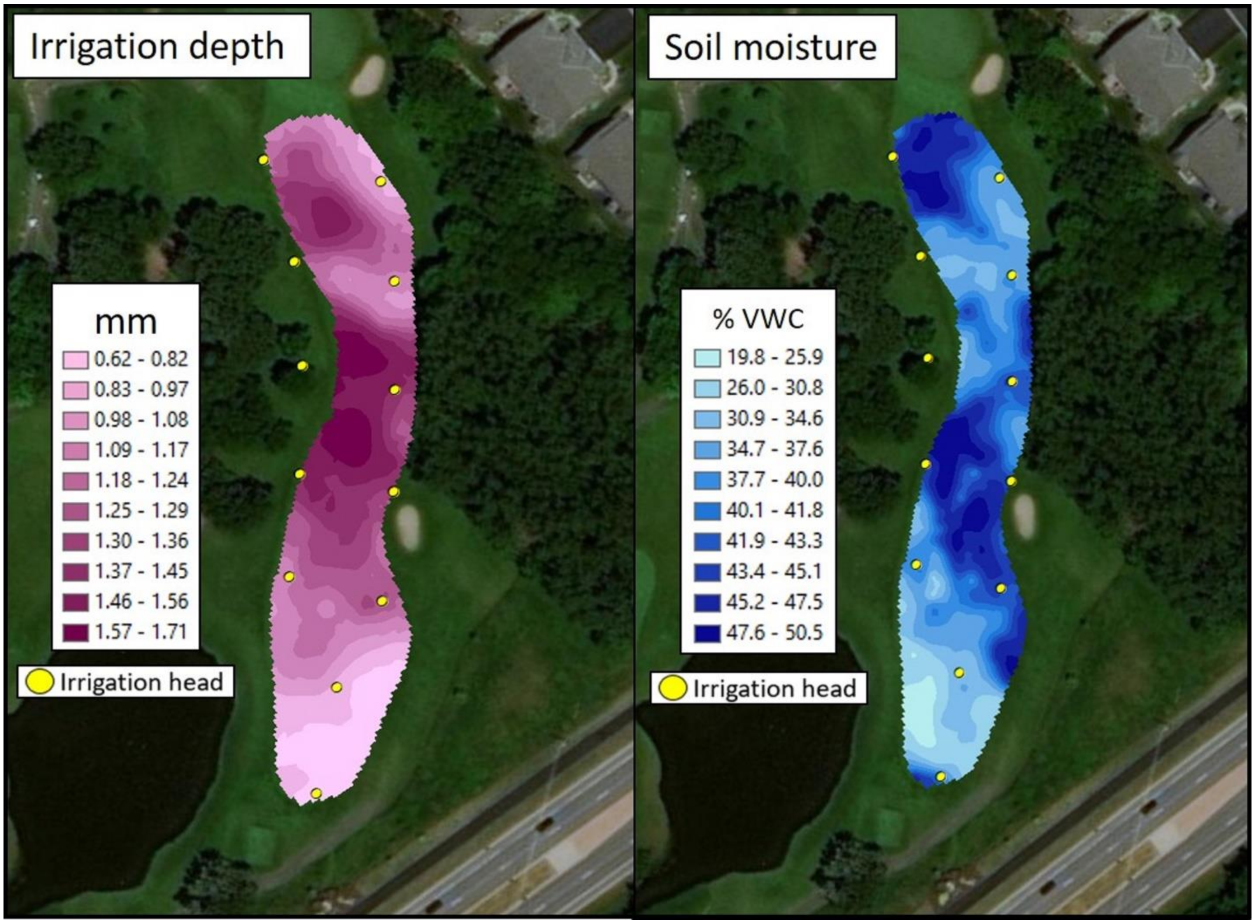


Figure 4. Applied irrigation depth (left; interpolated from catch can data on October 17, 2018) and soil moisture variability (right; interpolated from soil moisture data collected following irrigation on June 8, 2018) on one fairway receiving the soil moisture sensor-based treatment. Irrigation heads were programmed to make one full rotation during catch can audits (i.e. runtime of ~4 minutes per head).

USGA ID#: 2017-38-648

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

Project Leader: W. Dyer[1], D. Bremer[1], A. Patrignani[1], J. Friell[2], J. Fry[1], and J. Hoyle[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: 4 years
Total Funding: $129,733

Summary Points:

- Moisture release curves were generated in the laboratory from soils in each research plot.
- Determining proper thresholds for initiating irrigation in the field will be investigated.
- Combining real-time soil moisture information, evapotranspiration, and turfgrass canopy conditions we can test new irrigation scheduling techniques that reduce water use, while maintaining turfgrass quality.

Summary Text:

A critical challenge facing the turfgrass industry is the increasingly limited water for irrigation. Current irrigation strategies used by golf courses often rely on calendar schedules or deficit irrigation strategies that completely ignore soil moisture conditions. Integrating information from soil moisture sensors (SMS) to existing irrigation techniques has the potential to substantially improve the timing and amount of each irrigation event. By utilizing SMS to control irrigation, water savings have been as high as 70%, with greater savings in wet than dry climatic conditions (Chabon et al., 2017; Dukes, 2012). We propose to develop an innovative approach that integrates components of the soil-plant-atmosphere continuum to generate turfgrass irrigation decisions. We hypothesize that combining real-time soil moisture information, evapotranspiration (ET), and the turfgrass canopy condition will improve irrigation scheduling and reduce total water use relative to calendar schedules.

Methodology

Laboratory study

In this first phase of study, site-specific soil properties were analyzed in the laboratory by utilizing a HYPROP instrument (Meter Environment) which uses an innovative system of precision mini-tensiometers for automated measurements of soil moisture release curves. The WP4C instrumentation (Meter Environment) was also used in conjunction with the HYPROP to measure soil water potential within the ranges of -0.1 MPa to -300 MPa.

Field study

This research was conducted on sixteen 30 x 30 ft plots of ‘Meyer’ zoysiagrass (*Zoysia japonica*) at the Rocky Ford Turfgrass Research Center in Manhattan, KS. A new in-ground irrigation system was installed in early March 2018, which consisted of Toro sprinkler heads (T5PSS-RS) and a Turf Guard Base Station (Model TF-B). Zoysiagrass was sodded into the plots on 10 May, 2018. Initially, plots were mowed at their original height but after one month, the mowing height was gradually reduced to fairway height (0.5 inches). The plots were maintained well-watered until late July, when the zoysiagrass was established and all environmental measurement sensors had been installed. SMS were installed in each plot [Toro Turf Guard Sensors (TG-S2-R), which measured soil moisture at 2 and 5 inch depths, and Campbell Scientific CS655 at 4 inch depth]. Above-ground sensors were also installed for continuous measurements of canopy temperature (SI-111, Apogee Instruments) and NDVI (SRS, Meter Environment) on eight of the 16 plots. Dr. Josh Friell from Toro visited our site to assist with installation of the Turf Guard Sensors and to set up wireless communication between the sensors and the Base Station and related software.

Results to Date

Laboratory Study

HYPROP instrumentation measured water potential at saturation to -70 kPa, while the WP4C instrumentation measured the dry end of the curve. By combining both instruments, a full range moisture release curve was generated (Fig. 1). Curve-fitting water retention models (e.g. van Genuchten, 1980) can be used. Figure 1 depicts that as VWC decreases, binding of the water becomes stronger (water potential becomes more negative) due to smaller pore spaces tightly holding water through adhesion. It becomes exponentially more difficult for plants to extract water for transpiration as the soils dry. Results from the soil moisture release curve indicated a range in VWC from 39.5% at saturation to 11.3% at permanent wilting point (-1500, kPa) (Figs. 1 and 2). Measuring the upper and lower limits is essential to estimate the available water in a soil. By identifying the fraction of plant available water at which turfgrass shows signs of water stress within the upper and lower limit, one can then know precisely when to irrigate.

Field Study

Field measurements of soil water content are critical in irrigation system design, management, and scheduling. On August 6, a dry down was commenced to evaluate relationships between soil moisture and signs of drought stress in the canopy. However, above average precipitation (about 2x normal) during August and September confounded the dry down attempts (Fig. 2). Specifically, 8.09 inches was received in August and 7.64 in September, which was 3.97 and 4.21 inches above the 30-yr average. Precipitation in October was also 0.91 inches above average and by then the zoysiagrass was going into dormancy, particularly after the first frost on October 14.

During the months of September and October 2018, a steady decline in air temperature was observed, which was normal for that time of the year (i.e., late summer/early fall). As the air, canopy and soil temperatures decreased, the turf quality also declined due to dormancy (Fig. 3). During the summer months we would expect a rise in surface canopy temperature as soil moisture and NDVI decrease. Monitoring these variables will be especially important when various irrigation regimes are applied to research treatments during the 2019-2020 growing season.

Future research and expectations

Because above average precipitation during the fall of 2018 interfered with determining relationships in the field between soil moisture and canopy characteristics, cores of zoysiagrass will be taken from the field plot area and dry down experiments will be conducted in the greenhouse in the winter/early spring of 2019. These measurements will determine our initial irrigation thresholds in the field experiments during 2019. In those field studies, various irrigation treatments will be applied to plots including a traditional frequency-based irrigation, a deficit irrigation based on reference ET (ETo), irrigation based on SMS information, and a control treatment of zero irrigation (i.e., precipitation only). Our first step will be to refine our greenhouse-derived estimates of plant available water thresholds for initiating irrigation to field- based observations of turfgrass visual quality and the onset of drought-stress symptoms in the field. Using recorded VWC, turfgrass quality ratings, NDVI, field capacity (FC) and permanent wilt point (PWP), irrigation thresholds will be determined for each plot.

References

Chabon, J., D.J. Bremer, J.D. Fry, and C. Lavis. 2017. Effects of soil moisture-based irrigation controllers, mowing height, and trinexapac-ethyl on tall fescue irrigation amounts and mowing requirements. Int. Turf. Soc. Res. J.13:1-6. doi:10.2134/itsrj2016.04.0242

Dukes, M.D. 2012. Water conservation potential of landscape irrigation smart controllers. Trans. ASABE 55:563–569. doi:10.13031/2013.41391

M. T. Van Genuchten. 1980, SSSA Journal 44: 892-898.

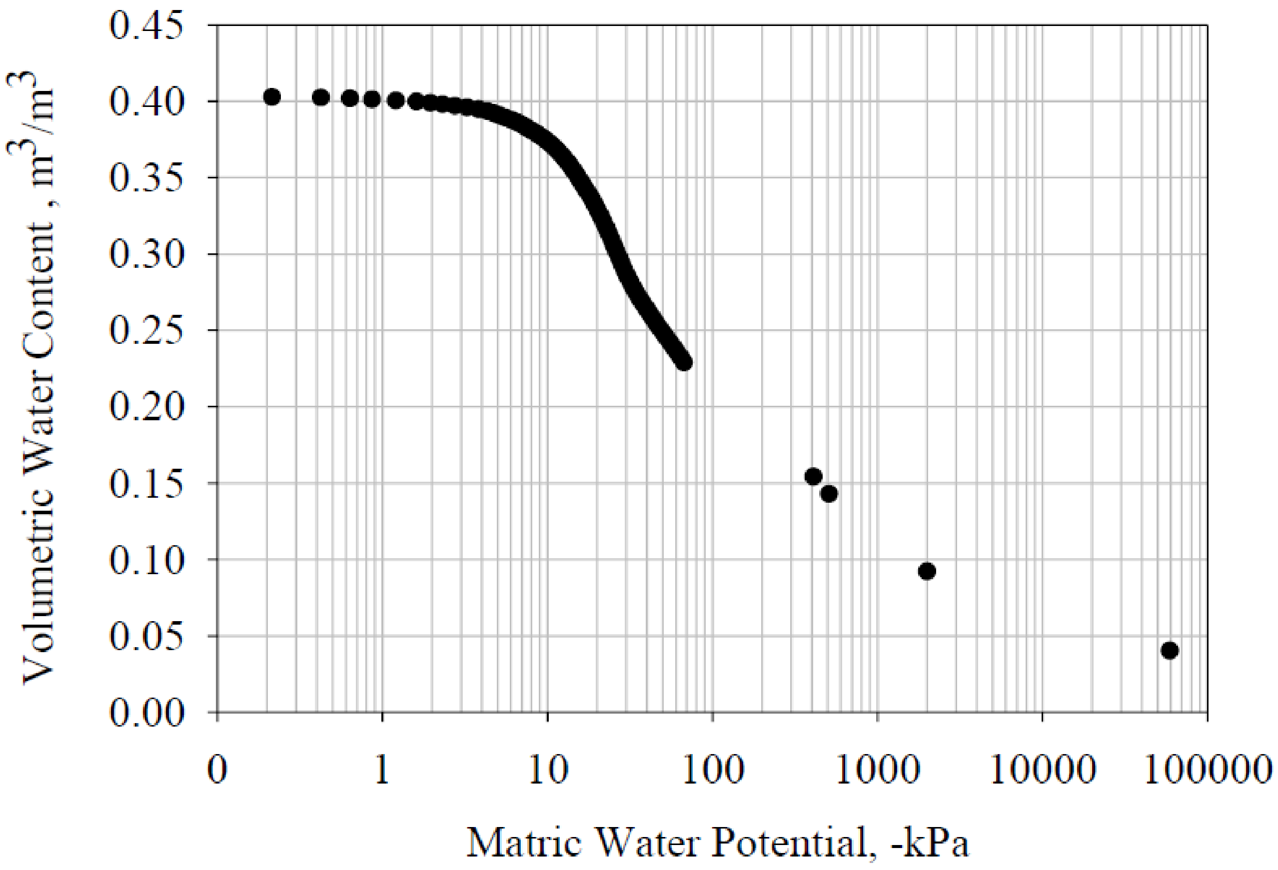


Figure 1. Moisture release curve depicting the relationship between matric water potential and volumetric water content (VWC) in the turfgrass rootzone.

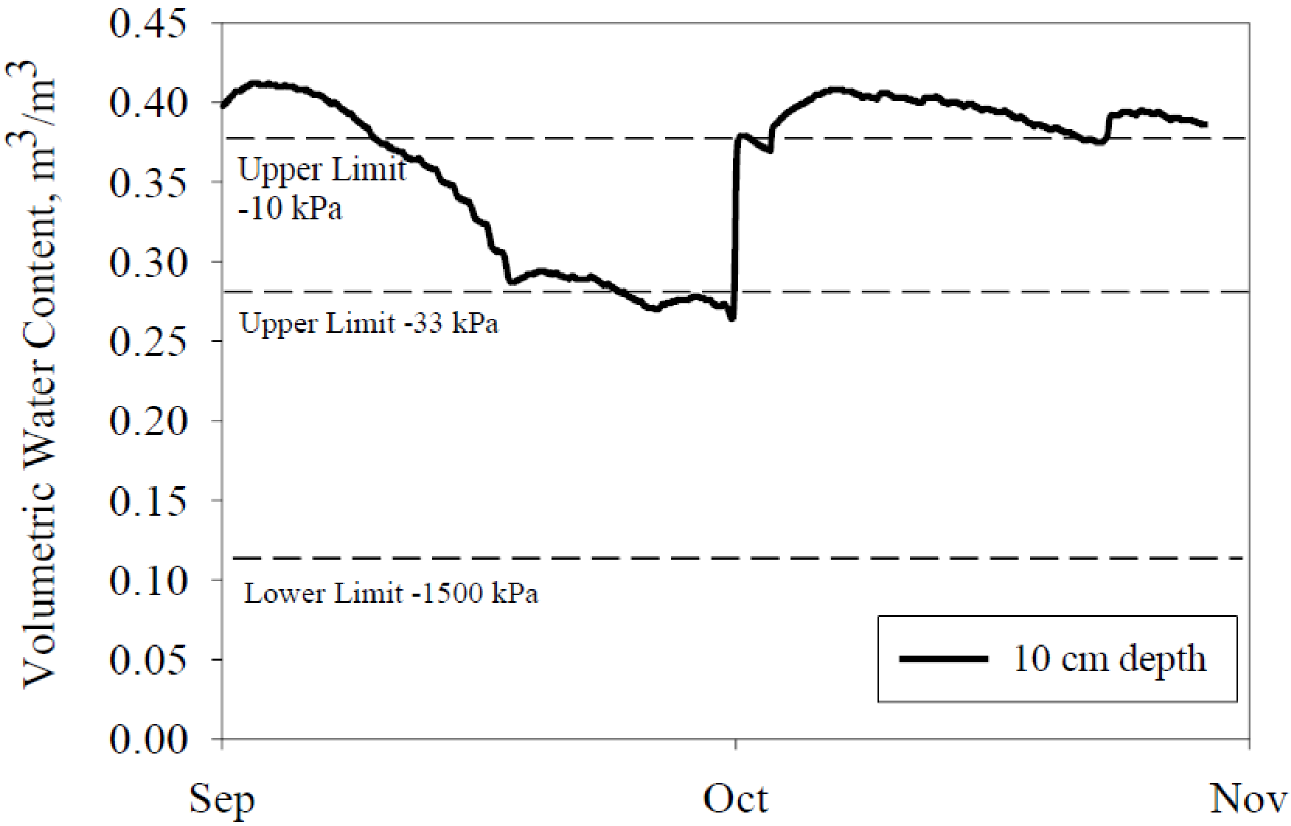


Figure 2. VWC at a 10 cm depth during the months of September and October 2018 showing upper and lower limits of available water.

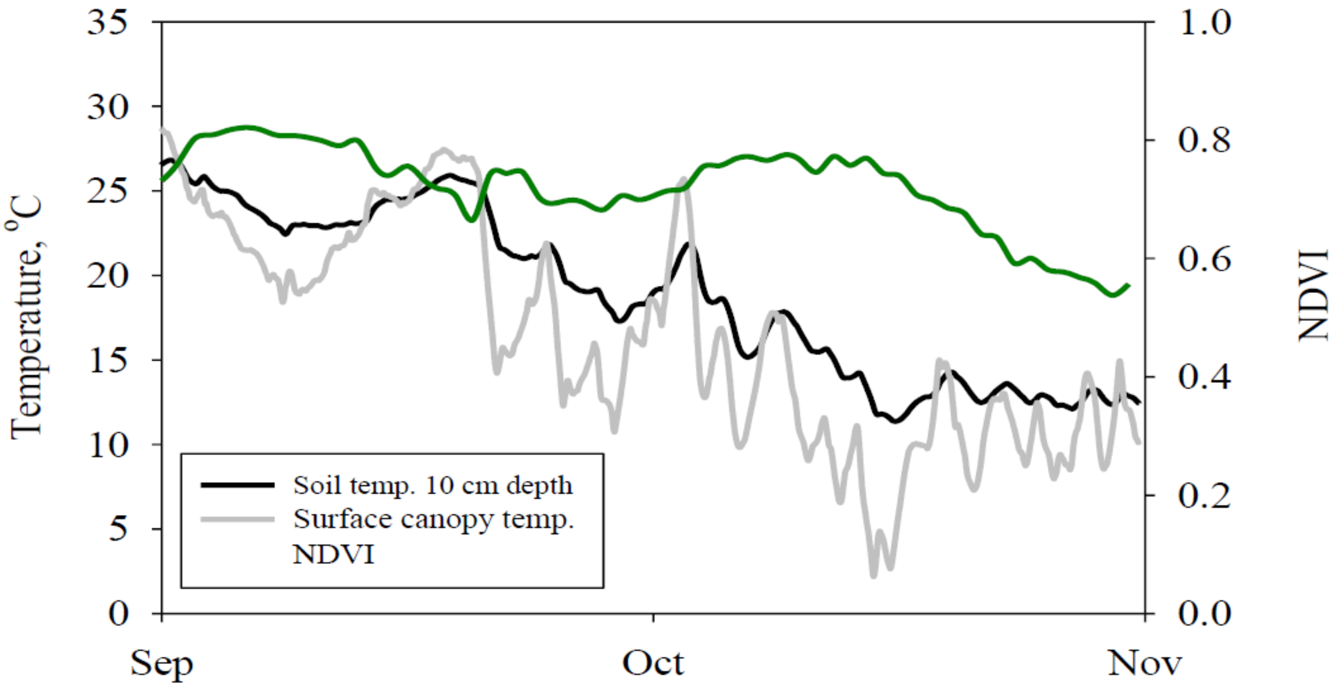


Figure 3. Comparison of soil temperature at a 10 cm depth and surface temperature of the turf canopy to NDVI measurements throughout the September and October months.

Figure 4. Initial site setup.

USGA ID#: 2018-05-655

Project Title: Data-Driven Irrigation Scheduling Techniques for Managing Sand-Capped Fairways

Project Leaders: Benjamin Wherley, Kevin McInnes, and Reagan Hejl
Affiliation: Texas A&M University, College Station, TX

Objectives: Evaluate feasibility and determine best management practices for irrigation of sand-capped fairways when irrigating based of various data-driven scheduling techniques.

Start Date: 2018
Project Duration: 3 years
Total Funding: $97,000

Summary Points:

- A 10,000 sq. ft. replicated sand-capping irrigation research facility has been constructed at Texas A&M University, College Station, TX.
- In August 2018, Latitude 36 bermudagrass was sprig-established onto a 5” sand-cap across the facility. Full coverage was achieved by mid-October.
- Various approaches to irrigation will be implemented in May 2019 and evaluated over two seasons, including wireless soil moisture sensor-based, reference ETo-based, NOAA FRET-based, and visual wilt-based irrigation.

Summary Text:
As golf course irrigation water quality continues to decline, sand-capping of golf course fairways is increasing. A 3-year USGA-funded Texas A&M study evaluated sand-capping depth by subsoil texture effects on Tifway bermudagrass fairway quality/performance. Results demonstrated that sand-capped fairways were surprisingly robust, with no significant quality or performance differences noted between 1 vs. 2 day-per-week irrigation regimes, when irrigated to 60% x reference ET levels. Although the upper root zone experienced rapid drying following irrigation, a saturated zone near the sand/subsoil interface combined with strong subsoil root development contributed to sand-capped turf tolerance to infrequent irrigation. A high degree of soil texture and moisture uniformity was also observed across sand-capped plots of uniform depth, suggesting that in-ground soil moisture sensors (SMS) could be a tool offering potential for irrigation scheduling and salinity management of these systems. SMS are currently underutilized across the industry, and primarily used only on putting greens. Given the substantial acreage and irrigation used on golf course fairways, SMS may provide superintendents a tool for more efficiently managing irrigation water in sand-capped systems. The recent open access availability of NOAA Forecasted Reference ET (FRET) data also now provides superintendents another tool for irrigation scheduling, yet it is unclear how accurately these predicted values approximate actual Penman-Monteith ETo.

In the summer of 2018, a 5” sand-cap was placed atop a fine sandy loam subsoil on two 5,000 ft^2 blocks at the Texas A&M Turfgrass Field Laboratory in College Station, Texas. The sand-cap, constructed from a medium coarse construction sand, was graded to attain a 1.5% turtle back slope running side to side across each block. A particle size analysis and water release curve for the sand is provided in Figures 1 and 2. After grading was complete (Figure 3), Latitude 36 bermudagrass was sprig-established in August 2018. Full irrigation levels and 13-13-13 was applied at a rate of 0.5 lbs N/1000ft^2 applied every 1-2 weeks during the grow-in period. Complete (100%) cover was attained in all treatment plots by mid-October. Turf blocks are currently being maintained at 0.5” height of cut with reel mower (Figure 4).

Each block contains eight 400 ft^2 subplot irrigation zones (16 zones total) for accommodating replicated irrigation treatments, which will be imposed May 2019. Irrigation treatments will be based off scheduling techniques including: 1) Wireless SMS (Toro TurfGuard Sensors), 2) Penman-Monteith Reference ET_o, 3) NOAA FRET, and 4) Visual wilt-based. The wireless SMS are currently being installed and will be monitored from a base station in close proximity to the field plots. Reference ET_o data will be gathered from an onsite weather station that is made publicly available from the Texas ET Network (texaset.tamu.edu). Forecasted Reference ET data will be attained from the NOAA website. Prior to treatment initiation, preliminary tests will be performed in order to determine appropriate thresholds for the wireless SMS and visual wilt-based plots. Once treatments are initiated data will include: visual quality, digital image analysis, NDVI, and root development characterization. Soil moisture status will be monitored along with the total quantities of water applied throughout the season for the respective treatments.

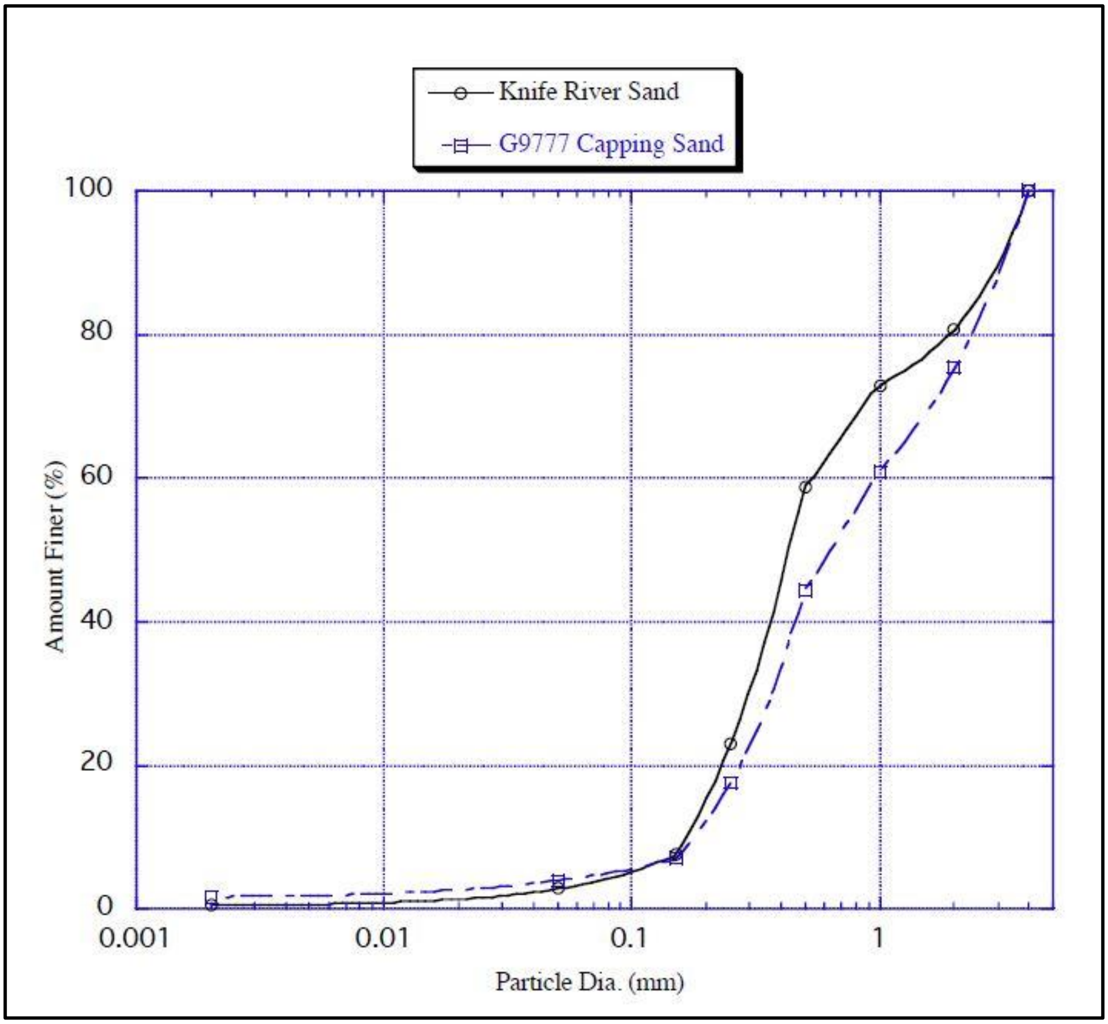


Figure 1. Particle size distribution as a function of particle diameter for the capping sand being used in the current project (‘Knife River Sand’) as well as another capping sand used at the facility (‘G9777 Capping Sand’).

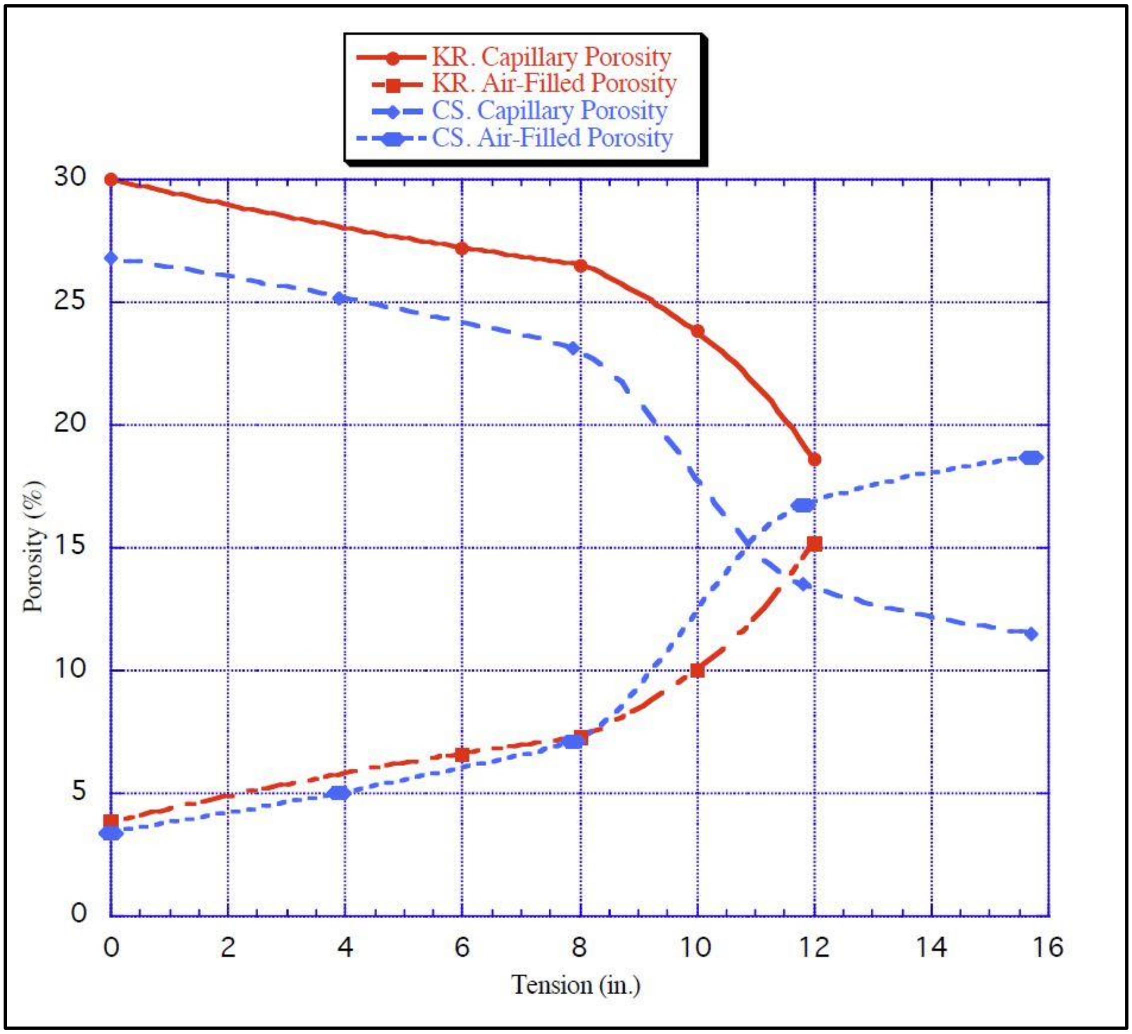


Figure 2. Pore space distribution as a function of tension for the sand being used in the current project (‘KR’) as well as another sand being used at the facility (‘CS’).

Figure 3. Image of the sand-cap final grade prior to sprig establishment in early August 2018.

Figure 4. Image of the full establishment of the Latitude 36 sprigs in mid-October 2018.

USGA ID#: 2018-06-656

Title: Enhancing Site-Specific Turf Irrigation Management and Developing Turf Deficit Irrigation Strategies Using Soil Moisture Sensors, Smart ET-Based Irrigation Controllers, and Remote Sensing

Project Leader: Dr. Amir Haghverdi
Affiliation: Department of Environmental Sciences, University of California Riverside

Objectives:
The overarching goal of this project is to develop recommendations for water conservation and turf irrigation best management practices in inland Southern California.

Start Date: 2018
Project Duration: 2 years
Total Funding: $49,491

Summary Points:

- Two warm season and cool season turfgrass species including tall fescue (Festuca arundinacea), and bermudagrass (Cynodon dactylon) were studied from May 1 to September 24 at UCR Agricultural Experiment Station in inland Southern California.
- Only 2% difference was observed on average between autonomous irrigation applicators by Weathermatic smart irrigation controller and optimum irrigation applications calculated based on ETref data collected from a nearby CIMIS weather station.
- The preliminary results suggest 10% water saving potential for both species compared to currently considered full irrigation applications (i.e. 80% and 60% for cool season and warm season turf).

Summary Text:

Implementation of smart irrigation technologies offer to improve water use efficiency by maintaining the soil water status at the active root zone within a predefined desired range. Advancements in smart irrigation technologies have led to affordable smart irrigation controllers. Much of the scientific research in recent years on the application of landscape irrigation technologies, including the use of smart controllers, has been done in humid regions (mainly in Florida and North Carolina) wherein the main focus has been to avoid over-irrigation when rainfall is abundant. Currently, information is lacking about the application of smart irrigation technologies leading to turf water conservation and deficit irrigation strategies in arid regions such as inland Southern California.

Methodology:

A total of 72 irrigation research plots were established at the University of California, Riverside Agricultural Experiment Station in Riverside, California. The plots were planted to sod tall fescue (Festuca arundinacea), and bermudagrass (Cynodon dactylon) in 2017 and for several months afterwards were under full irrigation for root development and grass establishment. We followed standard cultural practices to maintain the plots (i.e., control weeds, pests, fertilizers, mowing) throughout the experiment. For each species, 36 plots were organized in a factorial complete randomized block design to impose 12 irrigation treatments replicated 3 times. The 12 irrigation treatments consisted of 6 irrigation levels ranging from full to multiple deficit irrigation scenarios and

2 irrigation frequencies (i.e. watering 7 days a week versus watering 3 days a week). The irrigation treatments for both species are listed in Table 1. Each plot was irrigated by 4 quarter- circle (pop-up heads) sprinklers, all four controlled by a common solenoid valve for independent control of each plot. A Weathermatic Smartline SL 4800 smart irrigation controller was installed and used to autonomously impose all irrigation treatments. The smart controller was connected to a SLW5 wireless Weathermatic weather sensor and a SLFSI-T20 Weathermatic flow sensor to continuously monitor weather conditions and irrigation applications to the plots. To eliminate plot edge effect and avoid interference between adjacent plots, adequate borders (2-3 feet) were considered and measurements were taken at the center of each plot. The uniformity, and application rate of the system was determined by a catch can test following the standard protocol (ANSI/ASABE S626). Plots were irrigated between midnight and early morning to minimize evaporative losses and wind drift. In addition, total daily irrigation run time was divided into several irrigation applications to avoid runoff. We used California DWR's procedure (equation 1) outlined in model water efficient landscape ordinance to calculate irrigation water requirement.

$$IWR = \frac{PF \times ET_{ref}}{IE} \tag{1}$$

where *IWR* is the irrigation water requirement, *PF is* plant factor, ET_{ref} is reference evapotranspiration and *IE* is the irrigation efficiency. We programmed irrigation treatments outlined in Table 1 as PF in the smart controller at the beginning of the experiment. We also programmed the controller to apply extra water across treatments to take the IE of the system into account. The low half distribution uniformity of our system (= 0.81) was considered as IE. The controller calculated the ETref using temperature data collected by its weather sensor.

The performance and reliability of the ET-based smart irrigation controller for efficient autonomous turf irrigation management was evaluated against independent reliable daily ETref data collected from a nearby CIMIS (California Irrigation Management Information System) weather station. In addition, response of turfgrass to the deficit irrigation treatments and potential drought injury was carefully monitored across research plots every week (a total of 19 times) throughout the experimental period (May 1, 2018 – September 24) based on NDVI data collected using GreenSeeker handheld crop sensor. The time series of NDVI data collected were statistically analyzed via SAS software as repeated measures design to determine the impact of irrigation treatments on turf quality and health over time.

Results to date:

Figures 2 and 3 summarize the results of the study in 2018. Figure 2 depicts the cumulative irrigation applications by the Weathermatic smart controller for both species and the 12 irrigation treatments (i.e. 6 irrigation levels and 2 watering days). We also calculated the optimum irrigation application based on CIMIS station ETref data. The preliminary analysis of the data revealed promising performance for the Weathermatic smart controller for autonomous deficit irrigation management of both tall fescue and bermudagrass turf species in inland Southern California. On average across the 12 treatments, only 2% difference was observed between irrigation applied automatically by the Weathermatic controller and optimum irrigation application calculated based on CIMIS ETref data.

Figure 3 depicts the response of both species to irrigation treatments (in terms of NDVI values) over the course of the 5-month experimental period (May 1, 2018 – September 24). For bermudagrass, irrigation quantity had a statistically significant impact but effect of the irrigation frequency was not significant ($p < 0.05$). The interaction between irrigation level and irrigation frequency was not significant. The differences between the treatments were not significant between 60%, 55%, and 50 % irrigation levels suggesting that irrigation level can be reduced to 50% ETref during high ET months inland Southern California where water conservation is desired without having a significant impact on turf quality. For tall fescue plots, both irrigation quantity and frequency had significant impacts on turf quality ($p < 0.05$). It appears from the NDVI data that irrigating every day resulted in higher turf quality (NDVI values) for the tall fescue plots for most of the irrigation levels compared to irrigating only 3 days a week. The interaction of irrigation quantity and frequency had no significant effect ($p < 0.05$). The differences between 80%, 75% and 70% irrigation treatments were not statistically significant ($p < 0.05$). Further reduction in irrigation levels caused significant reduction in NDVI values. This findings, suggest a 10% water conservation potential for tall fescue below the accepted 80% full irrigation level.

Future expectations of the project:

We will continue this project in 2019 and closely monitor response of both species to different deficit irrigation strategies. We will focus on drone-based multispectral imagery to evaluate the drought injury due to deficit irrigation during high water requirement months. In addition, we will post process the soil moisture data collected using the 72 buried soil moisture sensors underneath 24 research plots. We will develop information on irrigation triggering levels using soil moisture sensors (based on soil potential and soil volumetric water content information). Finally, we will statistically analyze the data collected in both years and develop deficit irrigation management recommendation for both species to conserve water while maintaining the desired turf quality.

Figure 1. The research plots under tall fescue and bermudagrass turf species (left) and the Weathermatic weather-based smart irrigation controller used to impose irrigation treatments (right).

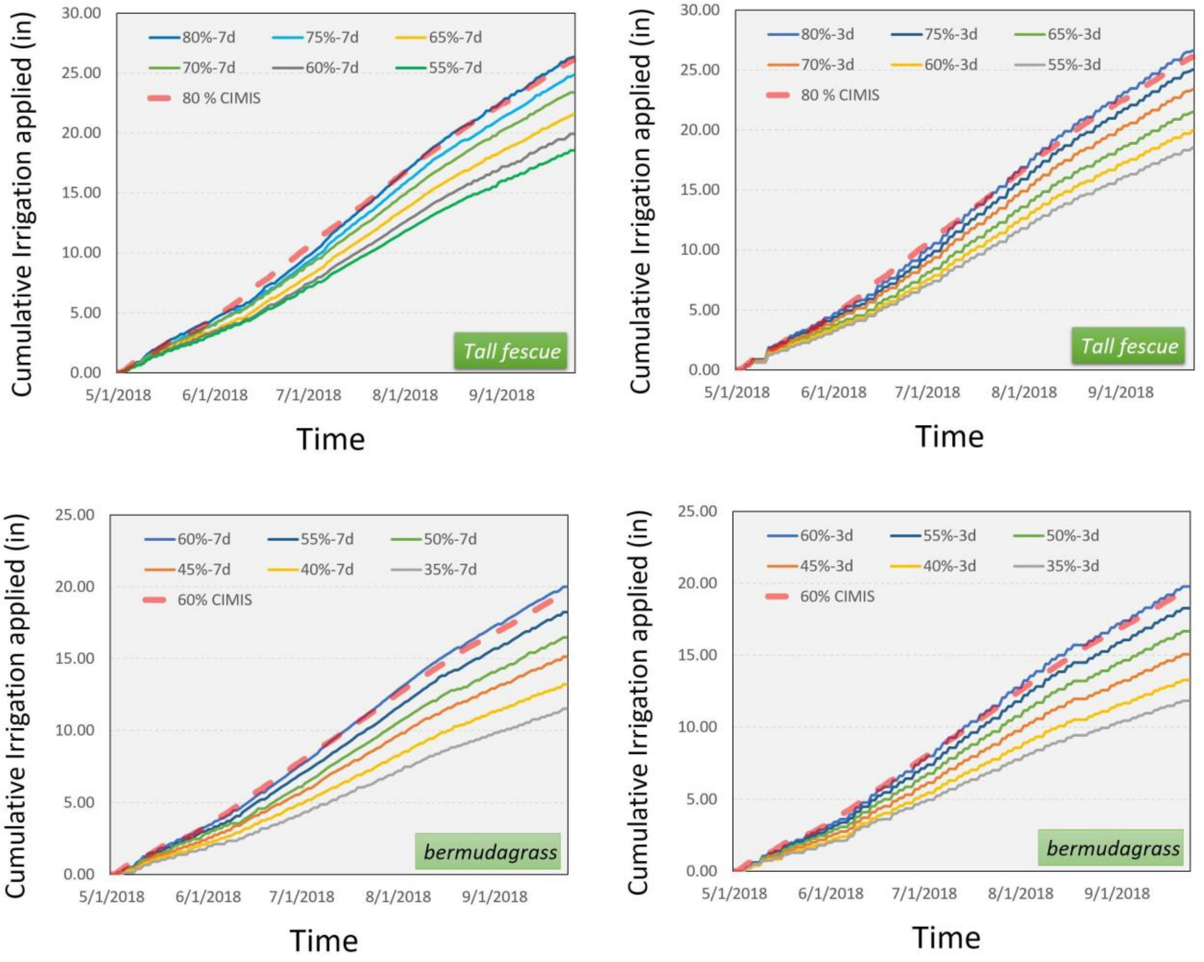


Figure 2. Performance of Weathermatic smart irrigation controller for autonomous full/deficit irrigation scheduling of tall fescue and bermudagrass turfgrass species. Solid lines represent cumulative irrigation applications by the smart controller for all treatments. The optimum irrigation application based on CIMIS ETref data (dashed lines) is only shown for the highest irrigation treatment for comparison.

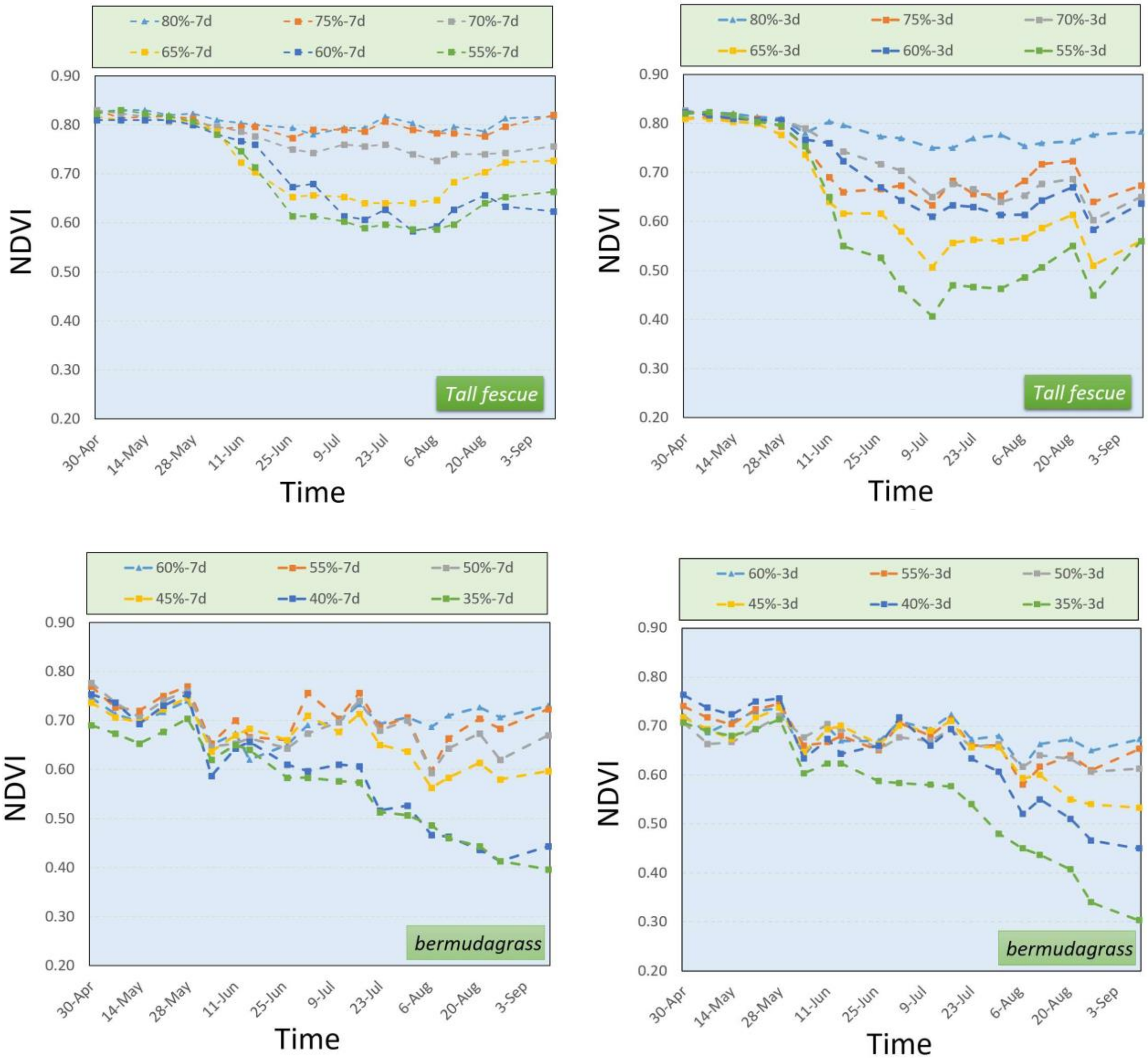


Figure 3. Response of tall fescue and bermudagrass turfgrass species to 6 irrigation levels and 2 irrigation frequencies (watering days).

Table 1. Irrigation treatments.

Species: Tall fescue	
Irrigation	55 % ETref, 60% ETref, 65% ETref, 70% ETref, 75% ETref, 80% ETref
Frequency	3 days per week, 7 days per week
Species: Bermudagrass	
Irrigation	35 % ETref, 40% ETref, 45% ETref, 50% ETref, 55% ETref, 60% ETref
Frequency	3 days per week, 7 days per week

USGA ID#: 2016-21-571

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

Project Leaders: James A. Murphy, James Hempfling, Bruce B. Clarke
Affiliation: Department of Plant Biology, Rutgers University

Objectives:

1. Evaluate dollar spot incidence and disease progress on six bentgrasses that vary in tolerance to dollar spot disease.
2. Assess the reliability of two weather-based models for predicting dollar spot epidemics on those cultivars and species.
3. Evaluate the effect of initial fungicide application timing on dollar spot incidence and disease progress on two bentgrass cultivars with low or high susceptibility to dollar spot.
4. Determine the extent that the initial fungicide application timing 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.

Start Date: 2016
Project Duration: 3 years
Total Funding: $90,000

Summary Points:

- Interpretation of the logistic model relative to disease progress is ongoing. However, there are preliminary observations to report:
    - Dollar spot forecasting with a logistic regression model had good accuracy during the middle of the growing for highly susceptible cultivars during 2015, 2016, and 2017.
    - Disease forecasting on low susceptibility cultivars may also be possible using the logistic regression model; however, a greater risk index and/or an assessment of the change of the risk index over time (slope) may be needed to improve model accuracy.
    - Disease recovery was observed during periods of decreasing risk index, albeit greater than 20%, further suggesting that a change in risk index over time (slope) may be a predictor of disease progress.
- Threshold-based applications reduced total fungicide inputs and the level of disease control, which ranged from moderate to excellent depending on the cultivar. Total fungicide input also varied with cultivar and, to a lesser extent, the initial fungicide timing factor.
    - Threshold-based fungicide applications on Declaration (low susceptibility) creeping bentgrass produced excellent disease control and required only one to five fungicide applications depending on the year and initial fungicide timing.
    - In contrast, threshold-based fungicide applications on Independence (highly susceptible) creeping bentgrass produced moderate disease control and required four to nine applications depending on the year and initial fungicide timing.

Summary Text:

Outbreaks of dollar spot (caused by *Clarireedia jacksonii* C. Salgado, L.A. Beirn, B.B. Clarke, & J.A. Crouch sp. nov.) occur on all cool-season turfgrass species worldwide and are especially problematic on golf course fairways. Management of dollar spot on fairways often involves sequential calendar-based applications of fungicides from early-spring to late-fall. Advancements in bentgrass cultivars with improved resistance to dollar spot, as well as the establishment of weather-based models to predict this disease provide opportunities to enhance the efficiency in managing this disease on golf courses. The extent to which host susceptibility affects fungicide inputs or the performance of disease predictive models in not well understood.

This research project is organized into two field trials. The first trial addressed objectives one and two listed above. A growing degree day (GDD) model (Ryan et al., 2012) for predicting the onset of disease symptoms and a logistic regression model (Smith et al., 2018) for predicting season-long disease activity were evaluated on six bentgrass cultivars ranging from high to low susceptibility to dollar spot (Figure 1). Five trial-runs (5 blocks each) were used to quantify dollar spot epidemics through each growing season (April to November; Figure 2). The use of multiple trial-runs enabled monitoring of disease progress through the entire season.

Generally, the cultivar response to disease summarized as the area under the disease progress curve (AUDPC) of infection center counts was: 'Independence' ≥ 'Penncross' ≥ 'Shark' > '007' > 'Declaration' and 'Capri' (Table 1). Cultivars also differed in the AUDPC of infection center diameter, but the response was slightly different than the response to infection center count. The cultivar ranking from greatest to smallest diameters was Penncross > Independence > Shark > 007 > Capri ≈ Declaration.

The onset of disease symptoms was delayed by 4 to 27 days in low susceptibility cultivars. However, neither the GDD model or 20% risk index for the logistic regression model reliably predicted disease onset for any of the cultivars. Further assessments of logistic regression model interpretations are being attempted, which may improve the ability to predict disease onset in spring. Forecasting disease with the logistic regression model during the middle of the growing seasons was reasonably accurate on highly susceptible cultivars (Figure 3). Forecasting disease progress on less susceptible cultivars also appeared possible with the logistic regression model; however, a greater risk index and/or taking into account the change of the risk index over time (slope) is likely necessary to improve prediction accuracy. Recovery from disease was often observed when the risk index declined, albeit greater than the 20% risk index currently recommended for triggering a fungicide application. Further analysis of the logistic model and disease progress data are ongoing.

The second trial addressed objectives three and four. Treatments in trial two were arranged as 2 x 8 x 2 factorial of bentgrass disease tolerance, and initial and subsequent fungicide timings. Declaration (low-susceptibility) and Independence (high-susceptibility) were treated with all possible combinations of eight initial fungicide timings (threshold-based [at the first appearance of disease symptoms]; calendar-based [May 20]; logistic regression model-based [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) and two subsequent fungicide timings (logistic regression model or disease threshold [>1 standard-size infection center per plot]).

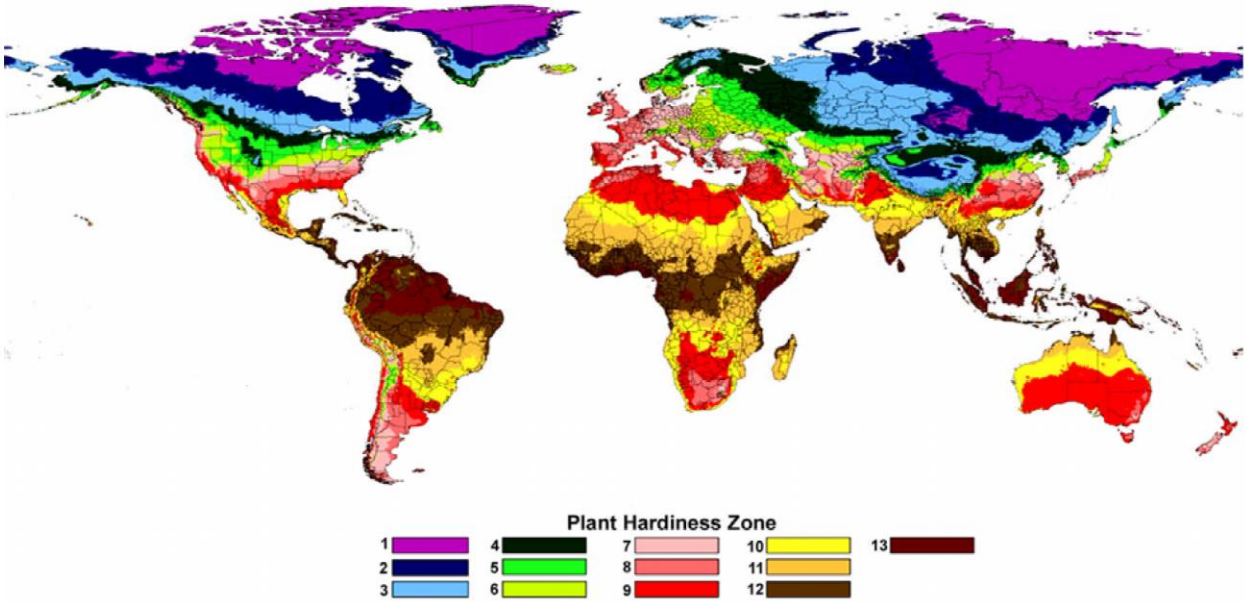
The cultivar and subsequent fungicide timing factors explained 59% or more of the variance in season-long AUDPC during the three years of the study (Table 2). Moreover, the interaction of cultivar and subsequent fungicide timing accounted for an additional 10 and 24% of the variation during 2015 and 2016, respectively. Excellent disease control was achieved on the low-susceptibility cultivar (Declaration) with little or no difference between model- and threshold-based subsequent fungicide timings; whereas, only the model-based subsequent fungicide applications were consistently effective at controlling disease on the high-susceptibility cultivar (Independence) (Table 3). Threshold-based fungicide applications on the high-susceptibility cultivar had a greater number of days with unacceptable disease control than the threshold-based program on the low-susceptibility cultivar.

One to five threshold-based applications were made to the low-susceptibility cultivar depending on the year and initial timing of fungicide application; whereas, four to nine threshold-based applications were made to the high-susceptibility cultivar (Table 4). The model-based timing resulted in six to nine applications for the low-susceptibility cultivar and seven to ten sprays per year for the highly susceptible cultivars depending on the year and initial timing for fungicide application. Nine applications were made per year for the calendar-based program.

Initial fungicide timing had no effect on season-long AUDPC during any trial year (Table 2). Differences in disease control during disease onset were small and short-lived among initial timings. Threshold- or calendar-based initial timings provided adequate disease control with one to three fewer annual applications of fungicides compared to earlier initial timings (data not shown). Initial fungicide timings made between 2- and 24-d before disease onset produced better disease control during the first outbreak compared to timings that were made more than 24-d before, less than 2-d before, or after disease onset.

This research demonstrates that fungicide inputs are needed for bentgrass cultivars, but the total number of applications varies with susceptibility to dollar spot. Additionally, the weather-based logistic regression model also reduced fungicide inputs but to a lesser extent than cultivar-susceptibility factor. This study only evaluated the extremes in cultivar susceptibility; assessment of cultivars with intermediate susceptibility is needed to provide golf course superintendents with the most effective and economical recommendations for control options. Results from this trial indicate that threshold-based applications on a low-susceptibility cultivar can produce excellent disease control and a large savings in fungicide inputs. Alternatively, logistic model-based or calendar-based applications were required for good disease control on a high-susceptibility cultivar, with model-based applications providing a modest savings in fungicide inputs.

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



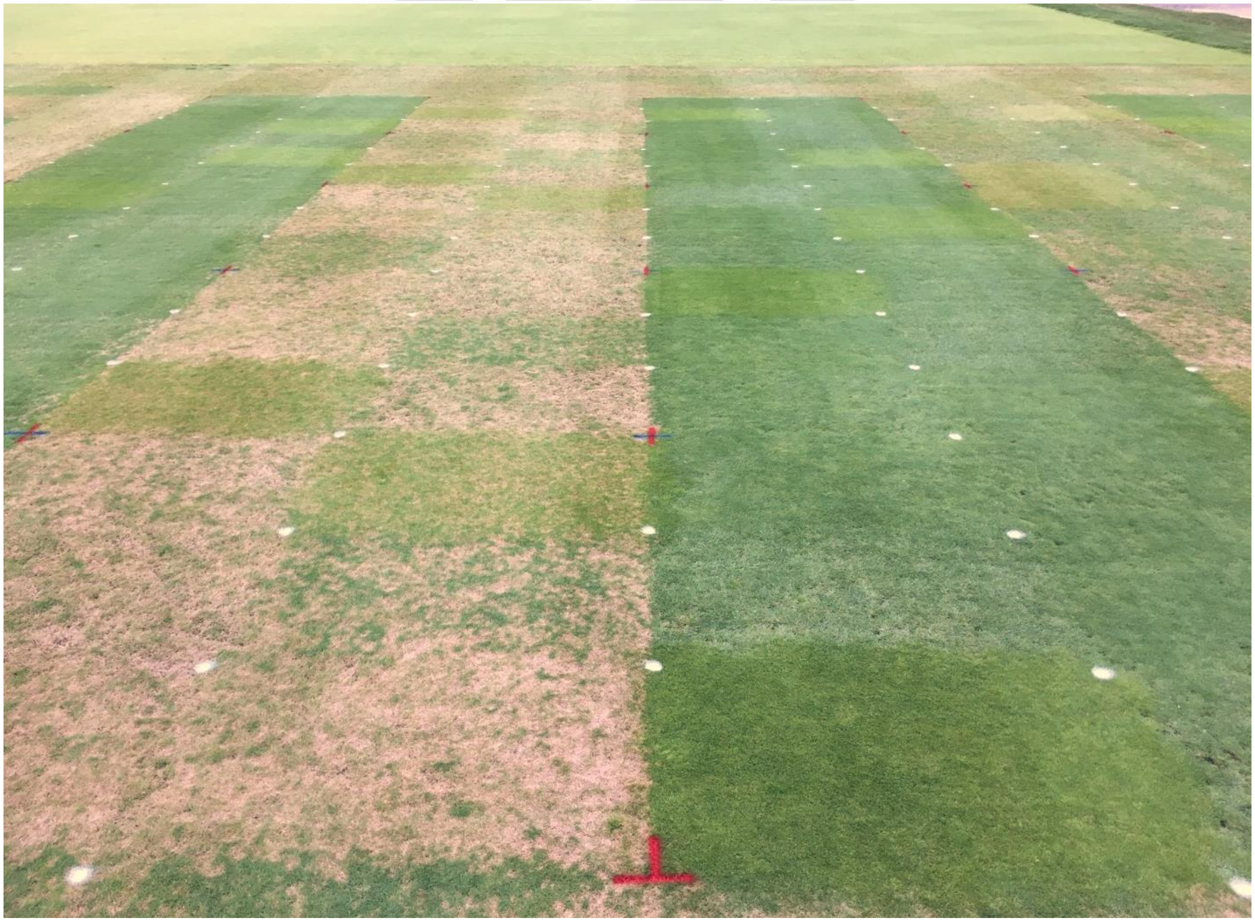


Figure 2. The study was duplicated in five runs that were released from (left) or maintained under (right) fungicide control to facilitate season-long evaluation of dollar spot epiphytotics.

Table 1. Cultivar response to disease, summarized as the area under the disease progress curve (AUDPC) for dollar spot infection center counts and diameters on bentgrass fairway turf during 2015, 2016 and 2017 in North Brunswick, NJ.

	Infection Center Count			Infection Center Diameter		
Cultivar[†]	2015	2016	2017	2015	2016	2017
	-- AUDPC[‡] --					
Capri	2763 d[§]	436 cd	4593 e	1205 e	683 e	1195 f
Declaration	1402 e	116 d	6076 d	943 f	506 e	1716 e
007	4110 c	1176 c	9864 c	1472 d	1369 d	2309 d
Shark	5925 b	3284 b	12447 b	1830 c	1923 c	3090 c
Independence	7470 a	5011 a	14878 a	2380 b	2325 b	3876 b
Penncross	7738 a	3077 b	12166 b	3038 a	2556 a	4504 a
Source	-- ANOVA --					
Cultivar	***	***	***	***	***	***
CV,%	6.8	36.4	7.1	4.0	8.9	7.1

*** Significant at the 0.001 probability level

†Capri colonial bentgrass (*Agrostis capillaris* L.) and Declaration, 007, Shark, Independence, and Penncross creeping bentgrasses (*A. stolonifera* L.).

‡The area under the disease progress curve encompassed disease progress over the 19 May to 25 Nov. 2015 (*n*=37), 14 May to 23 Nov. 2016 (*n*=30), and 24 May to 22 Nov. 2017 (*n*=67). Rating dates occurring during 12 Aug. to 9 Oct. 2015 and 17 June to 21 Aug. 2016 were excluded due to unintended disease suppression caused by fludioxonil applications.

§Within columns, means followed by the same letter are not significantly different according to $LSD_{(0.05)}$

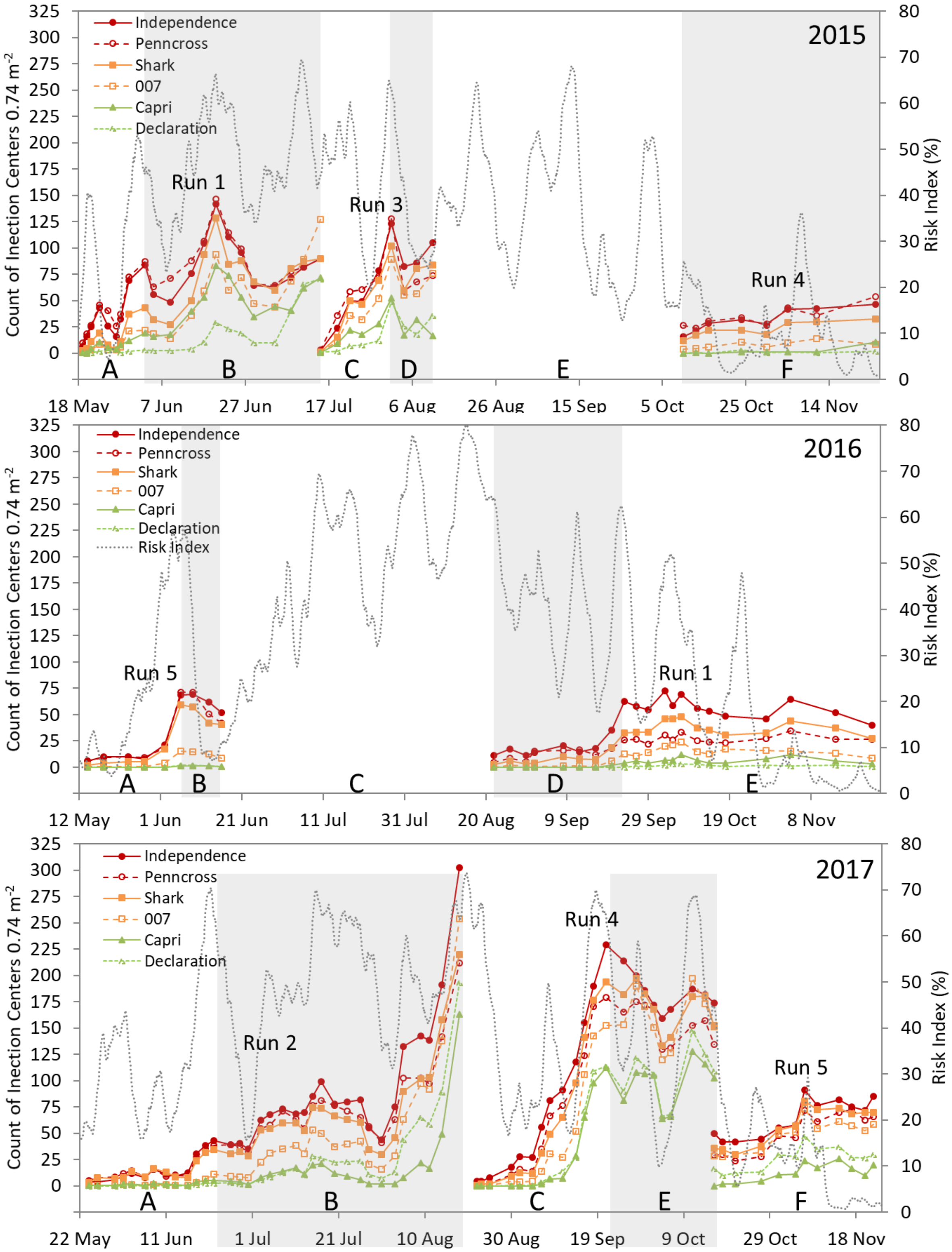


Figure 3. Cultivar response to disease measured as dollar spot infection centers counts on bentgrass fairway turf in North Brunswick, NJ during 2015, 2016, and 2017. Dates during period E of 2015 and period C of 2016 were excluded due to unintended disease suppression caused by fludioxonil.

Table 2. Analysis of variance of the area under the disease progress curve response to cultivar, initial fungicide application timing, and subsequent fungicide application timing on creeping bentgrass fairway turf in North Brunswick, NJ during 2015, 2016, and 2017.

Source	2015	2016	2017
	-- ANOVA; contribution to sample variance (%) --		
Cultivar (C)	*** (42)	*** (40)	*** (12)
Initial Fungicide Timing (I)	NS† (1)	NS (3)	NS (12)
C × I	NS (2)	NS (4)	NS (12)
Subsequent Fungicide Timing (S)	*** (40)	*** (26)	*** (47)
C × S	*** (10)	*** (24)	NS (1)
I x S	NS (3)	NS (2)	NS (3)
C × I × S	NS (2)	NS (2)	NS (10)
CV, %	65	103	113
Main effects			
Cultivar	------------------------ AUDPC‡ ------------------------		
Declaration	18.8 a§	1.8 a	49.5 a
Independence	81.6 b	91.4 b	100.1 b
Subsequent Fungicide Timing			
Logistic	19.4 a	10.8 a	24.5 a
Threshold	80.9 b	82.5 b	118.7 b

*** Significant at the 0.001 probability level.

†NS, not significant

‡The area under the disease progress curve for the observation dates of 19 May to 25 Nov. 2015 (*n*=47), 14 May to 23 Nov. 2016 (*n*=43), and 24 May to 22 Nov. 2017 (*n*=67).

§Within columns, means followed by the same letter are not significantly different according to $\text{LSD}_{(0.05)}$

Table 3. Interaction means for the area under the disease progress curve (AUDPC) response to cultivar and subsequent fungicide application timing on creeping bentgrass fairway turf in North Brunswick, NJ on during 2015 and 2016.

Cultivar	Subsequent Fungicide Timing	2015 Season Long	2016 Season Long
		------------------- AUDPC†	-------------------
Declaration	Logistic	3.2 a‡	0.3 a
Declaration	Threshold	34.3 b	3.2 a
Independence	Logistic	35.6 b	21.2 a
Independence	Threshold	127.5 c	161.7 b

†The area under the disease progress curve for the observation dates of 19 May to 25 Nov. 2015 (*n*=47) and 14 May to 23 Nov. 2016 (*n*=43).

‡Within columns, means followed by the same letter are not significantly different according to $LSD_{(0.05)}$

Table 4. 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	2016	2017	2015	2016	2017
Calendar	9	9	9	9	9	9
Logistic Model	8 to 9†	7 to 8	6 to 9	8 to 9	7 to 8	8 to 10
Threshold	3	1	4 to 5	6 to 7	4 to 5	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.

USGA ID#: 2018-20-670

Title: *Sclerotinia homoeocarpa* epidemiology and resistance development as measured through improved molecular detection techniques

Project Leaders: Paul Koch[1], Bruce Clarke[2], Jim Murphy[2], Geunhwa Jung[3], and Ning Zhang[2]
Affiliation: [1]Department of Plant Pathology, University of Wisconsin-Madison; [2]Department of Plant Biology and Pathology, Rutgers University; [3]Stockbridge School of Agriculture, University of Massachusetts-Amherst

Objectives:

1. Develop one or more molecular methods to effectively quantify *S. homoeocarpa* in the field and assess the fungal response to host genotypes, and cultural and chemical practices.
2. Determine impact of fungicide class and number of applications on the development of fungicide resistance in *S. homoeocarpa* populations through *in vitro* assays and molecular techniques.

Summary Points:

- Dollar spot sampling sites were established in New Jersey, Wisconsin, and Massachusetts and sampled repeatedly throughout the 2018 growing season.
- Two assays are in development for quantifying the dollar spot fungus in field samples. The first is a 'digital droplet PCR (ddPCR)' assay being developed at Wisconsin that is very new to Plant Pathology and represents a potential significant advancement for the detection of fungal DNA in field samples. The second is a more common 'quantitative PCR (qPCR)' assay being developed at Rutgers and Massachusetts that will provide an assay that nearly any research laboratory would be able to perform without the specialized equipment required of ddPCR.
- The ddPCR protocol developed at Wisconsin is highly sensitive and repeatable and appears to lessen some of the variability and 'noise' inherent to so many field DNA detection techniques. Wisconsin is currently using the ddPCR protocol to assay the field samples collected throughout 2018.
- The first version of the qPCR protocol developed at Rutgers was not specific enough to reliably differentiate non-treated controls from field samples, and a new and more specific assay is currently being developed. Assessment of the 2018 samples collected from New Jersey will be conducted once the new qPCR assay has been developed.
- Massachusetts also used a qPCR assay and was able to consistently detect the dollar spot fungus in the thatch of samples collected in the field. The fungal population did not appear to change in size throughout the 2018 season.
- Field studies using the respective assays described above that investigate the impact of various chemical and cultural practices on dollar spot pathogen development will be planned early in 2019 for implementation during the 2019 growing season.
- A molecular diagnostic system for dollar spot was developed at Massachusetts to detect mutations that confer resistance to SDHI fungicides. This system will be tested on more field isolates from Massachusetts, New Jersey, and Wisconsin in 2019.

Objective 1: Develop one or more molecular methods to effectively quantify *S. homoeocarpa* in the field and assess the fungal response to host genotypes, and cultural and chemical practices.

Year 1 Goal: Develop an effective S. homoeocarpa quantification technique that can be used in field studies in years 2 and 3 of the grant.

Wisconsin Update:
Field sampling: A field-sampling plot was established in May of 2018 at the OJ Noer Research and Education Facility in Madison, WI on a 'Penncross' creeping bentgrass stand maintained under fairway conditions. One half of the plot was inoculated in May with inoculum provided by Rutgers and the other half of the plot remained non-inoculated. A modified sampler provided by Rutgers was used to sample the plots once per month from May through September. At each sampling date 62 cores were collected (31 from each half) from the plot and immediately frozen at -20°C until DNA extraction could occur.

PCR primer development: Based on the work of Salgado-Salazar et. al 2018 we determined calmodulin, beta-tubulin and ITS regions would provide the most probable regions to identify primers with a high enough specificity to quantify organisms of the dollar spot pathogens within the *Clarireedia* genus and excluding closely related organisms. We leveraged bioinformatics to efficiently design the primers by modifying a primer-design pipeline utilizing the DECIPHER package in R. Our modification allowed DECIPHER to design primers to fit a set of genes from the *Clarireedia* genus while simultaneously excluding annealing to homologs of phylogenetically closely-related genera. This identified a primer set for each calmodulin, beta- tubulin, and ITS region. We tested each of the three primer sets on purified genomic DNA from *Sclerotinia homoeocarpa* ML715 (now classified as *Clarireedia* spp.) as well as several other organisms from the Sclerotinia genus. Specificity was evaluated using standard polymerase chain reactions (PCR) using a KAPA Biosystems polymerase system. Results indicated that calmodulin and beta-tubulin were specific to Sclerotinia homoeocarpa ML715, however ITS primers also amplified other Sclerotinia organisms although to a lesser efficiency. This identified primers for calmodulin and beta-tubulin as candidate primers to move forward with designing quantification protocols.

Evaluate qPCR as a method for reliable detection and quantification of the Dollar Spot pathogen within the turfgrass phytobiome. While potentially not as sensitive as the droplet digital PCR (ddPCR) method, qPCR is more readily available in research and diagnostic laboratories throughout the U.S. and represents a rapid and cost effective method for potentially identifying the dollar spot pathogen in field samples. Therefore, quantitative PCR (qPCR) was evaluated for sensitivity and reliability to the dollar spot pathogen from field samples obtained in WI. We found that the detection limit was a Cq-value of 30 for calmodulin primer (Fig 1A.) and a Cq-value of 35 for B-tubulin primers (Fig 1B). Beyond the 5th 10-fold dilution of genomic DNA DNA concentration was below the detection the limit, while DNA could be detected in some cases, reproducibility of the result became unreliable. Next, we performed Q-PCRs for three replicates on each of two types of field samples (extracted from areas of active lesions and inactive lesions). Based on the results of these tests with these primers, we were able to detect DNA from the dollar spot pathogen. However, the reproducibility of the test is questionable (Fig 2).

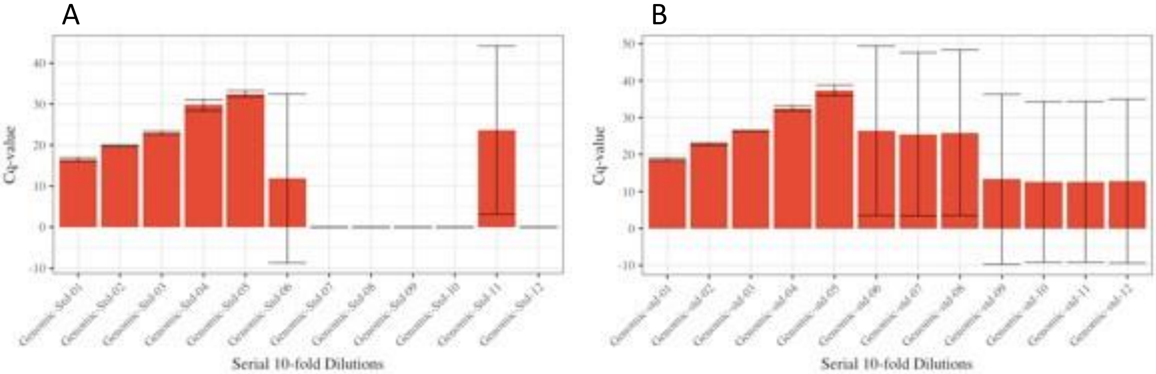


Figure 1. Quantatative PCR Limit of detection when amplifying genomic S. homoeocarpa ML715 DNA. A) qPCR performed using calmodulin primer. B) qPCR performed using β-tubulin primer. Quantification was perfomed in tripate and reported as averages of Cq threshold value. Error bars represent standard deviation.

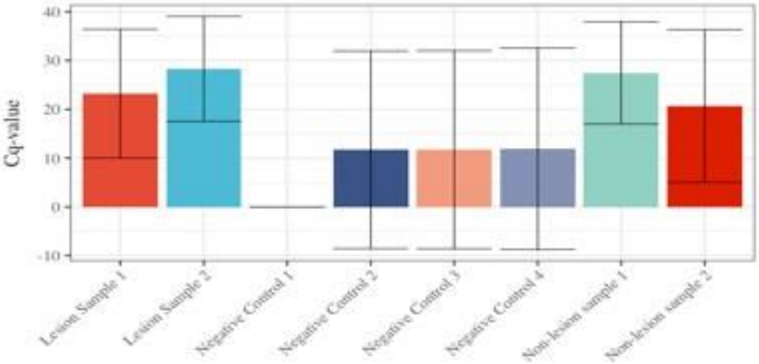


Figure 2. Evaluating the reliability and sensitivity of dollar spot detection and quantification from DNA extracted from field samples. Quantification was perfomed in tripate and reported as averages of Cq threshold value. Error bars represent standard deviation.

Evaluate ddPCR as a method for reliable detection and quantification of the dollar spot pathogen within the turfgrass phytobiome. In order to address the issues of specificity and sensitivity, we developed an assay using the more technical and sensitive method of ddPCR. First, we ran three replicates of quantifications of 10-fold serial dilutions of genomic DNA as a standard with each of the two primer sets to evaluate the sensitivity and reproducibility of the ddPCR system. We found that the detection limit was 2 gene copies per reaction (Fig 3A), which was much smaller (better) than qPCR. A similar detection limit was observed with genomic DNA dilutions when combined with DNA extracted from soil (Fig 3B) to evaluate how the sensitivity and reproducibility compared when the target gene was measure in the presence of a complex matrix of DNA. The curves were highly reproducible even down to the detection limit. We compared the beta-tubulin primer to the calmodulin primer to determine which primer would be the best candidate to use as an assay. First, we optimized the annealing temperature of both primers by performing a gradient ddPCR (Fig 4). We found that for calmodulin the annealing temperature was 59°C and for beta-tubulin the annealing temperature was 63.1°C, although at this annealing temperature beta-tubulin had positive signal in the water negative control samples. We verified that the detection limit at these annealing temperatures was not significantly different from the detection limits that we reported earlier in this study. When we tested both primer-assays for false-positives, beta-tubulin gave more false-positive counts when no DNA was present. However, the calmodulin primer had no false-positives. Since both primers had similar detection limits and sensitivity, the lack of false-positives (Fig 4C) means that the calmodulin primer-based assay would be more accurate. We recommend that the ddPCR method be applied with the calmodulin primer to quantify the dollar spot disease for years two and three of this study.

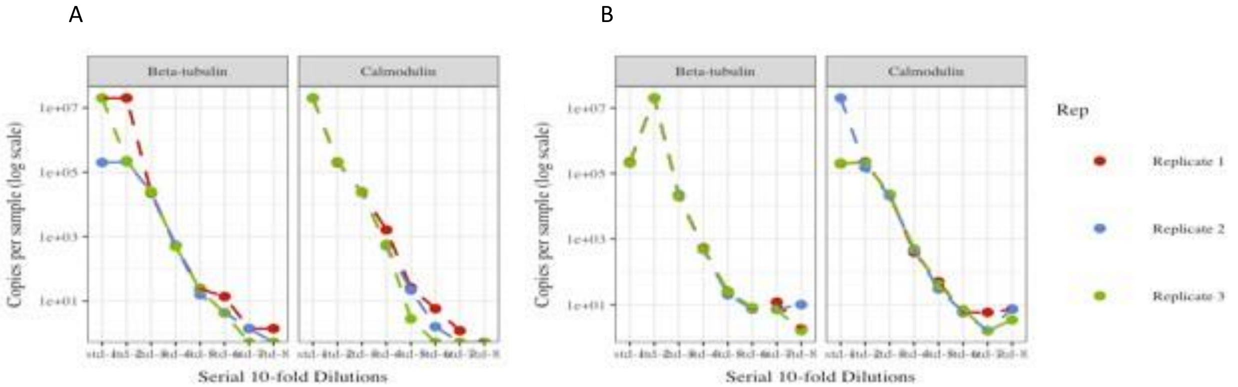


Figure 3. Limit of detection for ddPCR using both calmodulin and β-tubulin. Templates A) Purified genomic *S. homoeocarpa* ML715 and B) genomic *S. homoeocarpa* ML715 mixed with DNA extracted from soil. Quantification was performed in triplicate and reported as gene copies per sample and plotted on semi-log

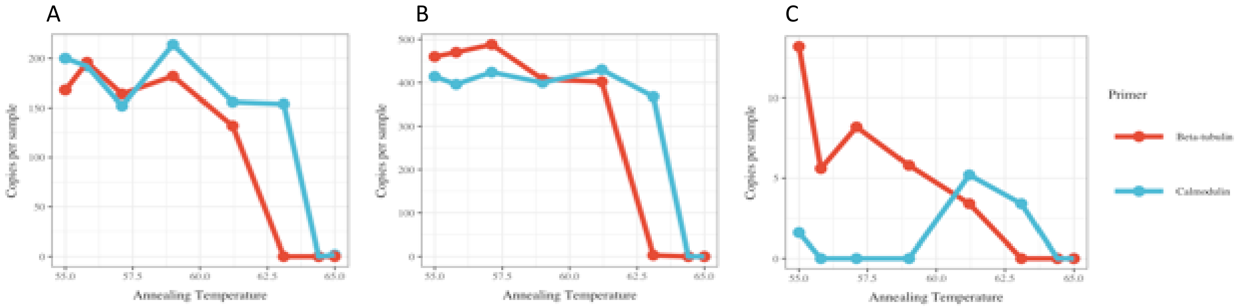


Figure 4. Optimal annealing temperature was determined for both calmodulin and β-tubulin primers. Droplet digital PCR was performed with gradient annealing temperature from 55C to 65C. Templates used A) Genomic S. homoeocarpa ML715 DNA, B) DNA extracted from field samples, and C) Water.

Determine sampling strategy for consistent detection of dollar spot pathogen. We tested the designed assay in the field using the identified primers and conditions mentioned above. ddPCR was more effective at detecting the dollar spot pathogen in field samples when compared to qPCR, as the ddPCR calmodulin assay was able to detect the pathogen in both active and inactive lesion samples (Fig 5). To determine the most effective way to process samples, we separately detected and quantified the pathogen associated with the leaf and the thatch. The turfgrass leaves showed higher levels of pathogen than the thatch (Fig 5), regardless of whether sample was contained from a lesion or a non-lesion. This data indicates separation of the thatch from the leaves is unneeded. As an interesting side-note, samples taken from previously- fungicide-treated lots contained the highest level of dollar spot pathogen (Fig 5). We were able to detect and quantify dollar spot in a single field sample. We tested 8 and 16 samples pooled together and determined that the level of pathogen detected proportionately increases with each pooling (Fig 6).

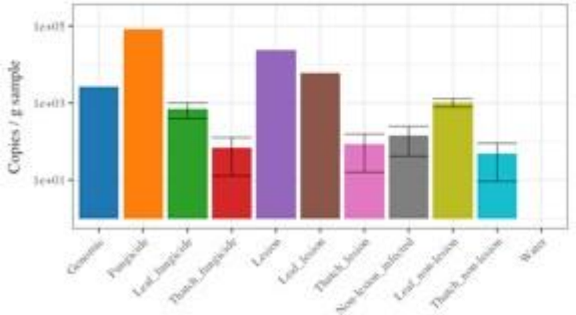


Figure 5. Largest portion of the dollar spot population resides within the leaves. Quantification was performed using a BioRad QX200 ddPCR system in triplicate and reported as average gene copies per sample and plotted on semi-log scales. Error bars represent standard deviation.

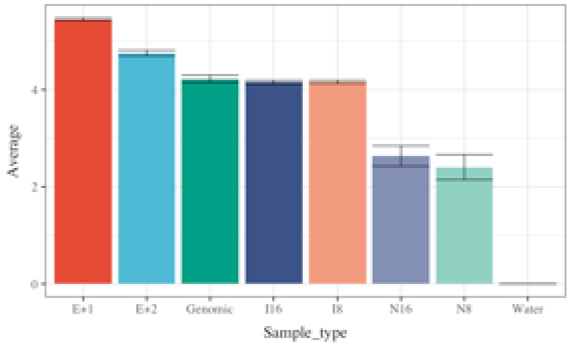


Figure 6. Pooling of samples for extraction results in proportionately increased pathogen detection. Quantification was performed using a BioRad QX200 ddPCR system in triplicate and reported as average gene copies per sample and plotted on semi-log scales. Error bars represent standard deviation.

Year 2 Goals: Now that an established quantification method has been developed we are currently processing all the field samples collected from Wisconsin during the 2018 season. We will meet in January with co-PIs to discuss specific field studies to implement in 2019 and 2020.

Rutgers Update:

Field sampling: A field-sampling plot was established in May of 2018 at Hort Farm No. 2 in North Brunswick, NJ on a 'Barracuda' creeping bentgrass stand maintained under fairway conditions. One-half of the plot was inoculated in May with inoculum provided by Rutgers and the other half of the plot remained non-inoculated. A modified sampler (golf club shaft) provided by Rutgers was used to sample the plots. Samples were taken weekly in May then once per month from June through October. At each sampling date 62 cores were collected (31 from each half) from the plot and immediately frozen at -20°C until DNA extraction could occur.

Evaluate qPCR as a method for reliable detection and quantification of the dollar spot pathogen within the turfgrass phytobiome. Quantitative PCR (qPCR) was evaluated for field samples obtained in NJ using the same primers, protocols, and reagents as used by WI. The only difference was that we used an Applied Biosystems StepOnePlus, Real-Time PCR System to carry out the qPCR reactions. We had to trouble-shoot the method since the negative control samples were amplifying at a higher cycle threshold than any of the environmental samples from the field, including samples isolated from active dollar spot lesions (Fig 7). We believe that the reason the negative controls samples were amplifying is that the primers in the reactions were binding together to form double stranded DNA structures that were recognized by the qPCR machine. The SYBR green protocol that was used cannot differentiate between double stranded DNA structures whether it is primer dimers or target sequence. Therefore, because of these problems and since WI also found the reproducibility of the SYBR green test was questionable, we have decided to develop a TaqMan qPCR probe to assess its sensitivity and reliability for the detection of the dollar spot pathogen from field samples.

Rutgers has experience developing TaqMan qPCR probes for other turfgrass pathogens as well as the genetic resources required for the development of a dollar spot TaqMan qPCR probe. Moreover, since TaqMan uses a probe specific to the target sequence instead of recognizing double stranded DNA, this should improve detection specificity and eliminate false recognition in the negative control samples.

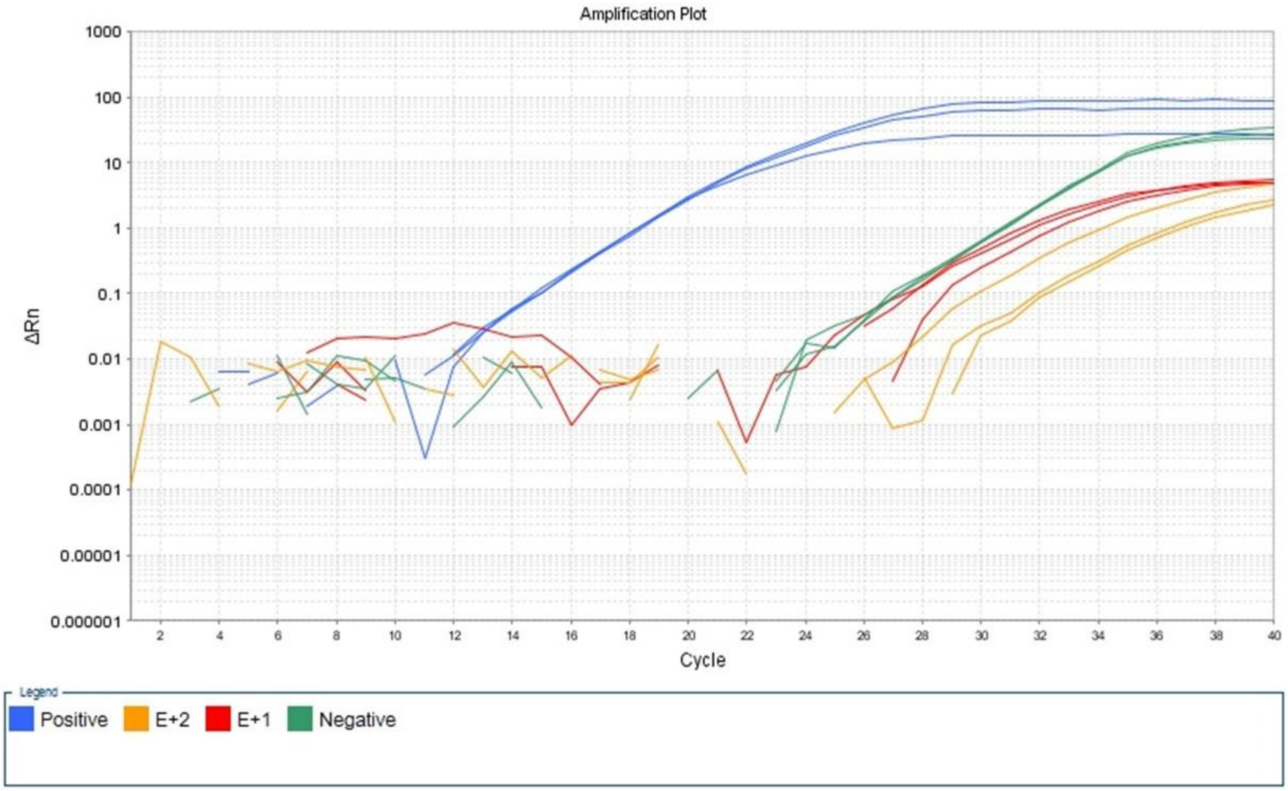


Figure 7. qPCR plot showing negative controls (water) outperforming most diseased samples taken from the field. Quantification was preformed using Applied Biosystems StepOnePlus Real-Time PCR System in triplicate.

Year 2 Goals: The TaqMan Assay is currently being developed at Rutgers to identify regions of interest that will allow for amplification of *Clarireedia* spp. and not other, closely related organisms. Fungal isolates from Salgado-Salazar et. al 2018 will be used to validate the accuracy of the TaqMan assay and then to detect the dollar spot pathogen in field samples collected from Hort Farm 2 in 2018.

Massachusetts Update:

Field sampling and storage of samples From June to October 2018, dollar spot infected (DSI) and non-infected (NDSI) thatch samples were collected from putting greens at the Joseph Troll Turf Research Center in S. Deerfield. Collected samples were stored in ice for transport to our lab on the UMass Amherst campus. Upon arrival, the samples were were frozen with liquid nitrogen and stored at -80 degrees.

Two genes of interest, elongation factor alpha (EF1α) and actin gene (*Shact*), were selected for *S. homoeocarpa* based on the information provided in Allen-Perkin et al. (2018) and Hulvey et al. (2012). Primers for these genes were selected based on these references and the annealing temperature for both genes was determined to be 60 C. Total DNA was extracted from each sample using a NORGEN Plant/Fungi DNA Isolation Kit and prepared for qPCR with QIAGEN QuantiTect SYBR Green RT-PCR Master Mix. All extracted DNA samples were analyzed in technical triplicates for each gene using a A QIAGEN Rotor-Gene Q RT-PCR cycler. A nuclease-free water blank was used as a negative control. Cycler parameters for qPCR were are as follows: hold of 95 C for 5 min, 40 cycles of 95 C for 5 s, and 60 C of combined annealing and extension for 10 s.

Critical threshold (Ct) values were recorded at a threshold value set to 0.00284 and are included in Figures 1 and 2. Error bars were used to represent the standard deviation of replicates. No Ct values were recorded for replicates 2 and 3 when *Shact* primers used and so the error bar was not calculated for the blank associated with the analysis of this gene.

Results:

In general, as seen in Figures 8 and 9, we saw fluctuations in Ct values for both genes across the dates sampled. This may have been due to sampling variations.

Additionally, according to Figure 8, the Ct values of all NDSI samples were higher in numerical than that of DSI samples with the exception of those collected on 07/06/2018 and 09/14/2018. Therefore, even though dollar spot had not yet manifested visibly in the form of infection centers, the fungi was still highly abundant in the thatch, and in this case even more so than where the disease was visually present.

According to Figure 9, the Ct values of the Shact gene of DSI and NDSI samples are almost linear, showing no significant difference between Ct values from July to October. Results indicated that dollar spot inoculum in the thatch samples did not fluctuate regard less of weather conditions, disease pressures and in the absence and presence of dollar spot infection centers.

Going forward, more biological replicates should be analyzed per sampling in order to obtain more reproducible data.

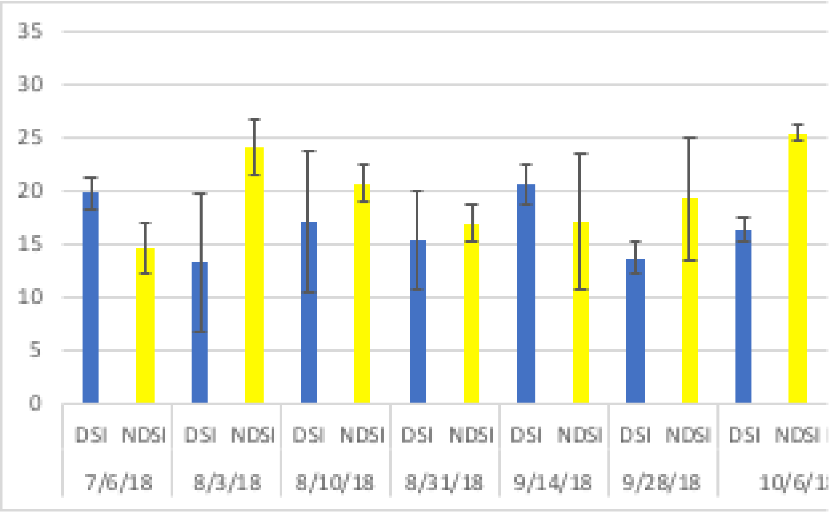


Figure 8. Graph of average Ct values obtained through **EF1alpha gene** analysis from dollar spot infected (DSI) and non-infected (NDSI) thatch samples on seven collection date.

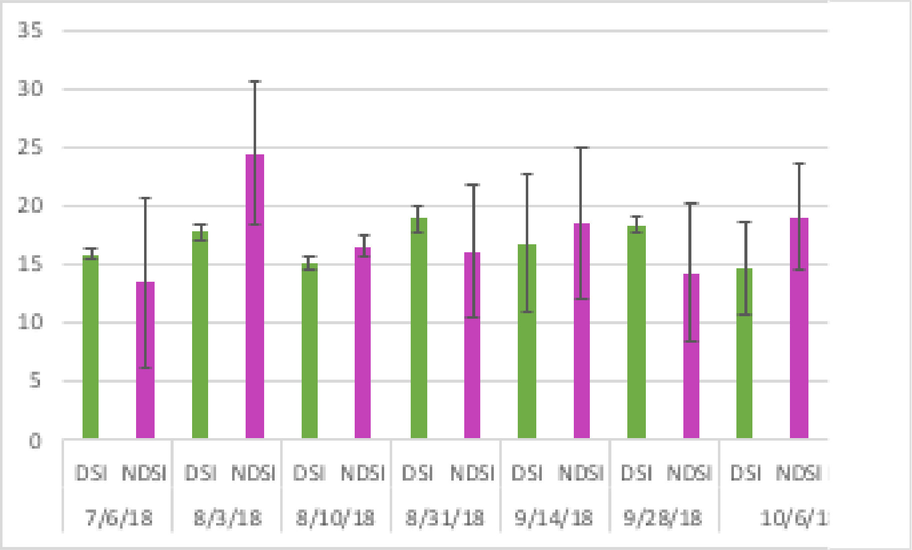


Figure 9. Graph of average Ct values obtained through **Shact gene** analysis from dollar spot infected (DSI) and non- infected (NDSI) thatch samples on seven collection dates.

Objective 2: Determine impact of fungicide class and number of applications on the development of fungicide resistance in *S. homoeocarpa* populations through *in vitro* assays and molecular techniques.

Year 1 Goal: Develop an effective molecular technique for detecting fungicide resistance within S. homoeocarpa populations that can be used in field studies in years 2 and 3 of the grant.

Massachusetts Update:

In vitro sensitivity assays of *S. homoeocarpa* field isolates were carried out for 4 SDHI active ingredients at a single discriminatory concentration (1,000 ug ml-1). Discriminatory concentrations were selected based on preliminary screening results that showed consistent growth differences between sensitive and resistant isolates. Fungicide-amended PDA (Potato dextrose agar medium) plates and non-amended PDA plates were inoculated in the center with Agar plugs (5 mm diameter) from fungal colonies of field resistant isolates previously collected from several golf courses and Rutgers University. These isolates are listed in Table 1.

After three days of incubation, two perpendicular diameters of mycelial growth were measured using a 16EX digital caliper (Mahr). Relative mycelial growth (RMG) % values of each isolate were then calculated by dividing the diameter of colonies grown on SDHI amended PDA by the diameter of those grown on non-amended PDA and multiplying by 100.

For rapid and accurate detection of SDHI mutations in resistant field isolates, we have developed a molecular diagnostic system that uses a PCR-based molecular marker known as dCAPS (derived Cleaved Amplified Polymorphic Sequence). The primers and the restriction enzymes for each SDHI mutation used for this study were in Table 2. An example of this molecular diagnostic test is included in Figure 10, which displays the banding pattern of PCR amplicons of field isolates with various SDHI mutations after having been digested with specific restriction enzymes.

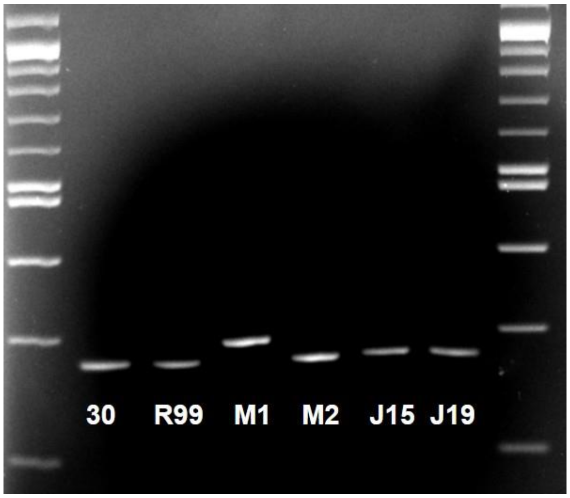


Figure 10. dCAP marker gel image showing bands after PCR amplicons containing various SDHI mutations were digested with restriction enzymes. The M1 resistant isolate with the SdhC-G91R mutation differentiated from the rest of the isolates when digested with a restriction enzyme.

Table 1. *Sclerotinia homoeocarpa* strains used in this study.

No.	Name	Description	Origin	Source
1	JT30	Fungicide sensitive strain	The Joseph Troll Turf Research Center, South Deerfield, Massachusetts	Popko et al., 2017
2	J-5	SDHI resistant strain (only pyridine-carboxamide class) harboring H267Y mutation in *ShSdhB* gene	Takehara Country Club, Hiroshima, Japan	Popko et al., 2017
3	J-19	SDHI resistant strain harboring G150R mutation in *ShSdhC* gene	Takehara Country Club, Hiroshima, Japan	Popko et al., 2017
4	M1	SDHI resistant strain harboring G91R mutation in *ShSdhC* gene	The Misquamicut Club, Westerly, Rhode Island	Popko et al., 2017
5	M2	SDHI insensitive strain harboring Silent mutation in *ShSdhB* gene (CTT to CTC) at codon 181	The Misquamicut Club, Westerly, Rhode Island	Popko et al., 2017
6	HRI11	Multidrug-resistant (MDR) strain harboring M853T mutation in *Shxdr1* gene	Hickory Ridge Golf Club, Amherst, Massachusetts	Sang et al., 2018
9	CT45	Dicarboximide resistant strain harboring I366N mutation in *Shos1* gene	Wethersfield Country Club, Wethersfield, Connecticut	Sang et al., 2017
10	R99 to -231	SDHI resistant strain (only pyridine-carboxamide class) harboring H267R mutation in *ShSdhB* gene	Rutgers University, New Brunswick, New Jersey	This study

Table 2. Primers and associated annealing temperatures and restriction enzymes for each dCAPS and CAPS analysis, and the sizes of products after digestion.

Target mutation	Restriction enzyme	Products (bp) after RE digestion	Annealing temp (°C)	Primer names	Primer sequence (5′-3′)
ShB-H267Y	MseI	Wild-type: 159 Mutant: 28, 131	72	F_dCAPS_SdhB_H267Y	GCAAGTCCTCGAGCAGTTGAGAATTGTTTNN
				R_dCAPS_SdhB_H267Y	TGGAACAGCGAAGAATACCTGGGACCAG
ShB-H267R	Hpy99I	Wild-type: 177 Mutant: 29, 88	72	F_dCAPS_SdhB_H267R	GACAACAGCATGAGCTTGTACAGACGTC
				R_dCAPS_SdhB_H267R	TTAAAAAGCCATCTCCTTCTTGATCTCCGCAATCGC
ShC-G91R	SmaI	Wild-type: 19, 277 Mutant: 296	72	F_dCAPS_SdhC_G91R	CCGCGCTAAACCGCATCCCG
				R_dCAPS_SdhC_G91R	AGCACTGGTCACACTCAACCCCACAAT
ShC-G150R	AvaII	Wild-type: 23, 243 Mutant: 266	72	F_dCAPS_SdhC_G150R	CGCATCCCAAGCCAAATGTCTCGGTC
				R_dCAPS_SdhC_G150R	CGCACCTCACCATCTACCAGCC
ShB-L181	BsmAI	Wild-type: 186 Mutant: 41, 145	72	F_dCAPS_SdhB_L181	TCAATTCTACAAACAGTACAAATCAATCAAGCCGTGTCT
				R_dCAPS_SdhB_L181	AGGTATTCTTCGCTGTTCCACCAGTACGAAGG
ShMDR1-M853T	NlaIII	Wild-type: 81, 90 Mutant: 171	69	F_CAPS_xdr1_M853T	GGCAACGATGCCAATTCACC
				R_CAPS_xdr1_M853T	GTTCATATGCAGCTCCGGGT
Shos1-I366N	MluCI	Wild-type: 140, 197 Mutant: 337	71	F_CAPS_os1_I366N	GAGAGACCTGCTCAGGGTGA
				R_CAPS_os1_I366N	GGTCCACCATGGAGTTGATGGT

USGA ID#: 2017-16-626

Title: An Integrated Pest Management Protocol for Managing Microdochium Patch in the Absence of Traditional Fungicides

Project Leader: Alec Kowalewski
Affiliation: Oregon State University

Objectives:

Two separate field trials exploring best management practices for the use of non-traditional fungicides for the suppression of Microdochium patch on sand-based annual bluegrass putting greens took place over two years. Both experiments began on the 29th of September 2016 and ended on the 30th of April 2017 and were repeated from the 28th of September 2017 to the 30th of April 2018. The dependent variables in both trials included percent disease and turfgrass quality (from 1 to 9 with 6 or greater considered acceptable).

Start Date: 2016
Project Duration: 3 years
Total Funding: $30,000

Experiment One:

The first experiment focused on different seasonal rotations and application frequencies of phosphorous acid either applied in combination with Civitas Defense or with sulfur on the suppression of Microdochium patch. The experimental design was a randomized complete block design replicated four times and included sixteen treatments.

Summary Points:

- At the peak of disease in both years of the study, there was no Microdochium patch present on treatments that were applied every 2 weeks (treatments 1 through 6) although some of these treatments did have disease earlier in the study but had recuperated as the trial progressed (Table 1).
- Treatments 1 through 6 were significantly different from the control in both years of the study at the peak of disease (Table 1).
- All treatments applied using a three-week frequency had some disease present in at least one of the two years at the peak of disease.
- Regarding turfgrass quality, the only treatments that were significantly different from the control occurred among application frequencies of every two weeks (Figures 1 and 2).

Future Expectations of the Project:

A journal article is being produced with an objective to first publish these results in a peer-reviewed scientific journal followed by a trade-journal summary article. In addition, these results are being shared widely to a state, national, and international audience.

Table 1. Outline of treatment components and application frequencies as well as the percent disease at the peak of disease for both years of the study.

Trt	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Percent Disease Jan 28, 2017		Percent Disease Feb 14, 2018	
1	Civ[z] + Dur[y] X 2wks		S[x] + Dur X 2wks			Civ + Dur X 2wks		0.0%	a[w]	0.0%	a
2	Civ + Dur X 2wks			S + Dur X 2wks		Civ + Dur X 2wks		0.0%	a	0.0%	a
3	Civ + Dur X 2wks			S + Dur X 2wks			Civ + Dur X 2wks	0.0%	a	0.0%	a
4	Civ + Dur X 2wks		S + Dur X 2wks				Civ + Dur X 2wks	0.0%	a	0.0%	a
5	Civ + Dur X 4 wks in rotation with S + Dur X 4wks							0.0%	a	0.0%	a
6	Civ + Dur X 2wks							0.0%	a	0.0%	a
7	S + Dur X 2wks							1.8%	ab	1.0%	ab
8	Civ + Dur X 3wks		S + Dur X 3wks			Civ + Dur X 3wks		0.9%	ab	2.5%	ab
9	Civ + Dur X 3wks			S + Dur X 3wks		Civ + Dur X 3wks		0.6%	ab	2.3%	ab
10	Civ + Dur X 3wks			S + Dur X 3wks			Civ + Dur X 3wks	1.1%	ab	0.5%	ab
11	Civ + Dur X 3wks		S + Dur X 3wks				Civ + Dur X 3wks	0.3%	ab	3.6%	ab
12	Civ + Dur X 6 wks in rotation with S + Dur X 6wks							3.8%	ab	0.1%	ab
13	Civ + Dur X 3wks							2.1%	ab	0.0%	a
14	S + Dur X 3wks							7.0%	ab	6.3%	ab
15	Fungicide Control (monthly applications using a fungicide rotation)							0.0%	a	0.1%	ab
16	Not treated Control							49.6%	b	64.6%	b

[Z] Civ = Civitas One applications of 8.5 oz/M.

[Y] Dur = Duraphite 12 applications of 3.14 oz/M.

[X] S = 0.25 # Sulfur / M.

[W] Means followed by the same letter are not significantly different according to Dunn’s all-pairwise comparison at ($\alpha \leq 0.05$).

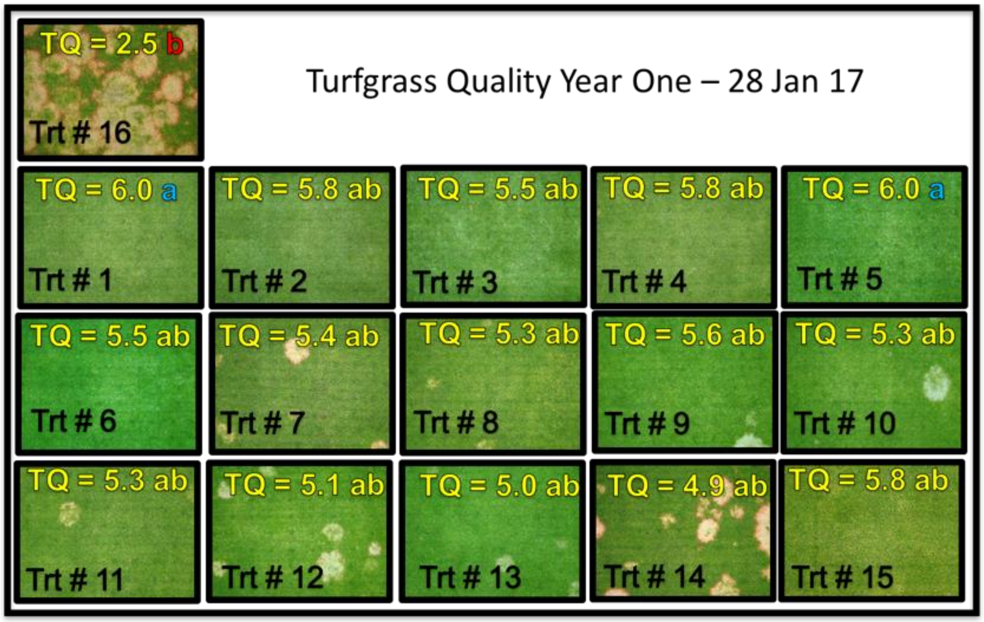


Figure 1. Turfgrass quality at the peak of disease for treatments applied starting on 29 Sep 16 on an annual bluegrass putting green in Corvallis, OR. Means followed by the same letter are not significantly different according to Dunn's all-pairwise comparison (α ≤ 0.05).

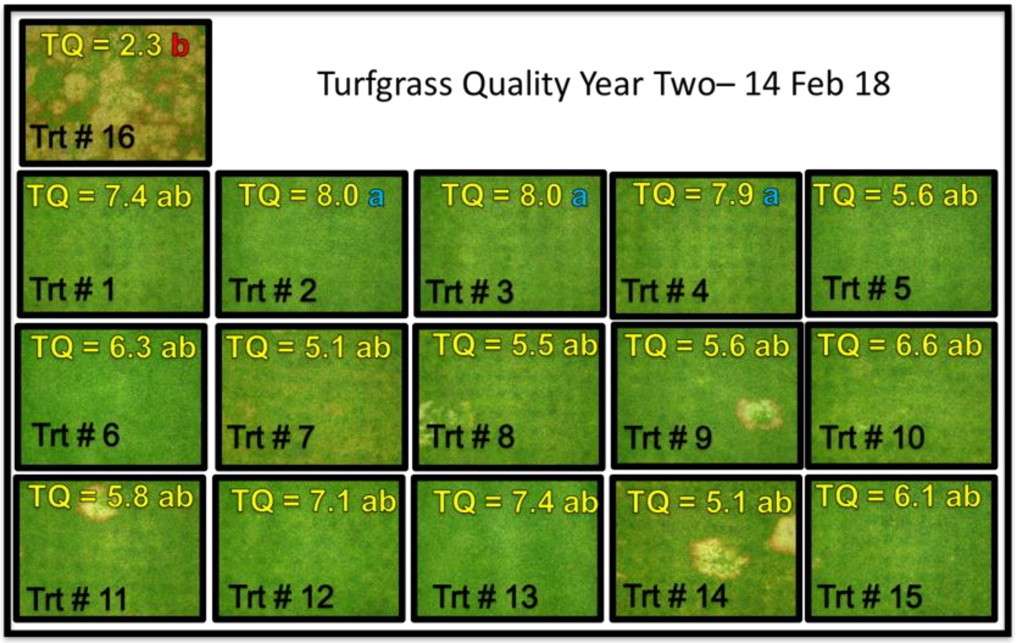


Figure 2. Turfgrass quality at the peak of disease for treatments applied starting on 28 Sep 17 on an annual bluegrass putting green in Corvallis, OR. Means followed by the same letter are not significantly different according to Dunn's all-pairwise comparison (α ≤ 0.05).

Experiment Two:

The second experiment explored 5 different rates of iron sulfate applied either with or without phosphorous acid on the suppression of Microdochium patch. The experimental design was a five by two factorial including five rates of iron sulfate and two rates of phosphorous acid replicated four times.

Summary Points:

- In both years of the trial, analysis of the percent disease data at the peak of disease, Jan 28, 2017 and Feb 26, 2018 respectively, showed that when phosphorous acid was applied, there was no significant benefit to the suppression of Microdochium patch by combining phosphorous acid with iron sulfate.
- In contrast to the first bullet point, phosphorous acid added to lower rates of iron sulfate did improve Microdochium patch suppression compared to iron sulfate applications alone (Figures 3 and 4).
- Regarding turfgrass quality at the peak of disease, no treatments received an acceptable turfgrass rating because of either the presence of disease or turfgrass thinning caused by the highest rates of iron sulfate (Figure 5 and 6).

Future Expectations of the Project:

A journal article is being produced with an objective to first publish these results in a peer-reviewed scientific journal followed by a trade-journal summary article. In addition, these results are being shared widely to a state, national, and international audience.

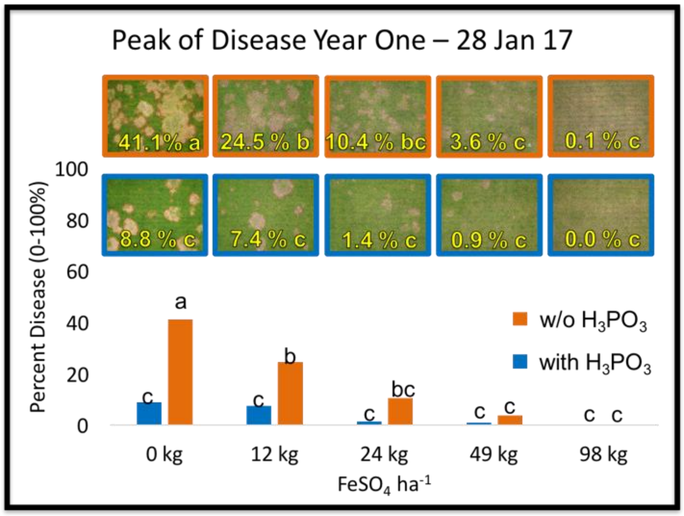


Figure 3. Percent disease for treatments applied every 2 weeks starting on Sep 29, 2016 on an annual bluegrass putting green in Corvallis, OR. Means followed by the same letter are not significantly different according to Fisher's protected LSD ($\alpha \leq 0.05$).

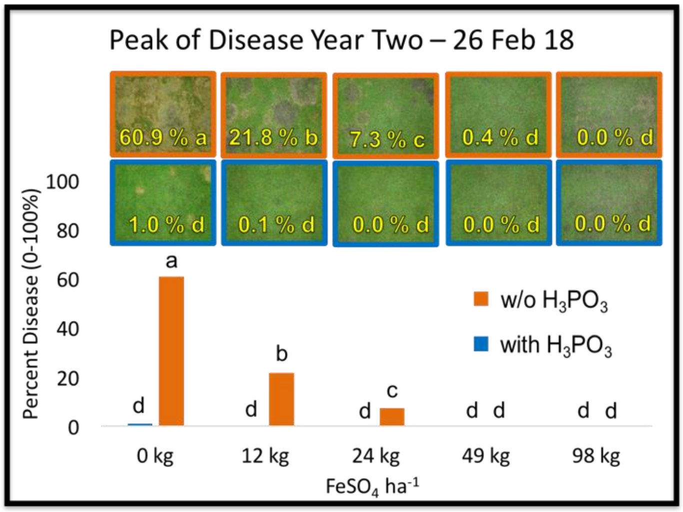


Figure 4. Percent disease for treatments applied every 2 weeks starting on Sep 28, 2017 on an annual bluegrass putting green in Corvallis, OR. Means followed by the same letter are not significantly different according to Fisher's protected LSD ($\alpha \leq 0.05$).

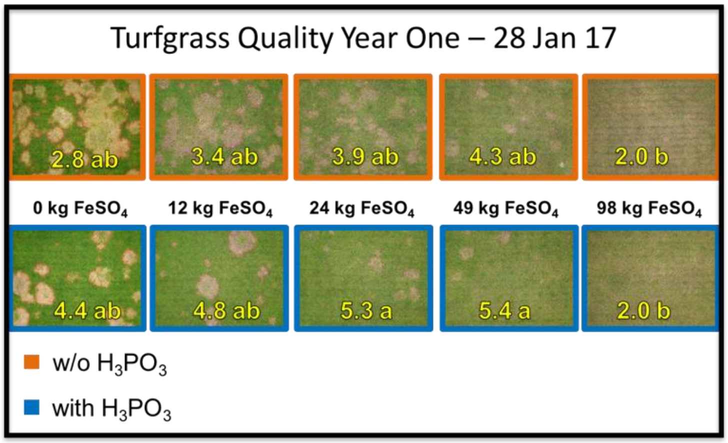


Figure 5. Turfgrass quality at the peak of disease for treatments applied starting on Sep. 29, 2016 on an annual bluegrass putting green in Corvallis, OR. Means followed by the same letter are not significantly different according to Dunn's all-pairwise comparison ($\alpha \leq 0.05$).

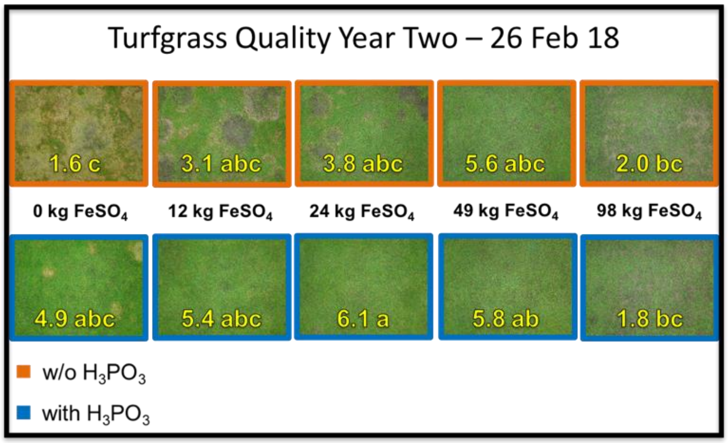


Figure 6. Turfgrass quality at the peak of disease for treatments applied starting on Sep. 28, 2017 on an annual bluegrass putting green in Corvallis, OR. Means followed by the same letter are not significantly different according to Dunn's all-pairwise comparison ($\alpha \leq 0.05$).

USGA ID#: 2017-18-628

Title: Effects of Nitrogen, Phosphate, and Potassium Rates on Microdochium Patch

Project Leader: Alec Kowalewski
Affiliation: Oregon State University

Objectives:
Evaluate the effects of monthly applications of nitrogen, phosphate, and potassium rates applied fall through spring on Microdochium patch development on an annual bluegrass putting green. The green will also be treated with sulfur + phosphite to lessen extreme disease symptoms which can routinely exceed 90% on our site.

Start Date: 2017
Project Duration: 3 years
Total Funding: $30,000

Summary Text:
In wet, northern climates with limited snow fall, Microdochium patch (*Microdochium nivale*) can be a devastating disease on annual bluegrass putting greens. In these climates, the turf does not go dormant and fertilizer applications are routinely made 12 months per year to mitigate golfer traffic. Anecdotal evidence from golf course superintendents suggest that applying urea alone incites this disease, but little is known about the effects of P & K applied in combination with Urea on annual bluegrass putting greens. However, recent research from Dr. Soldat at Wisconsin on bentgrass has shown that potassium applications increase Microdochium patch disease under snow cover. Other research from Schmid, Clarke, and Murphy at Rutgers has shown the importance of potassium applications on annual bluegrass for reducing anthracnose symptoms. Finally, much research has been done showing that annual bluegrass thrives with ample phosphorous. It's clear that N, P, & K have an effect on different diseases, but what that effect is on Microdochium patch growing on annual bluegrass not under snow cover is unknown.

This trial was designed as a 2 x 2 x 2 factorial with the factors being N, P, & K rates. The N-P-K applications are made monthly from October through April. From May through September, Anderson's soluble 28-5-18 + micros fertilizer is applied biweekly at 0.20 lbs N per 1,000 ft^2.

The N, P, & K rates are as follows:

1. Nitrogen (applied as urea 46-0-0):
    a. 0.10 lbs N/1,000 ft^2 applied monthly October thru April
    b. 0.20 lbs N/1,000 ft^2 applied monthly October thru April

2. Phosphorous (applied as Merchant Grade Phosphoric Acid (0-52-0)
    a. 0.000 lbs P/1,000 ft^2 applied monthly October thru April
    b. 0.025 lbs P/1,000 ft^2 applied monthly October thru April

3. Potassium (applied as Potassium Chloride 0-0-60)
    a. 0.00 lbs K/1,000 ft^2 applied monthly October thru April
    b. 0.10 lbs K/1,000 ft^2 applied monthly October thru April

Additionally, sulfur + phosphite were applied monthly October thru April to minimize disease symptoms.

Treatments:

Trt	N_Rate	P_Rate	K_Rate
1	0.10	0.0	0.00
2	0.10	0.0	0.10
3	0.10	0.025	0.00
4	0.10	0.025	0.10
5	0.20	0.10	0.00
6	0.20	0.10	0.10
7	0.20	0.025	0.00
8	0.20	0.025	0.10

Year One Results:

- There were no statistical differences in disease control until disease levels got above 5 percent which occurred on January 10th.
- The higher rate of nitrogen (0.20 lbs N/M/month) had more disease than the lower rate of nitrogen (0.10 lbs N/M/month) from January 10th up through the peak of disease on February 22nd.
- Surprisingly, after February 22nd, the higher rate of nitrogen led to less disease, presumably because it helped the turf recover and outgrow the disease in warmer weather.
- Nitrogen applied by itself had the most disease (at both nitrogen rates) from January 10th through the peak of disease on February 22nd.
- Nitrogen + potassium had the least disease from January 10th through the peak of disease on February 22nd.
- On 3 dates, Nitrogen + Phosphorous reduced disease when compared to Nitrogen only plots, but increased disease when compared to plots treated with N + K.

Future Expectations of the Project:

We are excited to see if these results will be duplicated in the remaining years. Early results from year 2 are again showing that plots treated with the higher rate of nitrogen have more disease than those treated with the lower rate, and that plots treated with nitrogen only at both rates have more disease than plots treated with N plus some combination of P, K, or both. However, we are not yet seeing that plots treated with N + K have the least disease, but disease levels are less than 2 percent.

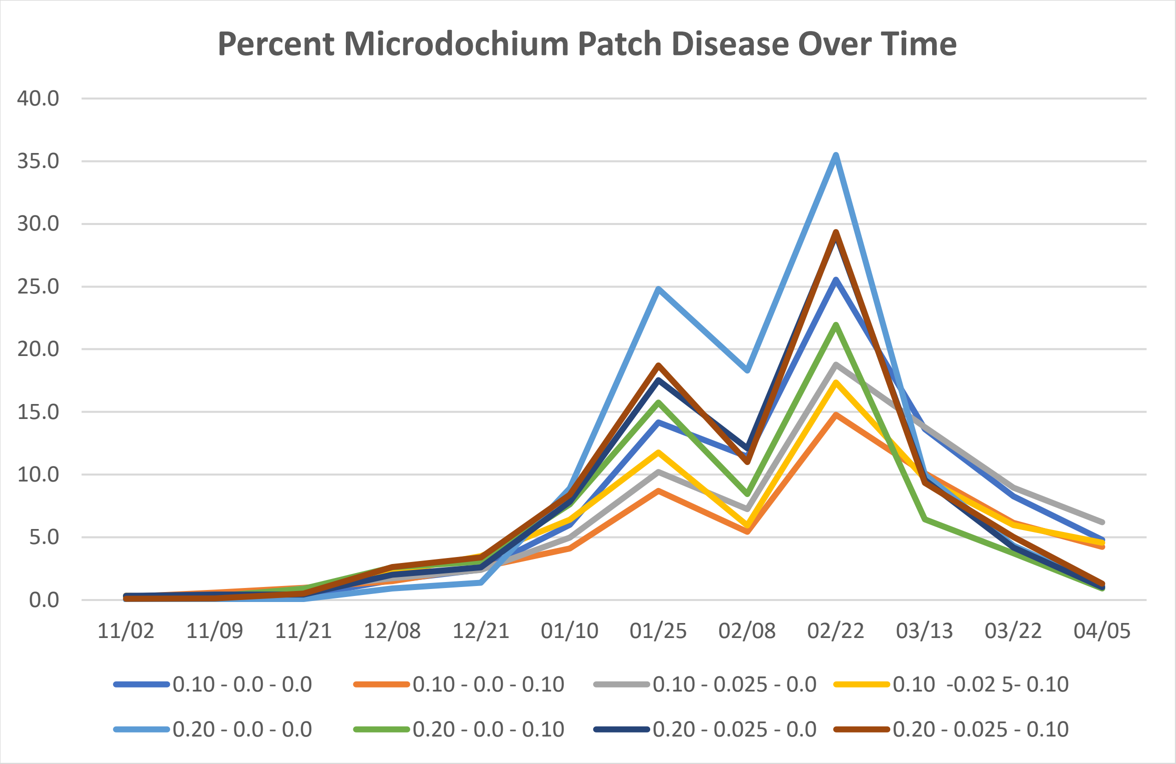


Figure 1. Percent Microdochium Patch Disease over time as affected by lbs. of N, P, and K (N-P-K) per 1,000 sq ft applied monthly.

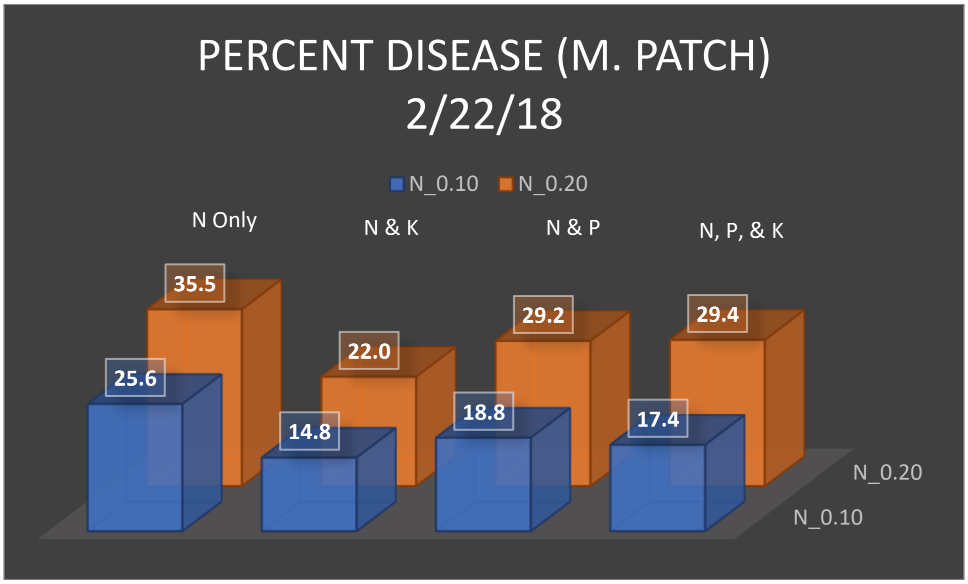


Figure 2. Percent Microdochium patch at peak of disease (2/22/18) as affected by N (applied at 0.1 and 0.2 lbs per 1,000 sq ft), P (0.025 lbs per 1,000 sq ft) and K (0.1 lbs per 1,000 qs ft) applied monthly.

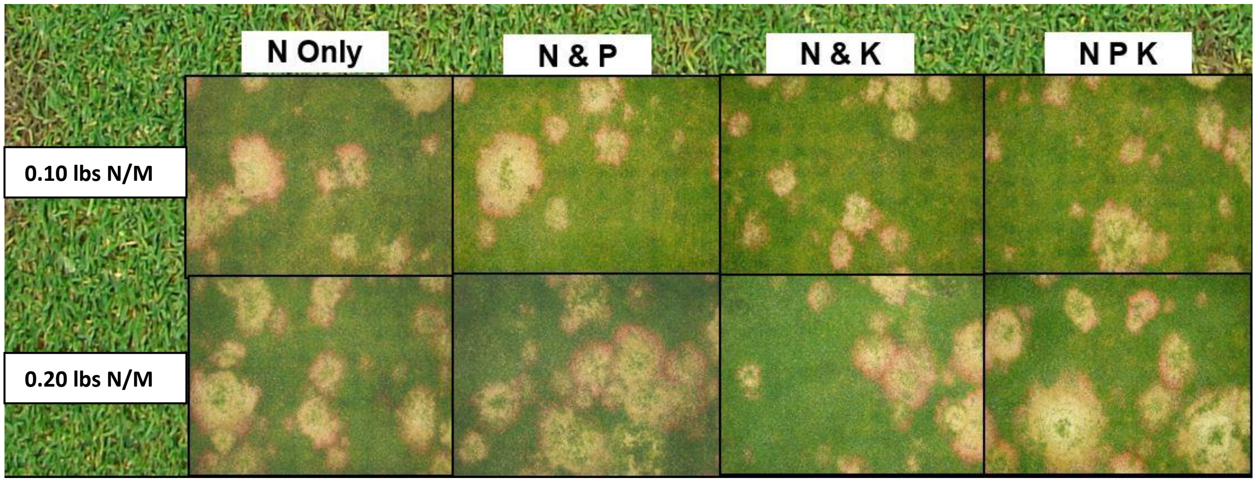


Figure 3. Light box photos, taken at peak of disease (2/22/18), as affected by N (applied at 0.1 and 0.2 lbs per 1,000 sq ft), P (0.025 lbs per 1,000 sq ft) and K (0.1 lbs per 1,000 qs ft) applied monthly.

USGA ID#: 2018-12-662

Title: Investing Factors Affecting Fungicide Performance on Golf Course Turf

Project Leaders: James Kerns, Ph.D. and Travis Gannon, Ph.D.
Affiliation: North Carolina State University

Objectives:

1. Determine the concentration of Segway (cyazofamid), Insignia (pyraclostrobin), Velista (penthiopyrad), and Bayleton (triadimefon) in clippings collected from creeping bentgrass and bermudagrass putting greens at various times after application.
2. Investigate the influence of mowing immediately after fungicide application (AFA), 1 day AFA, and 3 days AFA on dollar spot, Pythium root rot, and take-all root rot control.
3. Determine the effective concentration required to keep the diseases mentioned above suppressed

Start Date: 2018
Project Duration: 2 years
Total Funding: $34,800

Summary Points:

- Post application irrigation timing and mowing timing did not significantly influence the amount of fungicide removed in turfgrass clippings.
- The majority of fungicide is retained in the RAV (verdure/thatch) layer.
- Post application irrigation and mowing timing significantly influence the downward movement of fungicide into the soil profile.
- Irrigating immediately post fungicide application resulted in more fungicide being moved deeper into the soil profile within each DAT and over time.

Summary Text:

Fungicide fate and performance can be influenced by post application management practices (i.e. post application mowing timing and irrigation timing). Work conducted by Dr. Gannon and Dr. Jefferies found up to 34% of azoxystrobin can be removed in turfgrass clippings following a single mowing event one day after application. However, environmental fate and efficacy of fungicides influenced by post application management strategies has not been conducted on a golf course putting green. Therefore, the environmental fate and distribution of pyraclostrobin, triadimefon, penthiopyrad, and cyazofamid in soil and turfgrass clippings influenced by post application mowing and irrigation timings was evaluated on USGA spec bentgrass putting greens. Plots were treated with a single application of the aforementioned fungicides, irrigated either immediately or 6 hours after fungicide application with ¼” of water, mowed (non-sequentially, clippings collected) at 0, 1, 3 days after treatment (DAT), and analyzed using high performance liquid chromatography-mass spectrometry. Daily mowing resumed after 3 DAT (clippings collected and discarded). Cores were harvested using a standard 4.25” cup cutter and stored at 0°C until dissection and processing. Fungicide residuals were quantified in turfgrass clippings, remaining above ground vegetation (RAV; verdure/thatch), 0-1”, 1-2”, and 2-3” soil depths following the aforementioned treatments over time. To date, pyraclostrobin and triadimefon data has been analyzed and is presented as a percent of total applied.

Pyraclostrobin recovered in turfgrass clippings at 0, 1, and 3 DAT did not exceed 2.5% of total fungicide applied. The movement and distribution of pyraclostrobin over time following different irrigation and mowing treatments is illustrated in Figure 1. Post application irrigation timing and mowing timing did not significantly influence the percent of pyraclostrobin removed in turfgrass clippings. Within sampling days, post application irrigation timing did not influence the percent of pyraclostrobin detected in the RAV. However, differences were observed in soil subsections over the course of the experiment. For example, more pyraclostrobin was detected in the 0-1" soil layer when plots were irrigated immediately with 1/4" of irrigation. Similarly, at 3, 5, and 7 DAT, pyraclostrobin was only detected in plots receiving immediate irrigation. In the 0-1" soil layer at 14 DAT a significantly greater amount of pyraclostrobin was detected in plots receiving immediate irrigation compared to plots irrigated 6 hours after fungicide application

Triadimefon behaved similarly to pyraclostrobin. The movement and distribution of triadimefon over time following different irrigation and mowing treatments is illustrated in Figure 2. Less triadimefon was removed in turfgrass clippings when compared to pyraclostrobin. This may be due to the physiochemical properties of triadimefon (low K_{oc}=300 and high Ks=70). Irrigation timing and mowing timings did not significantly influence the amount of triadimefon removed in clippings or the amount detected in RAV. However, a greater amount of fungicide was detected in the 0-1" and 1-2" soil layers when irrigated immediately after application compared to plots irrigation 6 hours after the initial application. Triadimefon removed in the clippings and detected at various depths in the soil following different irrigation and mowing timings at 3 DAT is illustrated in Figure 3. Triadimefon was only detected in the 2-3" soil layer at 14 DAT when plots were irrigated immediately after application.

Post application irrigation timing, and to a lesser extent mowing timing, can influence fungicide movement through the soil profile. Delaying mowing events did not result in less fungicide removed in clippings, but may influence the downward movement and distribution of product into the RAV and soil. The current data suggests the majority of fungicide is retained in the RAV regardless of post application irrigation management strategy. However, irrigating immediately following fungicide application can move the fungicide deeper into the soil profile where the target pathogen(s) reside. Recovery (percent of applied) of pyraclostrobin and triadimefon ranged from 90-99% on 0 DAT confirming our analytical and sampling methodology.

Current data suggests fungicides with different physiochemical properties and mode of actions may respond differently to various post application management techniques. More refined statistical methods will be pursued to evaluate specific differences between treatments. The current data set is massive and for this report on simple ANOVAs could be conducted. Future reports will have a more robust statistical analyses. Residue analysis of penthiopyrad and cyazofamid are currently being processed and analyzed. We have quantified fungicide concentrations in RAV and various soil depths under field conditions following these post application management practices. This data will be used in conjunction with an *in vitro* fungicide assay to determine the concentrations required to suppress the dollar spot, Pythium root rot, and take-all root rot pathogen(s) growth. The environmental fate and movement of these compounds following post application management strategies will also be coupled with field efficacy and disease control studies.

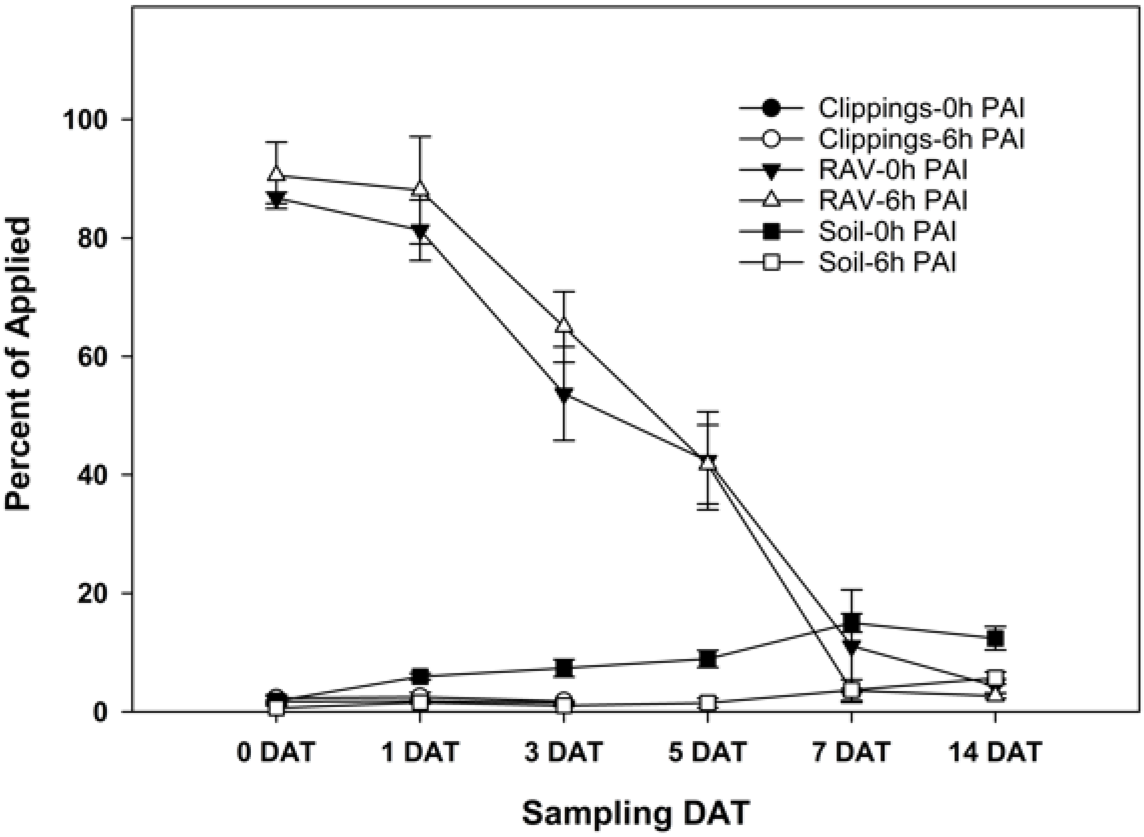


Figure 1. Influence of post application irrigation and mowing on pyraclostrobin residues recovered in turfgrass clippings, remaining above ground vegetation (RAV) and soil (0-2.54 cm). Post application irrigation (PAI) was applied at 0 hours (0h) or 6 hours (6h). Samples were collected on respective days after fungicide treatment (DAT).

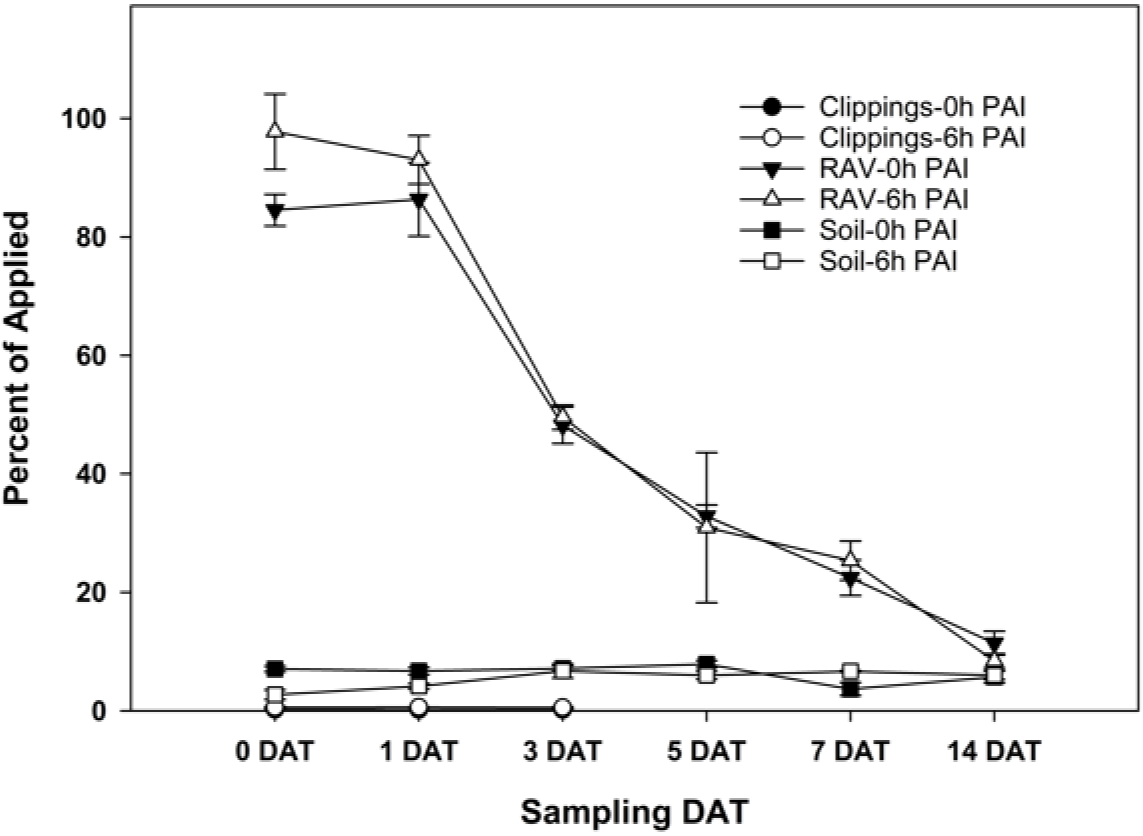


Figure 2. Influence of post application irrigation and mowing on triadimefon residues recovered in turfgrass clippings, remaining above ground vegetation (RAV) and soil (0-2.54 cm). Post application irrigation (PAI) was applied at 0 hours (0h) or 6 hours (6h). Samples were collected on respective days after fungicide treatment (DAT).

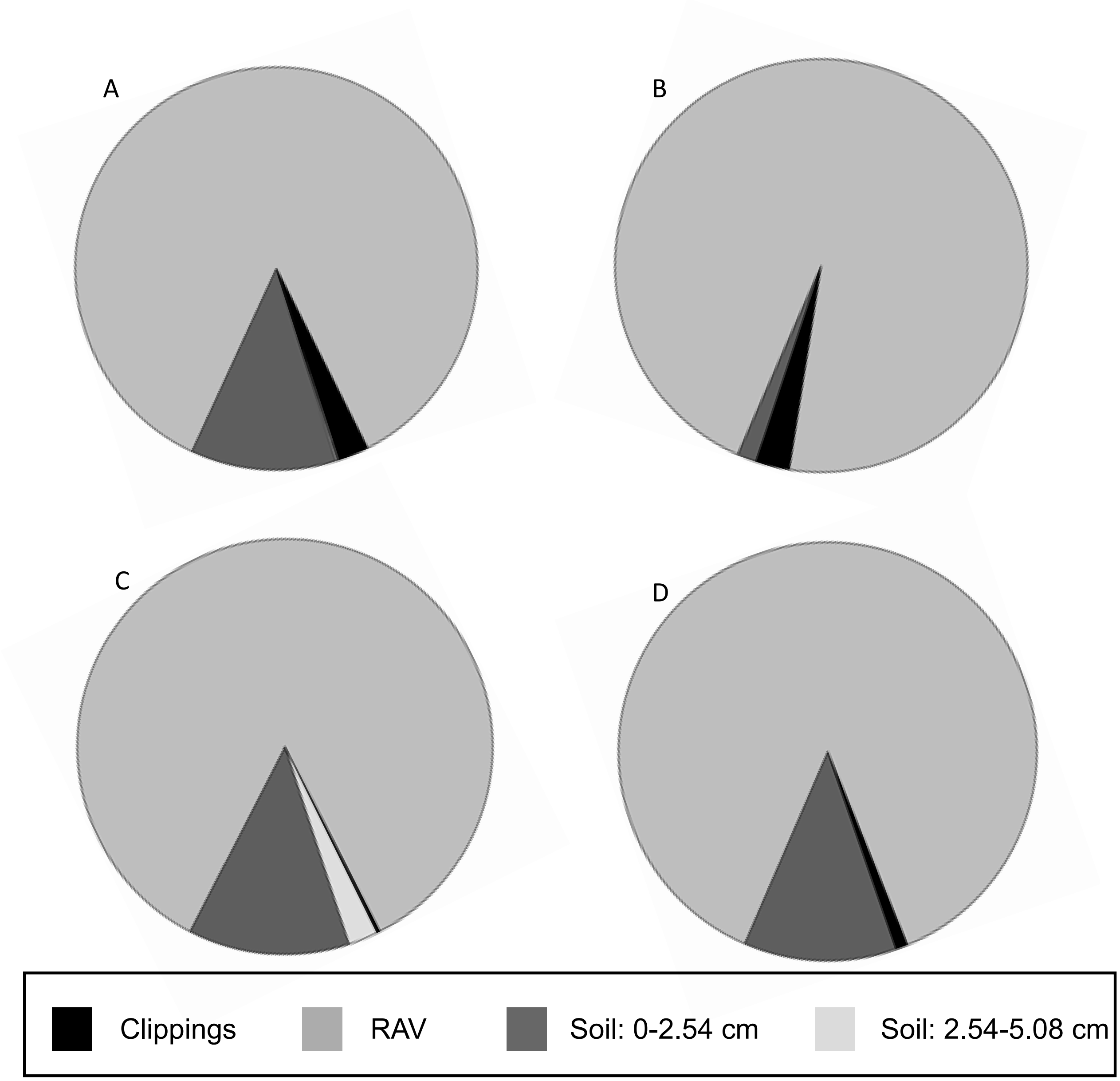


Figure 3. Distribution of fungicides in turfgrass clippings, remaining above ground vegetation (RAV), and soil (0-2.54 cm, 2.54-5.08 cm) sampled 3 days after fungicide treatment (DAT). **A)** Plots were treated with pyraclostrobin and received 0.64 cm of post application irrigation immediately following the fungicide application. **B)** Plots were treated with pyraclostrobin and received 0.64 cm of post application irrigation 6 hours after the fungicide application. **C)** Plots were treated with triadimefon and received 0.64 cm of post application irrigation immediately following the fungicide application. **D)** Plots were treated with triadimefon and received 0.64 cm of post application irrigation 6 hours after the fungicide application.

USGA ID#: 2016-23-573

Title: Effects of Mowing Height and Nitrogen Fertilization on Annual Bluegrass Weevil Oviposition, Larval Development, and Turfgrass Damage

Principal Investigator: Benjamin A. McGraw, Ph.D.
Affiliation: Pennsylvania State University

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.

Start Date: 2016
Project Duration: 3 years
Total Funding: $45,000

Summary Points:

- 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).
- 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.
- Adult activity on top of the turfgrass canopy was greatest when temperatures were between 14 and 18° C (57 and 64° F).
- 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.
- Larvae were capable of developing in all mowing height and fertility treatments. No significant differences in larval fitness were detected between treatments.
- Significant differences were detected in larval abundance (but not fitness) in plant growth regulated turf (trinexapac ethyl, trinexapac ethyl + ethephon) compared to untreated plots in 2017, but not 2018.
- Significantly more larvae were found in Primo plots than any other treatments in 2018. More research is required before conclusions can be made regarding the effect of growth regulation on ABW larval abundance and fitness

Summary Text:

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 (***Completed in 2017***)

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. Most 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° C and only low percentages were observed on top of the canopy when temperature were 10° 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° C. A polynomial regression model predicts that adults are most active on the surface between 14 and 17° 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 and 2018. 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 in either field season. Strong statistical differences were found between PGR treatments as well as N × PGR (Figure 3). However, these differences were not consistent between years. Fewer larvae were found in plots treated with trinexapac-ethyl (Primo) than those treated with ethephon- (Proxy) or those without growth regulation in 2017. In 2018, larvae were significantly more abundant in Primo- treated plots. More studies are needed to further elucidate the effects of PGRs on ABW fitness.

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.

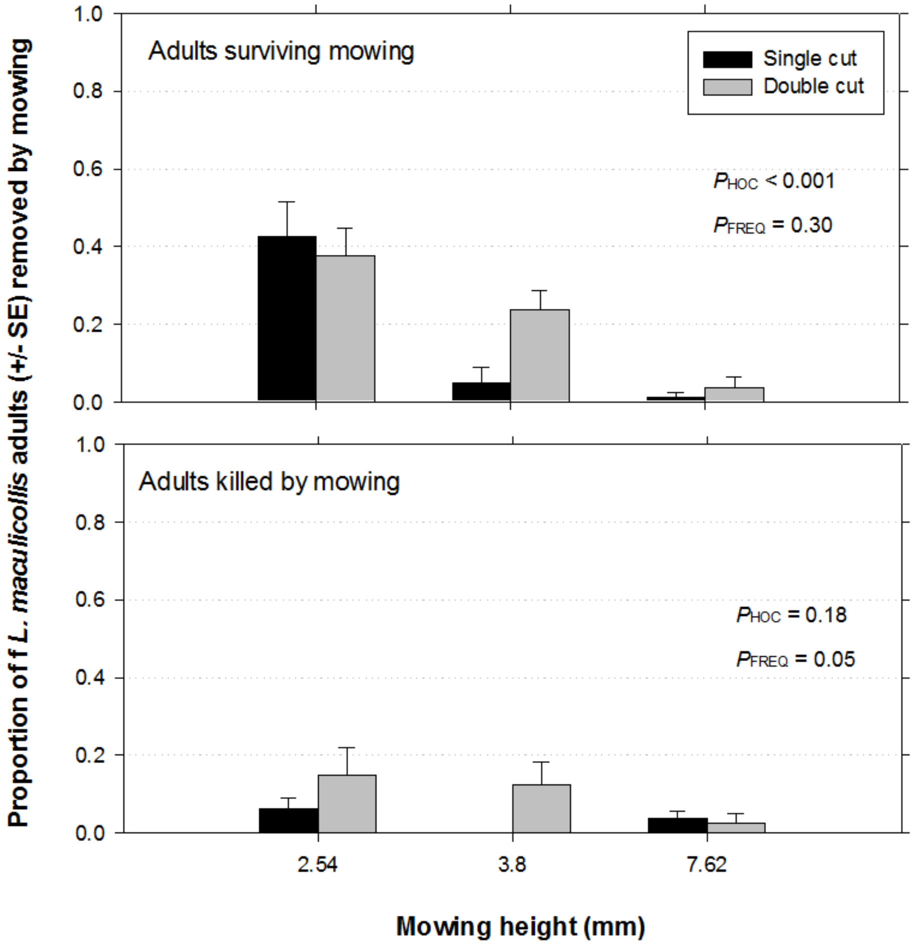
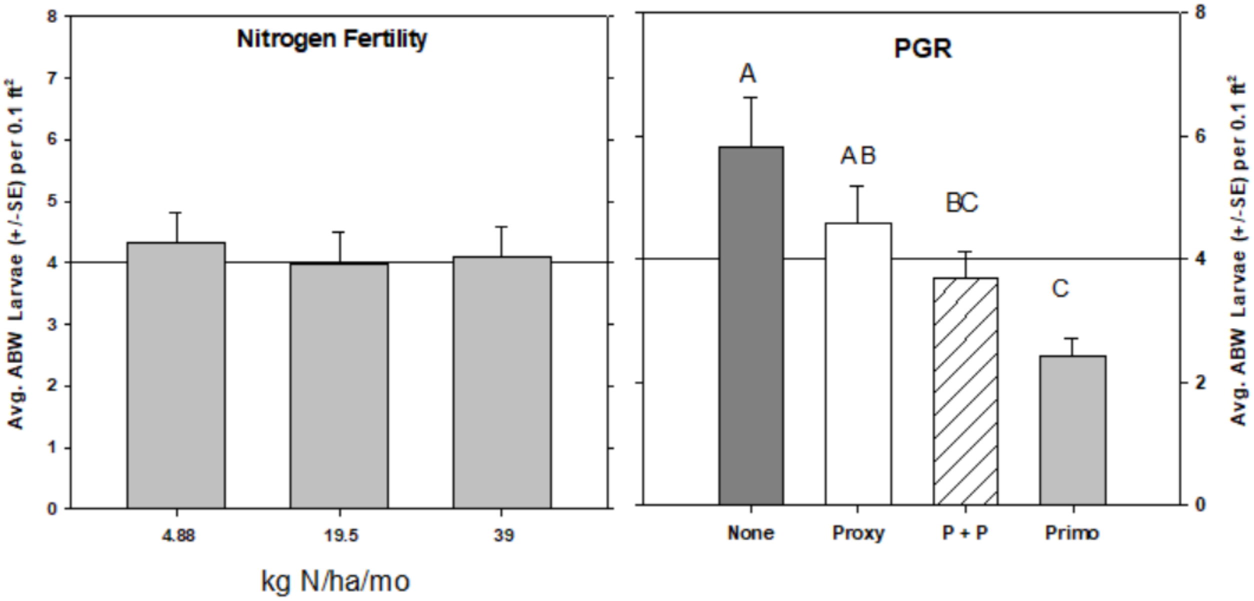


Figure 2. Effect of putting green mowing height-of-cut (HOC) and frequency (single and double cut) on the removal of *L. maculicollis* adults (2017). Polynomial contrasts were performed where ANOVA revealed significant effects at α = 0.05 level.

2017



2018

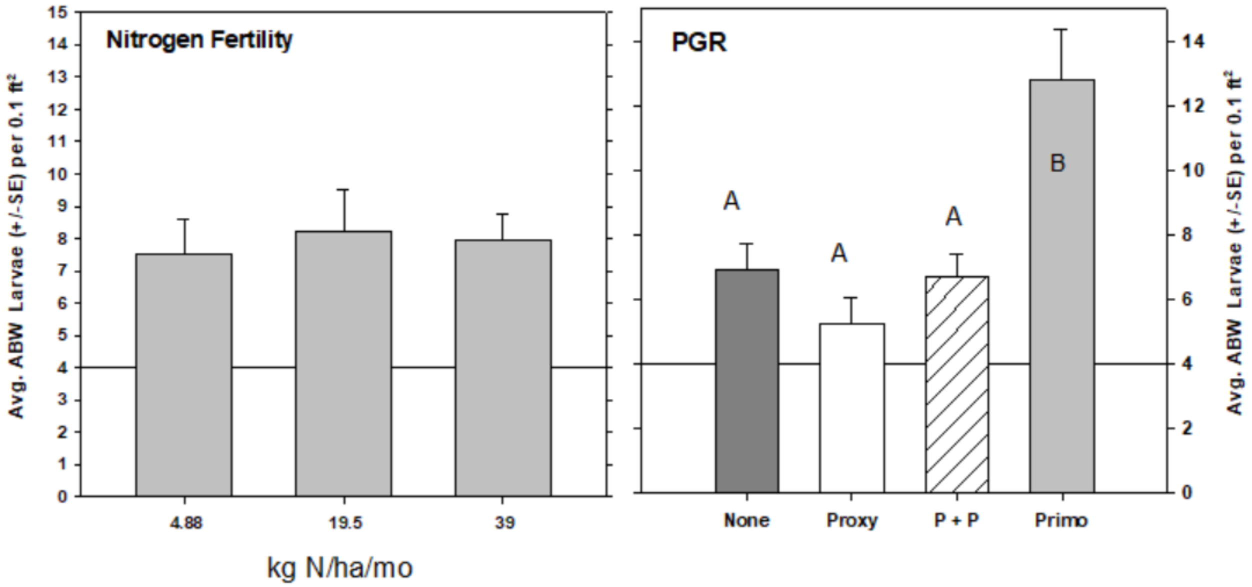


Figure 3. Effect of early-season nitrogen fertility and plant growth regulation on *L. maculicollis* larval abundance in no-choice field studies (2017-top, 2018- bottom). No significant differences were detected for fertility treatments in either year. Significant differences were detected between PGR treatments and PGR × Fertility treatments. Means marked with the same capital letter do not differ significantly within rate. The solid line represents the damage threshold for *L. maculicollis* (40 larvae/ft2).

USGA ID#: 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.

Start Date: 2018
Project Duration: 2 years
Total Funding: $38,976

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 in greenhouse and field experiments.
- Combinations of *M. brunneum* microsclerotia with the insecticide imidacloprid provided additive control of ABW larval populations in the field.
- Hydrogels had no significant effect on the performance of *M. brunneum* microsclerotia and their combinations with imidacloprid.

Summary Text:
The annual bluegrass weevil (ABW), *Listronotus maculicollis*, is a serious and expanding pest of short-mown golf course turf in eastern North America with demonstrated ability to develop resistance to a range of insecticide modes of action. These widespread resistance issues warrant the development of alternative control methods. While products based on the conidial spores of entomopathogenic fungi have thus far given unreliable control of ABW adults and larvae in the field, the use of fungal microsclerotia may improve economy and efficacy of fungus-based products. Some entomopathogenic fungi including *Metarhizium brunneum* naturally form microsclerotia in soil, which serve as survival structures. Applied microsclerotia granules produce infective conidial spores over several weeks, thus prolonging the residual effect of the fungus application. The addition of hydrogels may improve conidia production from microsclerotia in soil because hydrogels can hold large volumes of water when moistened and slowly release this retained water over time. This stabilizes soil moisture to the advantage of plants, fungi and other organisms.

In previously reported laboratory and greenhouse experiments, we had shown that the fungicides chlorothalonil and iprodione were compatible with *M. brunneum* F52 applied as microsclerotia but that propiconazole reduced conidia production by around 50%. Combinations of propiconazole +

trifloxystrobin and metconazole + pyraclostrobin were incompatible with the fungus in the laboratory experiment.

In laboratory experiments, adult ABW were susceptible to *M. brunneum* F52 applied as microsclerotia. However, no significant effect on survival of ABW adults and larval population densities was observed in greenhouse experiments with grass when treated with microsclerotia. In field experiments, microsclerotia applied to target the mid-sized larvae of ABW in spring, provided no significant control (0 – 17% suppression) while the insecticide imidacloprid alone provided 27 – 45% control. In combinations of the fungus with imidacloprid, mortality was additive, resulting in 34 – 64% control. The addition of hydrogel did not significantly increase mortality rates. Additional field experiments will compare the control efficacy of microsclerotia with that of commercial conidial spore formulations alone and in combinations with imidacloprid.

Figure 1. Damage caused by ABW larvae along fairway edge in late spring.

Figure 2. *Metarhizium brunneum* F52 colonies growing on agar plate.

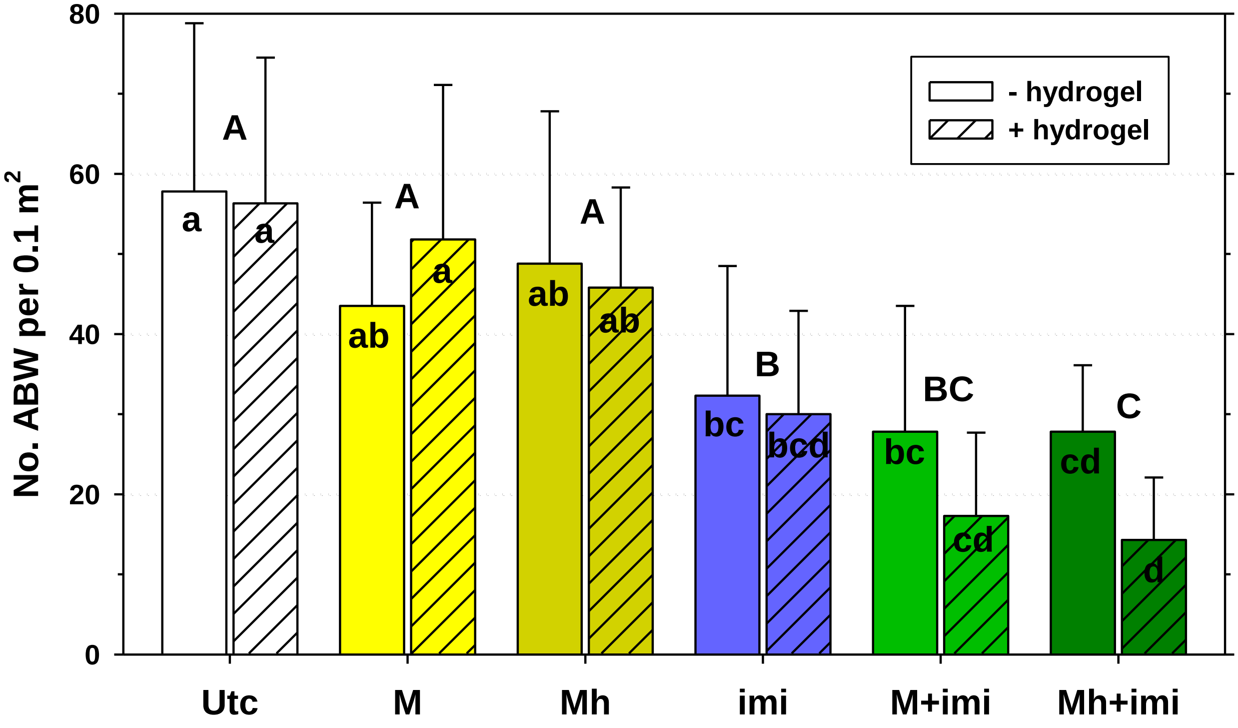


Figure 3. Mean density (± SEM) of ABW immature stages in golf course fairways treated the *Metarhizium brunneum* F52 microsclerotia at and (Mh), the insecticide imidacloprid (imi), and the combinations of both *M. brunneum* rates fungus with imidacloprid . Means with same lower case letter inside bar do not differ significantly (*P* = 0.05). Means (-/+ hydrogel combined) with same upper case letter above bars are do not differ significantly (*P* = 0.05).

USGA ID#: 2018-13-663

Title: Biorational Control of Annual Bluegrass Weevil Adults and Larvae with Petroleum-Derived Spray Oils and Soil Surfactants

Project Leaders: Benjamin A. McGraw, Ph.D.[1], Steven Alm, Ph.D.[2], Albrecht Koppenhöfer, Ph.D.[3]
Affiliation: [1]Pennsylvania State University; [2]University of Rhode Island; [3]Rutgers University

Objectives:

1. Determine effects of soil surfactant and Petroleum-Derived Spray Oil (PDSO) rate, soil moisture, and post-spray irrigation on adult annual bluegrass weevil (ABW) control.
2. Determine effects surfactant and PDSO rate, soil moisture, and post-spray irrigation on larvae control.
3. Determine effects of insecticide resistance on the efficacy of surfactant and PDSO applications.
4. Determine effect of adult ABW canopy-surface activity on product efficacy

Start Date: 2018
Project Duration: 2 years
Total Funding: $60,000

Summary Points:

- Both surfactants (Silwet, Helena Chemical Co.) and PDSOs (Civitas, Suncor Energy Inc.) can cause moderate to high adult mortality. Mortality was observed shortly after application (< 3 hrs), with most mortality occurring within 24 hrs.
- Moisture level significantly affected Civitas and Silwet efficacy. Low mortality was observed with all products at 50% saturation. Control with Civitas was improved at 150% filter paper saturation.
- Low adult surface activity and control by surfactants and PDSOs was observed in temperature- controlled, direct spray assays where post-application irrigation was withheld. No conclusions may be drawn from these data.
- No differences in susceptibility to surfactants or PDSOs were detected between pyrethroid resistant and susceptible populations.

Summary Text:

The annual bluegrass weevil (ABW), *Listronotus maculicollis*, is the most devastating and difficult to control turfgrass insect pest in eastern North America. Superintendents have traditionally relied on synthetic insecticides for ABW management, primarily using broad-spectrum adulticides (pyrethroids, chlorpyrifos) to control overwintered adults in spring before they begin egg laying. The recent increase in the development of pyrethroid- and multiple-resistant populations has created a dire need to develop non-chemical alternatives, especially for adult management. Preliminary laboratory trials suggest that oils and petroleum-derived spray oils (PDSOs) are capable of controlling adults, and that mortality is achieved quickly. These initial studies also determined that high levels of moisture are necessary to improve the contact activity of these products. The current research seeks to determine the variables that influence control, how control may be improved in the golf course environment, and whether these products may also have larvicidal activity.

Effects of surfactant and PDSO rate, soil moisture, post-spray irrigation, and insecticide resistance on adult control.

Experiments were conducted in Petri dishes (9 cm) lined with two moist filter papers. Ten overwintered adults from a pyrethroid-susceptible population were introduced in the dishes. Then treatments were sprayed using plastic atomizers. Control dishes were sprayed with water only. Mortality was evaluated at 3, 24, 48, and 72 h after treatment application. Experiments was conducted 3-4 times with 2 dishes per treatment.

Experiment 1 tested the effects of rate and spray volume. Filter papers were pre-moistened with 1.75, 1.5, 1.0 ml of water, so the final water content in each dish after spraying treatments was 2 mL (= saturation but no excess water). Three rates of Civitas (2.5, 4.0, 6.0 fl oz/1000 ft2 (M)) and Silwet (0.175, 0.25, 0.4 fl oz /M) were sprayed at three volumes (1, 2, 4 gal/M = 0.25, 0.5, 1 mL/dish). Control dishes were sprayed with water only. ABW mortality was evaluated at 3, 24, 48, and 72 h after treatment application. Both the surfactant (Silwet, Helena Chemical Co.) and PDSO (Civitas, Suncor Energy Inc.) caused moderate to high adult mortality (> 80% control), with most mortality occurring within 24 hrs (Figures 1 and 2). Applications of Civitas, but not of Silwet resulted in significant increases in mortality with time. Mortality in Silwet-treated dishes was significantly affected by rate. Rate was a significant factor in Civitas treatments and there was a weak effect of volume at 3 and 24 h.

Experiment 2 tested the effect of substrate moisture at one rate of each product (Civitas: 3 fl oz/M; Silwet: 0.175 fl oz/M). Moisture in the Petri dishes was added so the final moisture level was 50, 100, 150% saturation (1, 2, 3 ml per Petri dish including spray volume). Treatments were sprayed in a carrier of 2 gal/M. Moisture level significantly affected Civitas and Silwet efficacy at each evaluation time (Figure 3). For both products, 50% moisture had only very limited mortality (< 5%) which was significantly lower than for the higher moisture levels. For Civitas, mortality at 150% was significantly higher than at 100%. For Silwet, an increase of ~30% across evaluations times was never significant.

Experiment 3 tested the susceptibility to Civitas and Silwet of a bifenthrin-susceptible (PB) and a bifenthrin-resistant population (EW) was tested. Civitas (3 fl oz/M) and Silwet (0.25 fl oz/M) were sprayed in a carrier volume of 2 gal/M. No differences in the susceptibility to Silwet and Civitas were observed between pyrethroid resistant and susceptible populations (Table 1).

Effect of adult ABW canopy-surface activity on product efficacy.

The effect of adult surface activity on product efficacy was assessed in growth chamber studies. Briefly, adults were placed on a *P. annua* turf cores and held at a constant temperature (10, 17, or 25° C) for 24 hr. After the acclimation period, turf cores were removed from their incubator individually for photographing (to detect presence on the surface), followed immediately by treatment application, and then immediately placed back into the incubator. Treatments were applied using a hand sprayer/atomizer and calibrated to deliver products in a carrier volume of 2 gal/M. No post application irrigation was provided. Control was assessed 24 hr after application.

A significant correlation between surface activity and temperature was observed, but the lowest average activity was observed at 17° C, or what was predicted to be the optimum for ABW surface activity based on previous research. Mortality was very low in all treatments, with Silwet providing the highest control (12.5 -13%).

Future expectations:

Future research will be directed towards evaluating Civitas in the field against adults and larvae. Phytotoxicity was observed when Silwet was applied at 5.0 fl oz/M in preliminary greenhouse and small plot field trials. These rates are important for achieving moderate to high levels of control, and therefore this surfactant must be omitted from future testing. Laboratory experiments have demonstrated that moisture is critical to achieving high levels of control. Therefore, field experiments to be conducted in the upcoming year will examine ways in which turfgrass managers may manipulate moisture in the canopy and/or rootzone (e.g. carrier volume, pre- and post -application irrigation).

Other potential experiments may include exploring potential synergism between surfactants/PDSOs and pyrethroids in both susceptible and pyrethroid-resistant populations.

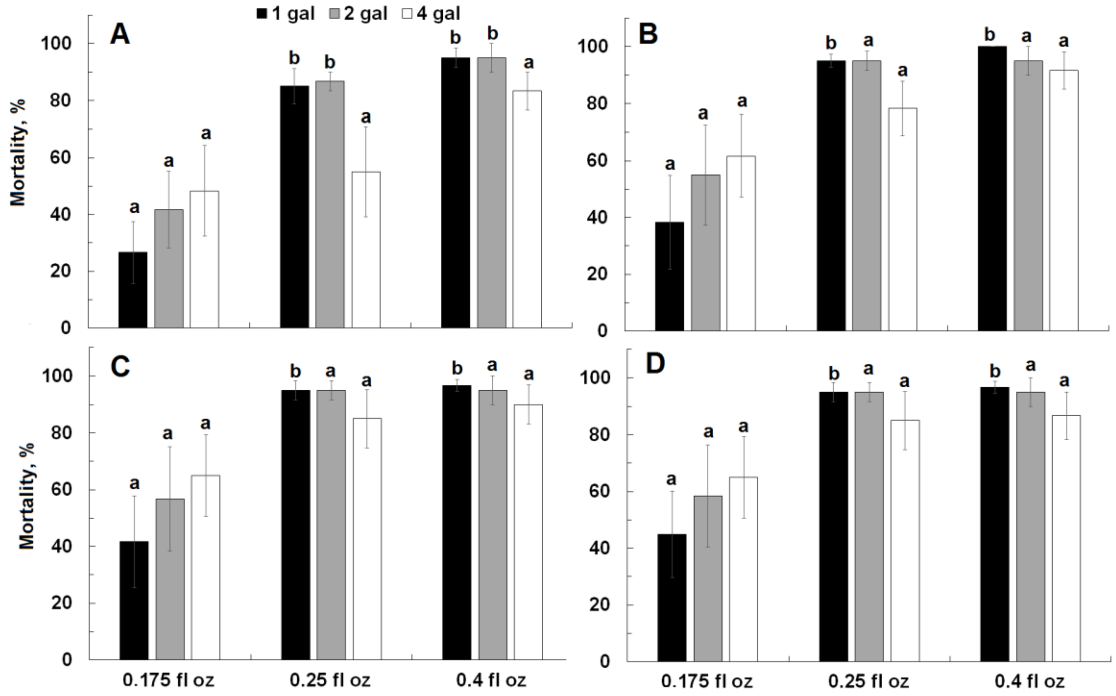


Figure 1. Effect of three Silwet rates (0.175, 0.25 and 0.4 fl oz per 1000 sq ft) applied at different volumes (1, 2, and 4 gal per 1000 sq ft) on mortality of ABW adults evaluated at 3 h (A), 24 h (B), 48 h (C) and 72 h (D) after treatment. Mortality is corrected for the control mortality (48 and 72 h). Means marked with the same letter do not differ statistically within the application volume (among rates tested).

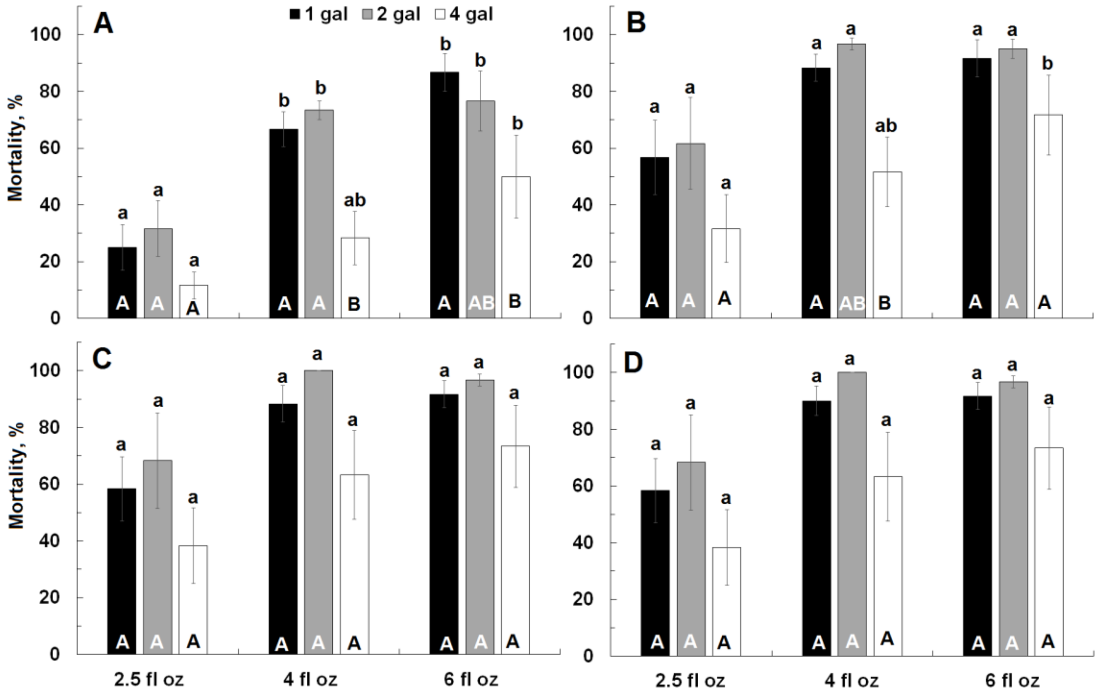


Figure 2. Effect of three Civitas rates (2.5, 4.0 and 6.0 fl oz per 1000 sq ft) applied at different volumes (1, 2, and 4 gal per 1000 sq ft) on mortality of ABW adults evaluated at 3 h (A), 24 h (B), 48 h (C) and 72 h (D) after treatment. Mortality is corrected for the control mortality (48 and 72 h). Means marked with the same lower case letter do not differ statistically within the application volume. Means marked with the same capital letter do not differ significantly within rate.

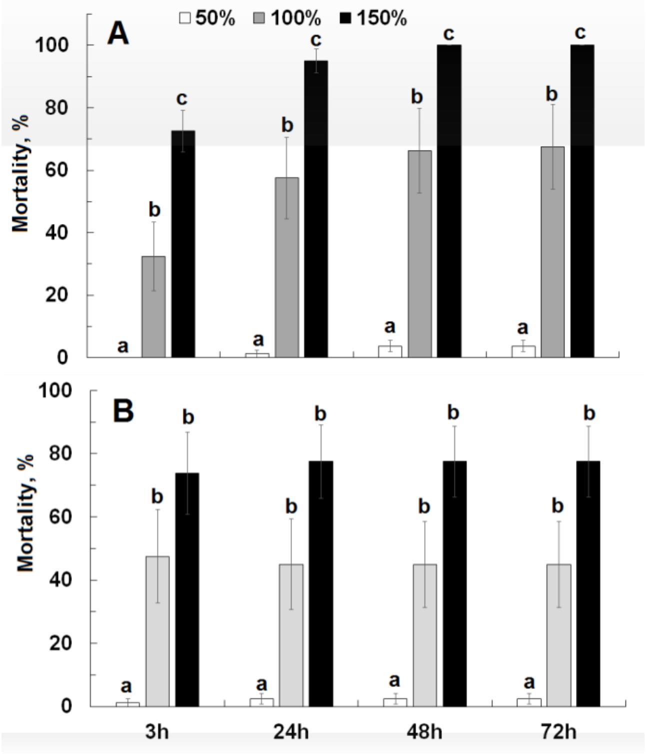


Figure 3. Effect of Civitas (A) and Silwet (B) applied at different moisture levels (50%, 100%, 150% filter paper saturation) on mortality of ABW adults evaluated at 3 h, 24 h , 48 h and 72 h after treatment. Means marked with the same letter do not differ statistically within each evaluation time.

Table 1. Percent mortality of susceptible (PB) and resistant (EW) ABW adults exposed to Civitas and Silwet (2 gal/M spray volume, 100% filter paper saturation).

TRT	Population	3 h		24 h		48 h		72 h	
		Mortality	SE	Mortality	SE	Mortality, %	SE	Mortality	SE
Civitas	EW	33.3	11.4	63.3	12.0	73.3	9.4	70.6	10.2
	PB	44.4	13.0	70.0	14.7	72.2	14.3	72.2	14.3
Silwett	EW	71.1	11.7	64.4	11.4	60.8	11.3	56.8	10.9
	PB	73.3	9.6	68.9	10.1	63.7	10.9	58.9	10.7

USGA ID#: 2017-03-613

Title: Use of fraise mowing and herbicides to eradicate bermudagrass

Project Leaders: Mike Richardson[1], John McCalla[1], Jim Brosnan[2], and Greg Breeden[2]
Affiliation: [1]University of Arkansas, [2]University of Tennessee

Objectives: To investigate various herbicide treatments for bermudagrass eradication, applied either prior to or after fraise mowing.

Start Date: 2017
Project Duration: 2 years
Total Funding: $7,000

Summary Points:

- Herbicides had a significant effect on bermudagrass control across all rating dates at both trial locations and there was also a significant fraise mowing x herbicide interaction.
- Fraise mowing generally improved herbicide activity on bermudagrass control, especially at the Arkansas location (Figures 2 and 3).
- At both locations, better control was observed when the herbicide was applied following fraise mowing or before and after fraise mowing (Figure 2).
- Herbicide treatments applied before fraise mowing only provided bermudagrass control at 4 weeks after fraise (WAF) treatments but plots had recovered at 12 weeks after fraise (Figure 2).
- Multiple herbicide applications (before and after fraise mowing) generally provided the best bermudagrass control when compared to the untreated checks at both the Arkansas and Tennessee sites (Figure 2).

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 "fraise 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 fraise mowing that has not been investigated is whether aggressive fraise 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 fraise 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 herbicide treatments for bermudagrass eradication, applied either prior to or after fraise mowing.

Materials and Methods

In 2017, this study was conducted on two sod production farms, including Modern Turf in Rembert, SC and Bayou Bend Turf Grass in Bastrop, LA . In 2018, studies were conducted at the University of Arkansas Extension and Research Center, Fayetteville AR and the East Tennessee AgResearch and Education Center in Knoxville, TN. Each study site was set up as a split-split plot design with fraise mowing treatments being assigned to the whole plots and herbicide timing and treatments applied as the split plots. The experiment was conducted on several cultivars at various locations. Locations, dates of herbicide applications and dates of fraise mowing are detailed in Table 1.

The fraise mower used for these trials was a Koro Field Top Maker 1200 (Campey Turf Care Systems, Cheshire United Kingdom) set to a depth of 3.75 cm (Figure 1). Herbicide treatments in 2018 included the following:

1. Roundup Pro at 7.7 L ha^{-1} + Fusilade II at 1.75 L ha^{-1} + nonionic surfactant (0.25%)
2. 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 focus on the 2018 trial sites and observations.

Results

Overall, these results demonstrated that fraise 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 fraise mowing, in an effort to achieve 100% bermudagrass control in a timely fashion.

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Acknowledgements:

The authors gratefully acknowledge support received from the two sod companies and their staff that hosted these experiments in 2017, 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 fraise mowing equipment to each site in 2017 and to Rick Kadlec of GLK Turf Solutions for providing the equipment at the Arkansas site in 2018.

Figure 1. Koro Field Topper being used to fraise mow plots at the Fayetteville Research Station in 2018.

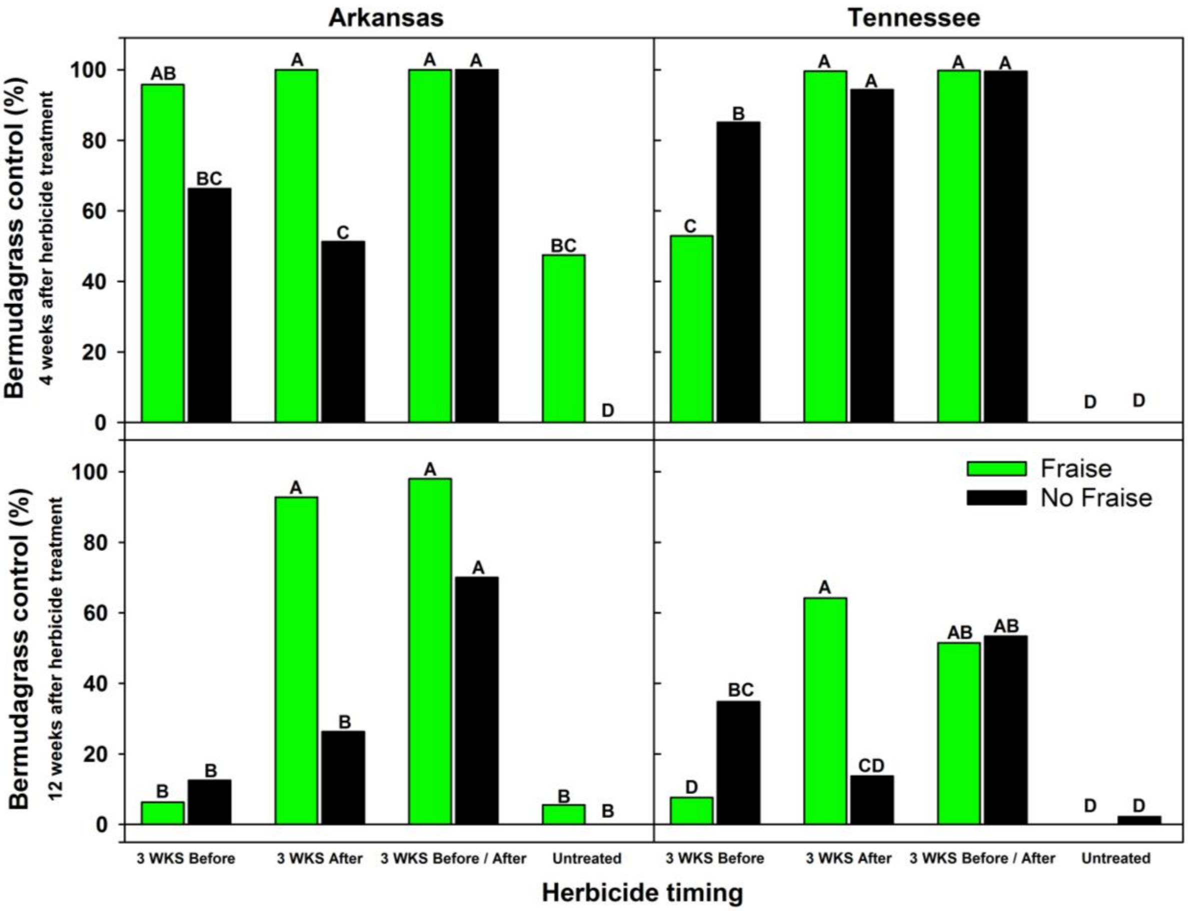

Figure 2. Effects of fraise mowing and various herbicide application dates on bermudagrass control at both the Arkansas and Tennessee sites at 4 weeks and 12 weeks after the final herbicide applications. Within each graph, bars with different letters are statistically different according to Fisher's Protected Lease Significant Difference (P=0.05).

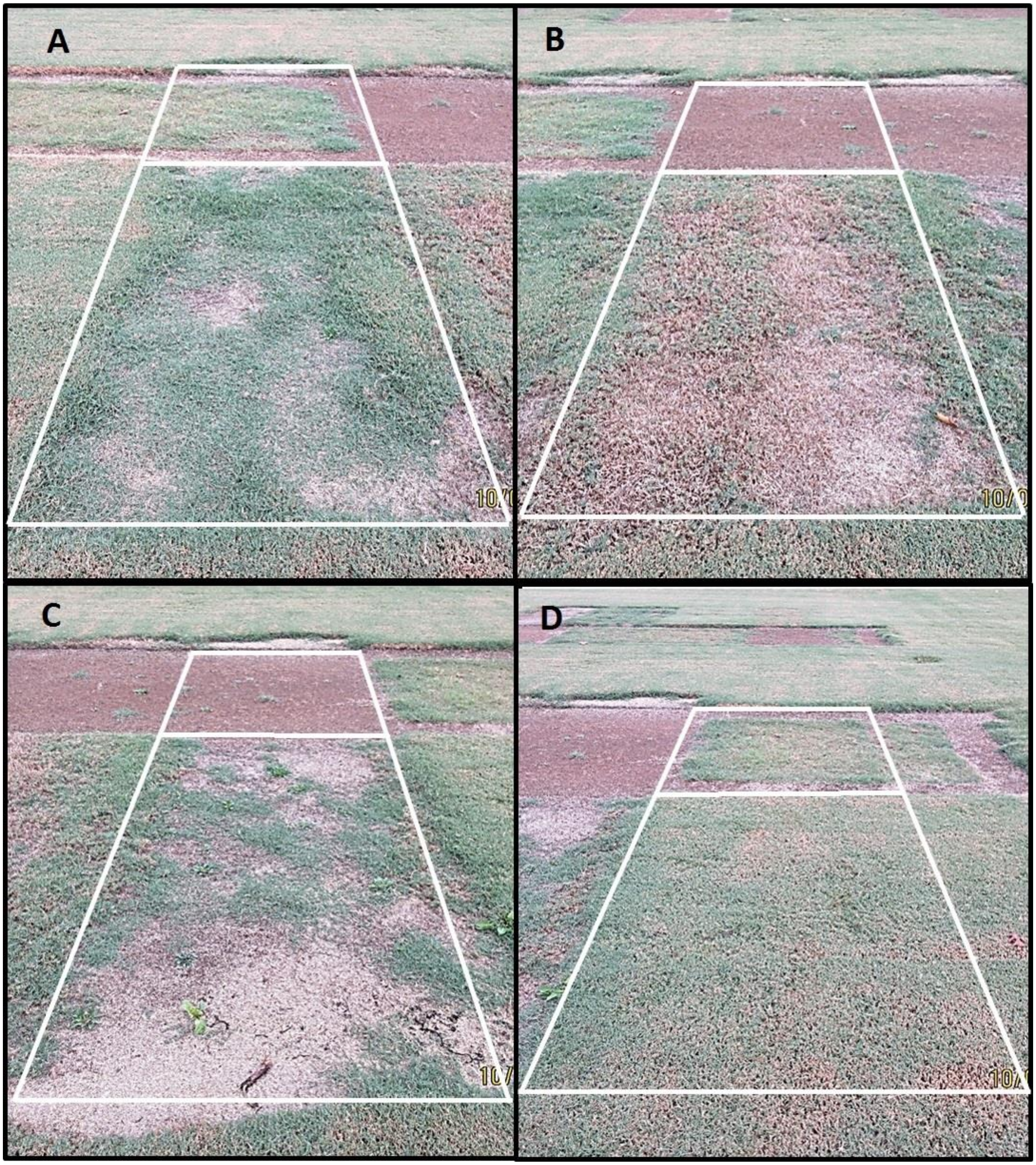

Figure 3. Bermudagrass control, as affected by fraise mowing and herbicide applications, at 12 weeks after final herbicide application in Fayetteville AR. Within each image, the non-fraised plots are positioned in the foreground. The herbicide timings are as follows: A) 3 wks before fraise mowing, B) 3 wks before and 3 wks after fraise mowing, C) 3 wks after fraise mowing, and D) no herbicide.

Table 1. Site descriptions and application dates for herbicide timing and fraise mowing treatments.

Year	Location	Cultivar	Pre-fraise herbicides	Fraise mowing	Post-fraise herbicides
			----------------	date applied	----------------
2017	Modern Turf Rembert SC	Celebration	6/5/2017	6/13/2017	7/11/2017
2017	Bayou Bend Sod Bastrop LA	Tifway	6/30/2017	7/10/2017	7/31/2017
2018	University of Arkansas Fayetteville AR	Tifway	6/4/2018	6/22/2018	7/14/2018
2018	University of Tennessee Knoxville TN	Tifway	5/14/2018	6/4/2018	6/26/2018

USGA ID#: 2018-07-657

Title: Developing Methods to Diagnose Herbicide Resistance in Goosegrass

Project Leaders: James T. Brosnan, Ph.D. and José J. Vargas
Affiliation: University of Tennessee

Objectives: Develop diagnostic assays to screen mature goosegrass plants from golf course turf for resistance to various pre- and postemergence herbicides.

Start Date: 2018
Project Duration: 2 years
Total Funding: $78,800

Summary Points:

- Herbicide-resistant goosegrass is becoming increasingly problematic on golf courses throughout the United States.
- Golf course superintendents have few means of confirming herbicide resistance in goosegrass in a timely manner leaving them little guidance regarding proper management in-season.
- Although it is the most widely used PPO-inhibitor for goosegrass control on golf courses, oxadiazon may not be the ideal herbicide to use in developing a diagnostic assay to screen goosegrass for resistance to this mode of action.
- Agar-based assays for screening goosegrass for resistance to ALS inhibiting herbicides are currently being developed.

Summary Text:
Once a problem in only the southernmost regions of the United States, goosegrass (*Eleusine indica*) has become a troublesome weed throughout the entire southern region, and has moved north into the transition zone and mid-Atlantic regions of the United States. Limited herbicide options for selective goosegrass control in these areas has driven selection pressure for goosegrass biotypes resistant to several different herbicidal modes of action, which serves to compound the problem of controlling goosegrass on golf courses. A two-year projected was initiated at the University of Tennessee in 2018 to develop diagnostic assays to screen mature goosegrass plants from golf course turf for resistance to various pre- and postemergence herbicides.

Protoporphorinogyen Oxidase (PPO) Inhibiting Herbicides: An electrolyte leakage assay developed for agronomic weeds was refined for use in screening mature goosegrass plants from golf courses for resistance to the PPO inhibiting herbicide oxadiazon. Thirty-two leaf segments of goosegrass biotypes suspected to be resistant and susceptible to oxadiazon were placed in plant tissue culture boxes (Magenta GA-7, Bioworld, Dublin, OH) filled with 100 mL of a solution containing the following: sucrose (2%), 1mM 2-(N-morpholino)ethanesulfonic acid buffer (MES), a non-ionic surfactant (0.25%) and 100 µM of oxadiazon. Eight cucumber (*Cucumis sativus*) leaf segments (1 cm_2) were included in similar plant tissue culture boxes as a positive control for comparison. This design provided 32 cm of cut leaf tissue (per species/biotype) in contact with herbicide-buffer solution. Electrolyte leakage was quantified by measuring electrical conductivity of the buffer-herbicide solution inside each plant tissue culture box before inclusion of leaf segments and then on four-hour intervals thereafter until 16 hours had elapsed. Initial pilot experiments suggested no benefit to incubating boxes in darkness prior to collecting electrical conductivity data nor collecting data beyond an exposure period of 16 hours. Data were collected using a conductivity cell (PYPC12S. Sartorius. Bohemia, NY) affixed to a electrochemistry meter (Model 250.

Denver Instrument. Bohemia, NY) and expressed as change in electrical conductivity (ΔEC) over time. This experiment was replicated several times during 2018 with data from each subjected to regression analysis in Prism (v7.0d). Interestingly, minimal increases in ΔEC where observed when exposing both goosegrass biotypes to oxadiazon, whereas ΔEC values for cucumber increased dramatically (Figure 1). This response suggests that oxadiazon may not be the ideal herbicide to use in developing a diagnostic assay to screen goosegrass for resistance to PPO inhibitors. The aforementioned method will be refined in 2019 for use with other PPO inhibitors including flumioxazin, fomesafen, or oxyfluorofen.

Acetolactate Synthase (ALS) Inhibiting Herbicides: A biotype of goosegrass with putative resistance to ALS inhibiting herbicides was collected during 2018 and is being propagated for use research during 2019. Our objective is to refine the agar-based assay used by Brosnan et al. (2017) to screen annual bluegrass (*Poa annua*) for resistance to ALS inhibitors for use on goosegrass.

Literature Cited

Brosnan, J.T., J.J. Vargas, E.H. Reasor, R. Viggiani, G.K. Breeden, and J.M. Zobel. 2017. A diagnostic assay to detect herbicide resistance in annual bluegrass (*Poa annua*). Weed Technology. 31: 609-616.

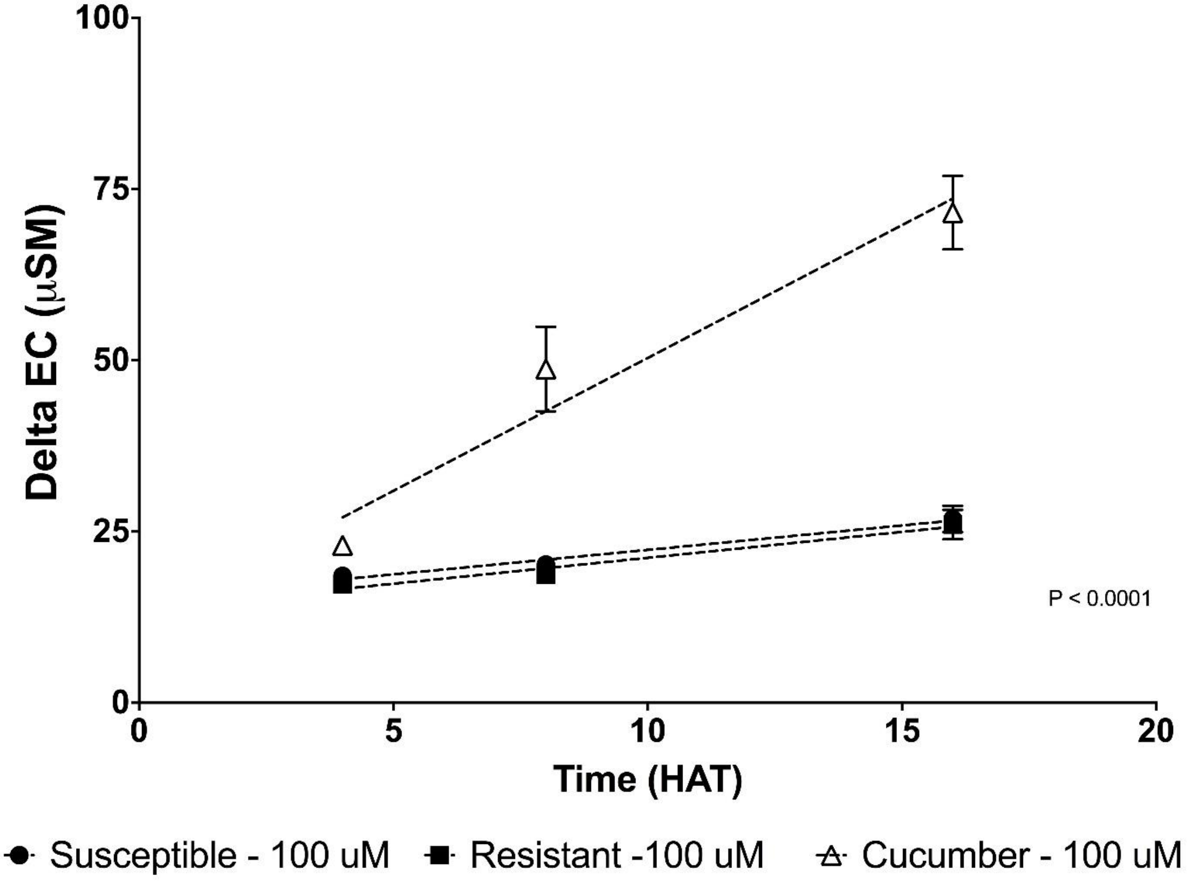

Figure 1. Change in electrical conductivity (ΔEC) from 0 to 20 hours after treating susceptible or resistant goosegrass biotypes and cucumber with oxadiazon.

USGA ID#: 2016-19-569

Title: Characterizing Growth and Life History of Silvery-Thread Moss in Cool-Season Putting Greens: Assessing Vulnerability to Stress in the Life Cycle

Project Leaders: Lloyd Stark[1], Steven Keeley[2], and Zane Raudenbush[3]
Affiliation: [1]University of Nevada Las Vegas; [2]Kansas State University; [3]Ohio State ATI

Objectives:

1. Accumulate genotypes of *Bryum argenteum* from a range of putting green and native habitats and place these into pure cultures.
2. Elucidate the life history strategies of putting green vs. native genotypes of *Bryum argenteum*.
3. Determine how this moss species responds to stresses in its life cycle, including how carfentrazone and desiccation influence the ability of the moss to regenerate.

Start Date: 2016
Project Duration: 3 years
Total Funding: $45,000

Summary Points:

- Accessed, organized, and grew to pure culture, 17 genotypes of *Bryum argenteum* from golf course putting greens and 17 genotypes of *B. argenteum* from native habitats, for purposes of comparing their life history and stress responses.
- Conducted a six-month life history experiment using the 34 cultures above, and including a treatment of nutrients vs. no nutrients. Our major findings, published in *Weed Science*, are that plants from putting greens diverge from plants from non-putting green habitats in (i) growing much faster both laterally and vertically, (ii) colonizing more quickly, (iii) producing more shoots, (iv) producing more "aerial rhizoids" (specialized extensions from the shoots to anchor it among the grasses and likely functioning in making space for the moss plants), and (v) focusing energy on asexual reproduction through shoot fragments rather than sexual reproduction or even specialized asexual reproduction.
- Based on the findings from this experiment, we concluded that either (i) recent natural selection pressures have yielded a species with a combination of traits adapted to putting green survival, or (ii) successful genotypes of the species are preexisting in the native environment, and only these strains survive the putting green environment.
- Designed and implemented an experiment testing the tolerance of putting green and native *B. argenteum* genotypes to carfentrazone concentrations, light intensity variation, and surfactant concentrations. This experiment in progress has already yielded evidence of recent natural selection on putting green strains indicating resistance to carfentrazone. In addition, the most promising avenue of future research involves the development of a surfactant to treat infestations of this moss in putting greens.

Summary Text:

The rationale behind this project was to investigate a moss (*Bryum argenteum*, also known as the Silvery-Thread Moss) that is a weed on golf course putting greens. This moss can appear whitish and can affect golf ball rolling dynamics. Thus, it is not appealing from both an aesthetic and a playability perspective. Our first objective was to explore its life history, i.e., the abilities of the plants to germinate, establish, rates of growth, and reproductive aspects. We compared these life history traits to determine if those strains (genotypes) of mosses occurring on putting greens behaved similarly, with regard to life history traits, as those strains of mosses of the same species, which did not occur on putting greens. With the assistance of golf course superintendents across the USA, we assembled a group of 17 genotypes of mosses from putting greens and 17 genotypes of mosses from native habitats, and termed these plants (all the same species) as "*Green*" and "*Native*" genotypes. In the lab, we purified these plants of contaminants by successive subculturing, eventually (after some months) producing 34 pure-strain cultures to test. To our surprise, despite belonging to the same species (a curator of mosses at the Missouri Botanical Garden confirmed the identity of the plants), the mosses collected from putting greens exhibited a significantly different set of life history traits than the *Native* plants. The mosses from *Greens* were much more vigorous in traits relating the growth rate than *Natives*, namely (i) growing much faster both laterally and vertically, (ii) colonizing more quickly, (iii) producing more shoots, (iv) producing more "aerial rhizoids" (specialized extensions from the shoots to anchor it among the grasses and likely functioning in making space for the moss plants while blocking turfgrass germination), and (v) focusing energy on asexual reproduction through shoot fragments rather than sexual reproduction or even specialized asexual reproduction. This experiment was conducted for six months, and the results published in the journal *Weed Science*, appearing in the September 2018 issue. These findings led us to conclude that one of two scenarios is responsible for the ability of this species to successfully invade putting greens across the country: (i) this highly variable (polymorphic) species has evolved strains that have preexisting traits relating to rate of growth and establishment that allow them to coexist with grasses, and these strains only can survive in this unique habitat, where they thrive in an environment that is constantly subjected to disturbance in the form of high nutrient load, repetitive cutting, and aerification; or (ii) in the span of just a few decades, natural selection has promoted a set of life history traits revolving around the ability to establish quickly, grow rapidly laterally and vertically, and regenerate asexually in the putting green setting.

Based on the results of the first experiment and the field observations at golf courses in Ohio by Dr. Raudenbush, we designed the second full experiment to test the effects of carfentrazone, light, and (to follow) surfactants on the ability of Silvery-Thread Moss to survive and regenerate. Carfentrazone-ethyl, known commercially as Quicksilver, is the most popular product to selectively suppress Silvery-Thread Moss in putting greens. However, the moss is seldom killed by application of carfentrazone (CZ) and tends to regenerate and recolonize some weeks after an application of CZ. Therefore, we designed an experiment to determine how light and CZ concentration affect the ability of the moss to both photosynthesize and regenerate from stem fragments. This experiment is outlined below and is currently in progress, scheduled to complete during the Spring of 2019. Our experimental treatments include the following, enlisting a subset of 6 *Native* genotypes and 8 *Green* genotypes, with a 1 h exposure to CZ and a 10 h exposure to light:

Experimental Design
Control with no Light
Control with Low Light (1000 PAR, photosynthetically active radiation)
Control with Intermediate Light (1500 PAR)
Control with High Light (2000 PAR, equivalent to full sunlight)
CZ under no Light, varying concentrations of CZ
CZ under Low Light, varying concentrations of CZ
CZ under Intermediate Light, varying concentrations of CZ
CZ under High Light, varying concentrations of CZ

Our preliminary findings (Figure 1 & 2) indicate that Light interacts with CZ in partially inhibiting the photosynthesis and regeneration capability of the moss, and that there is evidence that the Silvery-

Thread Moss in *Greens* has recently evolved a resistance to CZ under higher light conditions. In addition, the "normal" concentrations recommended for CZ on putting greens is much too low to have much of an effect. This resistance to CZ exhibited by *Green* genotypes of the moss likely has recently evolved in response to the use of Quicksilver on putting greens by superintendents over the last few decades. Moss shoots treated with a 5× concentration of CZ and subjected to High Light produced fewer regenerant (new) shoots if the genotypes originated from *Greens* (but not for *Native* genotypes). We conclude that the regrowth of Silvery-Thread Moss in putting greens following application of CZ is due to the ability to regenerate primarily through protonema, and that this ability is unique to *Green* genotypes and not *Native* genotypes, indicating recent resistance.

Future expectations of the project will be to test the effectiveness of a surfactant (coating agent) on the ability of the moss from *Greens* to regenerate, as the second leg of the experiment in progress. Initial indications are very promising, with a lab-designed and environmental friendly surfactant highly effective in controlling this moss.

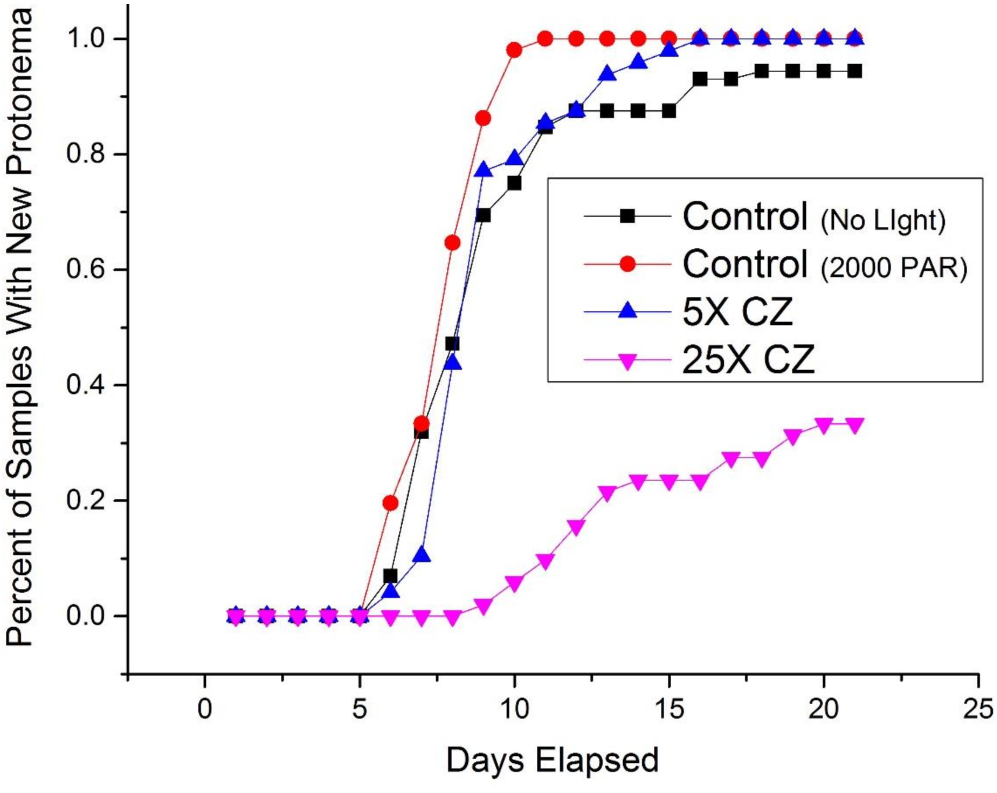

Figure 1. Protonemal production of shoots of Silvery-Thread Moss from putting greens treated with Carfentrazone at 5× and 25× suggested concentrations and exposed to No Light or High Light conditions.

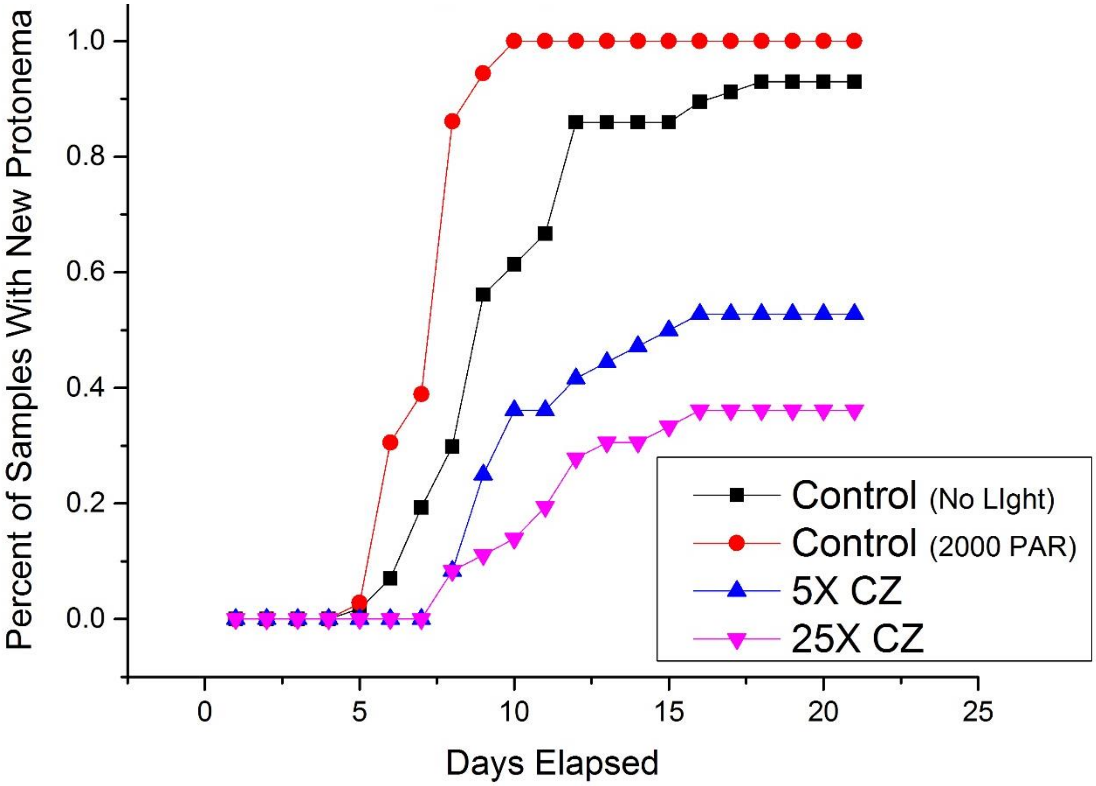

Figure 2. Protonemal production of shoots of Silvery-Thread Moss from non-putting green habitats treated with Carfentrazone at 5× and 25× suggested concentrations and exposed to No Light or High Light conditions.

Figure 3. Photograph of a Silvery-Thread Moss infestation in Ohio.

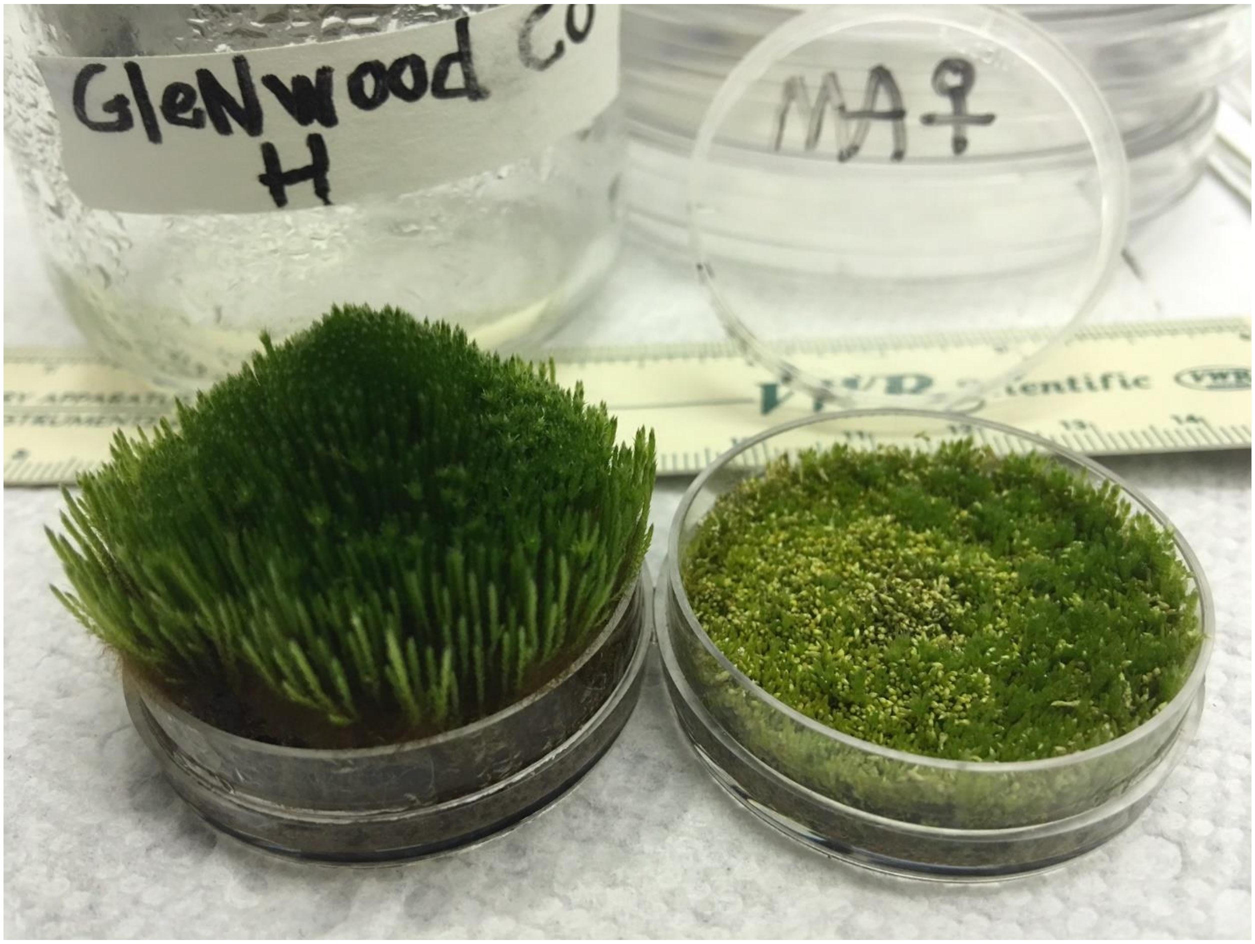

Figure 4. Photograph comparing a typical putting green genotype of Silvery-Thread Moss after 6 months in lab culture (at left), with a typical native habitat genotype of Silvery-Thread Moss after 6 months in lab culture (at right).

3. PRODUCT TESTING

The goal of product testing is to support and direct independent research that provides consumers unbiased information regarding product efficacy. This information helps consumers make financially and environmentally sound product purchasing and use decisions. These experiments also provide USGA agronomists data to support recommendations about products that have incomplete scientific information about potential agronomic benefits.

USGA ID#: 2016-24-574

Title: On-Site Testing of Grasses for Overseeding of Bermudagrass Fairways

Project Leader: Kevin Morris
Affiliation: National Turfgrass Evaluation Program

Start Date: 2016
Project Duration: 3 years
Total Funding: $90,000

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.

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*).

Trial locations were selected in important use areas and/or locations with challenging environments or unique characteristics.

Golf Course	Location	Cooperator	University
Jekyll Island Golf Club [1]	Jekyll Island, GA	Dr. Clint Waltz	Georgia
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.

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.

Figure 1. Overseeding trial at Jekyll Island Club in Jekyll Island, GA.

Figure 2. Overseeding trial at Tucson Country Club in Tucson, AZ.

Figure 3. Overseeding in 2016 for the trial at the Rawls Course at Texas Tech in Lubbock, TX.

USGA ID#: 2018-17-667

Title: Creeping Bentgrass Injury Potential from Carfentrazone-Ethyl Following Treatment with Bensulide

Project Leaders: Roch Gaussion and Zane Raudenbush
Affiliation: University of Nebraska-Lincoln and Ohio State University ATI

Objectives:

1. Determine the safe-application interval for carfentrazone-ethyl at 2.0, 3.3, or 6.7 fl oz/A on creeping bentgrass previously treated with bensulide.
2. Determine if irrigation timing following bensulide application is the true culprit of reports of injury.
3. Determine the duration of injury following applications that result in injury.

Start Date: 2018
Project Duration: 2 years
Total Funding: $20,000

Summary Points:

- Results indicate superintendents can safely apply carfentrazone-ethyl 14 days after a spring application of bensulide.
- Applying carfentrazone-ethyl within 7 days of bensulide will potentially cause injury.
- Phytotoxicity caused by an application of carfentrazone-ethyl was transient and caused no lasting effects on turfgrass quality.

Summary Text:

Carfentrazone-ethyl (Quicksilver® T&O) is the most commonly used herbicide for controlling silvery-thread moss (Bryum argenteum Hedw.) in creeping bentgrass (Agrostis stolonifera L.) putting greens. The herbicide exhibits strong selectivity as creeping bentgrass rapidly metabolizes carfentrazone-ethyl following an application. However, creeping bentgrass injury has been reported if carfentrazone-ethyl is applied soon after treatment with bensulide (Bensumec), but the safe application interval varies as much as 68 days depending on the source of the recommendation. Further, safe-interval recommendations are based on carfentrazone-ethyl use rates of 6.7 fl oz/A, but the most recent dose response research indicates that a rate of 3.3 fl oz/A is the lowest effective rate for moss control with silvery- thread moss. Injury may be less when lower rates of carfentrazone-ethyl are used. In the proposed research, we will determine the safe interval for a single application of carfentrazone- ethyl at 2.0, 3.3, or 6.7 fl oz/A following treatment with bensulide.

In 2018, field studies were conducted from April-August in Lincoln, NE and Creston, OH on creeping bentgrass putting greens built to USGA recommendations. Putting greens were mowed 6 d wk-1 at 0.125 inches and received regular topdressing and fertilizer applications. Plots were irrigated as needed to prevent drought stress and fungicides were applied preventatively to control disease.

Treatments were evaluated using a 2 (preemergence herbicide) × 3 (carfentrazone-ethyl rate) × 9 (carfentrazone-ethyl timing) factorial treatment structure in a randomized complete-block design. Preemergence herbicide levels were 1) Bensulide (Bensumec 4LF) at 7.3 fl oz acre-1 irrigated with 0.5 inches of water immediately after application, and 2) untreated. Levels of carfentrazone-ethyl were 2.0, 3.3, and 6.7 fl oz/A. Carfentrazone-ethyl timing levels were achieved by applying each rate at 0, 1, 3, 7, 14, 21, 35, 49, or 63 days after treatment (DAT) with bensulide. Treatments were applied to 3 × 5 ft. plots using single nozzle, CO2-powered sprayer with a spray volume of 80 gal/A. Bensulide was applied on April 30 and May 5 in Nebraska and Ohio, respectively (Fig 1). Turfgrass visual quality (1=necrotic, dead turf; 6 = minimum acceptable quality; 9 = optimum turf quality) was rated weekly throughout the growing season when applications were complete. Normalized difference vegetation index (NDVI) measurements were recorded weekly using a hand-held active crop canopy meter (CS-45; Holland Scientific, Lincoln, NE).

At 7 DAT, an application of carfentrazone-ethyl following spring-applied bensulide did not significantly reduce turfgrass visual quality or NDVI in Nebraska or Ohio, regardless of herbicide rate or timing. A minor amount of phytotoxicity was observed when carfentrazone- ethyl was applied at 0, 1, and 3 days after bensulide (Fig 2.), but the effects were short-term and undetectable by 7 DAT; no injury was observed for carfentrazone-ethyl applications occurring at 7, 14, 21, 35, 49, or 63 DAT with bensulide. First year results from this research indicate superintendents can use carfentrazone-ethyl 14 days after spring-applied bensulide without concerns of phytotoxicty.

Bensulide is a root absorbed organophosphate preemergence herbicide that controls weeds by inhibiting cell division in meristematic root tissue. Bensulide is strongly absorbed to soil organic matter, so a majority of the herbicide remains near the soil surface. Established turfgrasses withstand an application of bensulide, because their root system is deeper in the soil profile, causing them to absorb a trace amount of herbicide. Desirable turfgrass species metabolize organophosphates using cytochrome P-450’s and glutathione s-transferases, but incrementally increasing the dose of these xenobiotics will eventually result in turfgrass injury. It is unclear why previous researchers reported injury from an application of carfentrazone- ethyl >30 days after an application of bensulide; however, a compromised root system could potentially cause desirable species to intercept a greater amount of bensulide, which would decrease their ability to metabolize carfentrazone-ethyl.

A follow-up field study in 2019 will be conducted at Nebraska and Ohio to more accurately determine the safe application interval for carfentrazone-ethyl following spring- applied bensulide. A small amount of injury was observed in 2018 at 0, 1, and 3 DAT for all rates of carfentrazone-ethyl, but no injury was observed at 7 DAT. In 2019, carfentrazone-ethyl will be applied at 0, 1, 3, 5, 7, 10, 14, and 21 DAT with bensulide. Additionally, a 2x rate of carfentrazone-ethyl (13.4 fl oz/A) will be added to simulate the effects of misapplication from sprayer overlap and provide insight regarding herbicide metabolism.

Figure 1. Catch-cups positioned in untreated plots to confirm 0.5 inches of irrigation were applied immediately following application of bensulide in Creston, OH on May 5, 2018.

Figure 2. Injury to creeping bentgrass plots caused by an application of carfentrazone-ethyl three days after spring-applied bensulide in Creston, OH. Arrows indicate plots treated with carfentrazone-ethyl at 6.7 fl oz/A.

USGA ID#: 2018-18-668

Title: Evaluation and Comparison of Organic vs. Synthetic Organic Herbicides for Turfgrass Weed Control

Project Leader: Bruce Branham
Affiliation: University of Illinois

Objectives:

1. Determine the efficacy of non-conventional and organic herbicides for postemergence broadleaf weed control in cool-season turfgrass.
2. Compare efficacy of these products in spring and fall application windows.
3. Run simultaneous trials at 12 other Midwest universities to develop a robust data set that can be published and included in regional extension publications.

Start Date: 2018
Project Duration: 1 year
Total Funding: $10,000

Summary Text:

This trial was coordinated by the University of Illinois and cooperating institutions included University of Nebraska, Kansas State University, North Dakota State University, University of Wisconsin, University of Iowa, University of Kentucky, Purdue University, Michigan State University, Ohio State University, and the University of Maryland.

In the spring of 2018, trials were initiated at the above universities evaluating 6 organic or non-synthetic herbicidal products, a conventional herbicide control (Trimec), and a control. Four of the non-synthetic products have the same active ingredient, chelated iron, one product (trade name A.D.I.O.S) is essentially table salt, NaCl, and one product is the essential of clove, eugenol. In addition, there were three optional treatments that included as their active ingredients Borax, rosemary oil, or cinnamon oil. A fourth optional treatment looked at the efficacy of a ½ rate of one of the iron chelate products. This trial was repeated in early September at all locations.

Figure 1. Treatment responses in Illinois on 15 June 2018, five weeks after the first treatment and one week after the second treatment. Trials were initiated in the spring of 2018 to evaluate six organic (i.e., non-synthetic) herbicidal products, a conventional herbicide control (Trimec), and an untreated control. Numbers in plots indicate treatments in the top of the image.

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4. ENVIRONMENT

USGA ID#: 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:

1. Conduct a survey to quantify water quality and biotic communities of lentic turfgrass ecosystems across 25 courses within the Chicago Metropolitan area.
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 Points:

- Initial results suggest macro-and microinvertebrate diversity could be lower in golf course ecosystems compared to natural forest preserve ponds/ephemeral wetlands.
- Azoxystrobin had no measurable, consistent influence on aquatic organisms (biofilms or amphibians).
- Nitrogen and N+P additions led to an increase in size and development rate of American toads.

Summary Text:
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 second year of our study (Year 1 was detailed in 2017 annual report), we continued to quantify water quality and chemistry, algal concentrations, and micro- and macroinvertebrate and amphibian diversity and density from collected samples 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). In addition, we implemented a mesocosm-based experiment investigating the influence of pesticide and nutrient additions on aquatic ecosystems.

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. To date, we processed over 250 macroinvertebrate samples for identification and identified/quantified abundance and diversity for over 25 microinvertebrate samples. We are on schedule to have all samples (over 1,000 in total) identified by the end of summer 2019. *These data will help elucidate the degree to which golf course ponds harbor biodiversity compared to adjacent systems considered more natural*.

To date, our results show species diversity of macroinvertebrates on golf course lentic ecosystems (Shannon's H'=0.63) is lower than that of permanent, fish-filled (H'=1.98) and ephemeral, fishless adjacent ecosystems (H’=1.19); however, these data represent a limited sample size (Fig. 1). Microinvertebrate diversity in April and August was also variable, but was more similar across lentic ecosystem types than macroinvertebrates (Figs. 2 and 3)

Experimental mesocosms: We designed a mesocosm-based study to investigate the influence of the fungicide azoxystrobin, and nitrogen and phosphorus additions on aquatic ecosystems. In spring/summer 2018, we implemented a randomized experiment with 9 treatments (High/Low fungicide, nitrogen (N), phosphorus (P), N+P, and control) – see Table 1 for mesocosm treatment concentrations. Each treatment was then replicated with 4-6 mesocosms using organisms from three trophic levels: amphibians (American toads and Leopard frogs), dragonfly nymphs (Genus *Pantala* and *Leuccorhinia*), and biofilms for a total of 120 mesocosm units. Our results suggest chlorophyll *a* and phycocyanin concentrations did not differ across treatments (Fig. 4), but American toads raised in low concentrations of azoxystrobin were smaller compared to control or high concentration mesocosms (Fig. 5). We also found that high nutrient levels, particularly nitrogen (Fig. 6) and N+P (Fig. 8) resulted in larger frogs at metamorphosis, but low phosphorus concentrations led to smaller frogs (Fig. 7). Our results with respect to dragonflies, zooplankton, Leopard frogs, and mesocosm water quality are still ongoing/being analyzed.

Future expectations: By spring 2019, 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 winter 2019. In addition, as discussed in our proposal, in spring 2019 we plan to utilize concentrations 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) to the interactive crosses of these aquatic inputs.

Table 1. Concentrations of Azoxystrobin, nitrogen, phosphorus, and N+P found in wetlands across 55 lentic ecosystems sampled and the concentrations used in the 2018 mesocosm study. MEAS = mean values; Tx = treatment concentration (Low or High concentration).

Systems	Azoxystrobin (ppb)		Phosphorus (μg/L)		Nitrogen (μg/L)	
	MEAS	T_x	MEAS	T_x	MEAS	T_x
Golf course	2.1, 24		58		252	
Permanent-FP	NA	1.4 (L), 14.3 (H)	43	99 (L), 1700 (H)	421	263 (L), 7350 (H)
Ephemeral	NA		300		57	

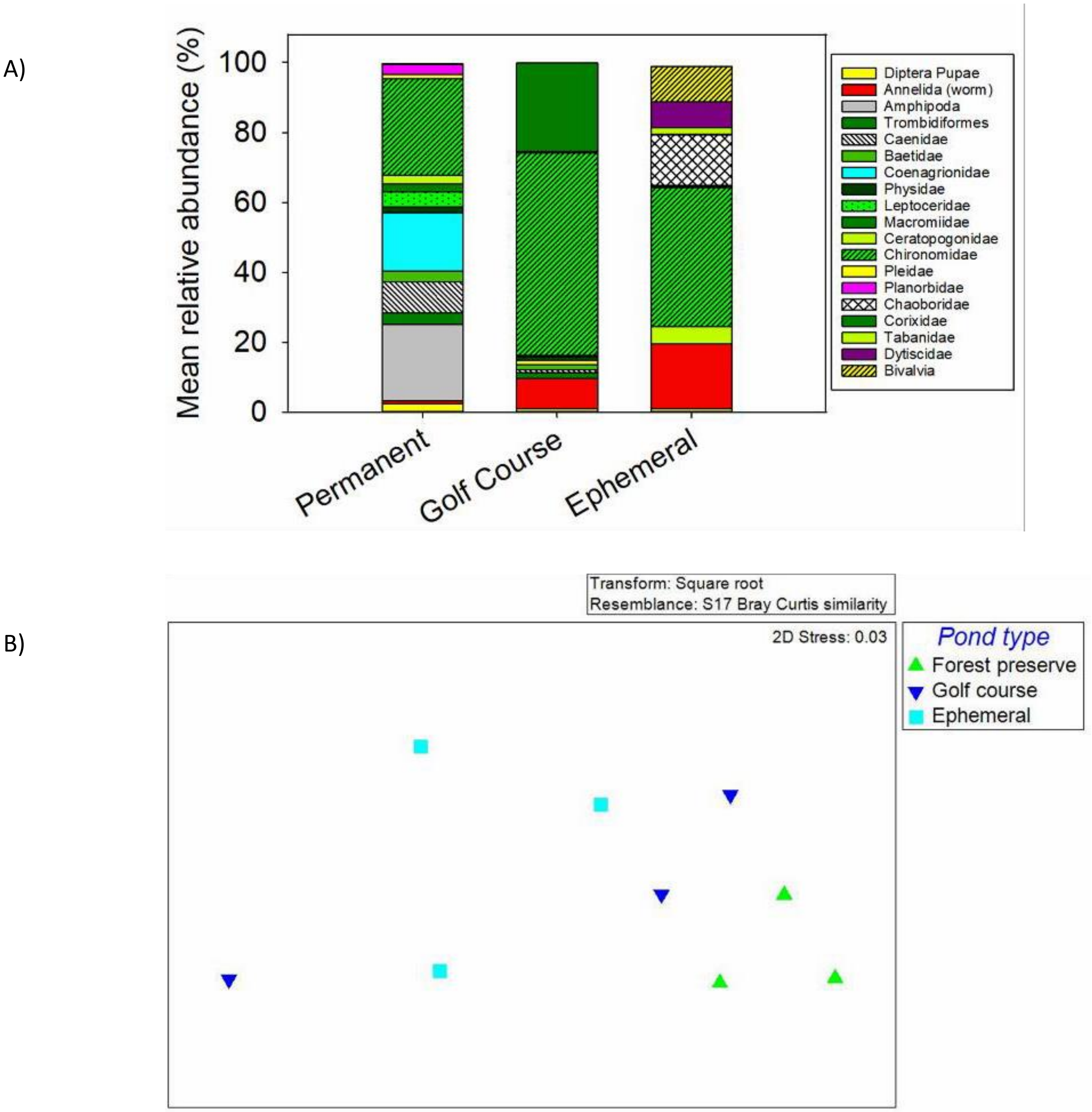

Figure 1. A) Mean relative abundance of macroinvertebrate families in permanent, fish-filled ponds within forest preserves or golf courses, and ephemeral wetlands in August 2017. Only taxa representing over 1% of relative abundance across all sites are presented. B) Non-metric Multidimensional Scaling (nMDS) results for macroinvertebrate community structure across treatments in August 2017.

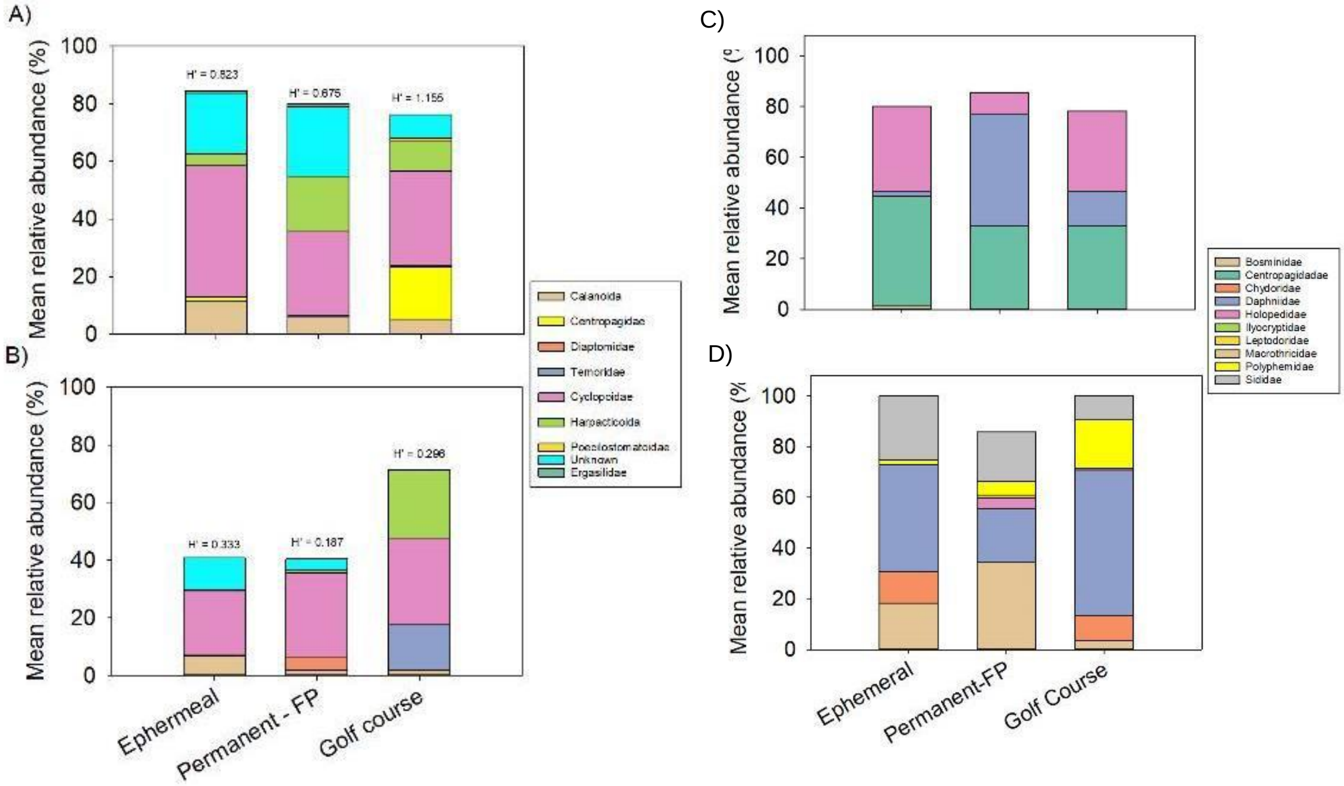

Figure 2. A) April and B) August mean relative abundance (%) of Cladocera, and C) April and D) August mean relative abundance (%) of Copepoda across golf course, ephemeral, and permanent, fish-filled lentic ecosystems.

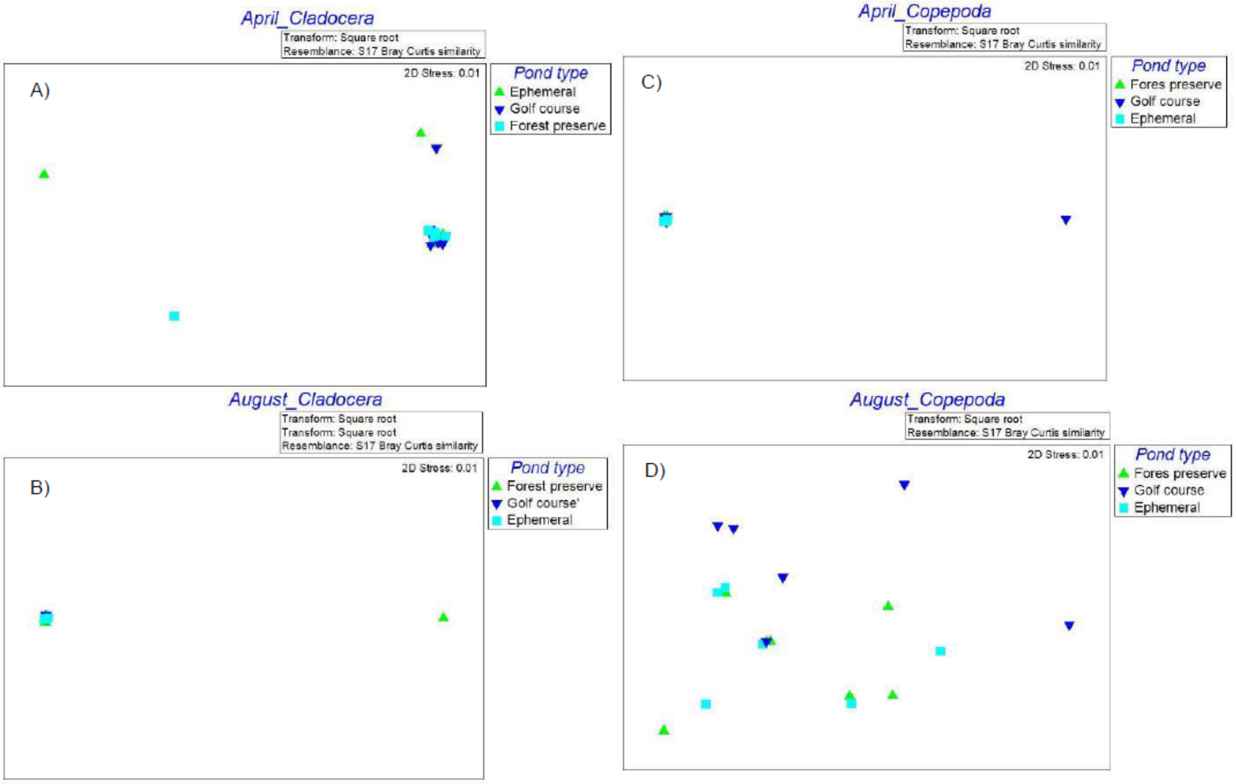

Figure 3. Non-metric Multidimensional Scaling results for: A) April and B) August Cladocera, and C) April and D) August Copepoda across golf course, ephemeral, and permanent, fish-filled lentic ecosystems.

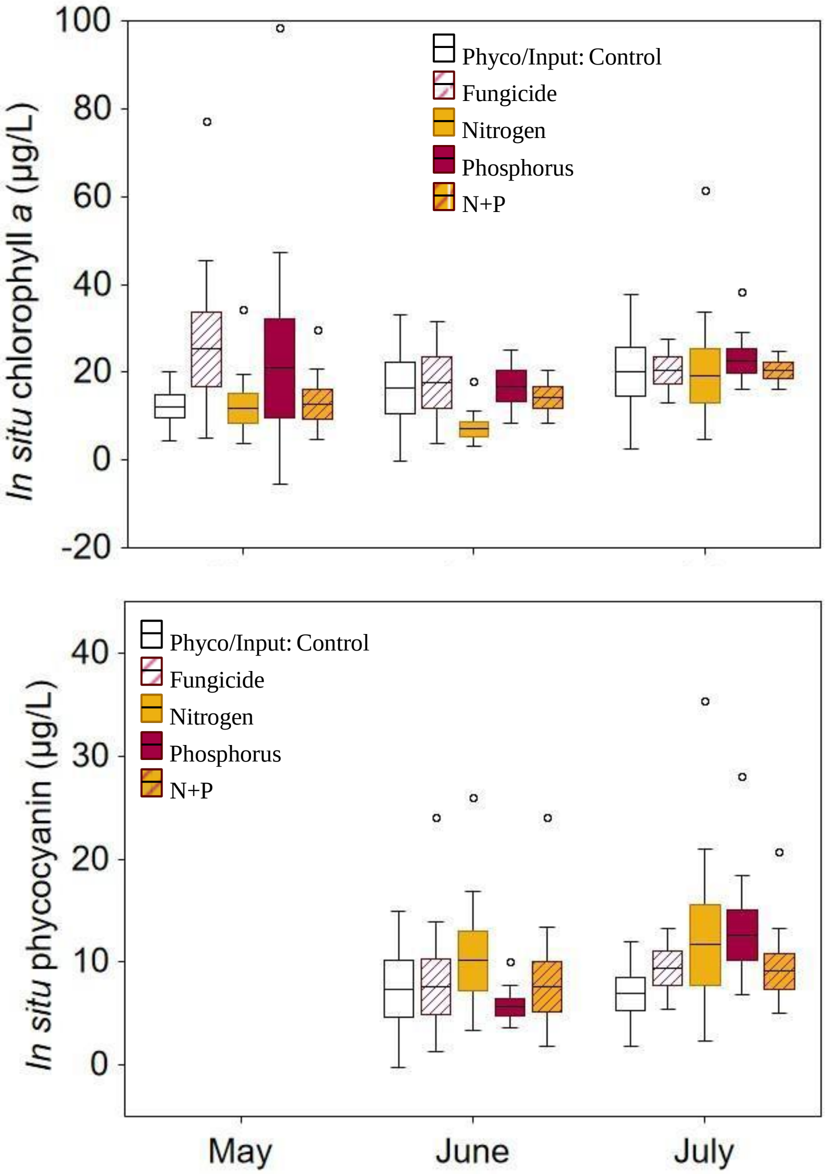

Figure 4. Box plots representing the mean (line within box), standard error (boxes) and minimum/maximum (whiskers) values for *in situ* chlorophyll *a* (µg/L) and phycocyanin (µg/L) concentrations across fungicide and nutrient treatments.

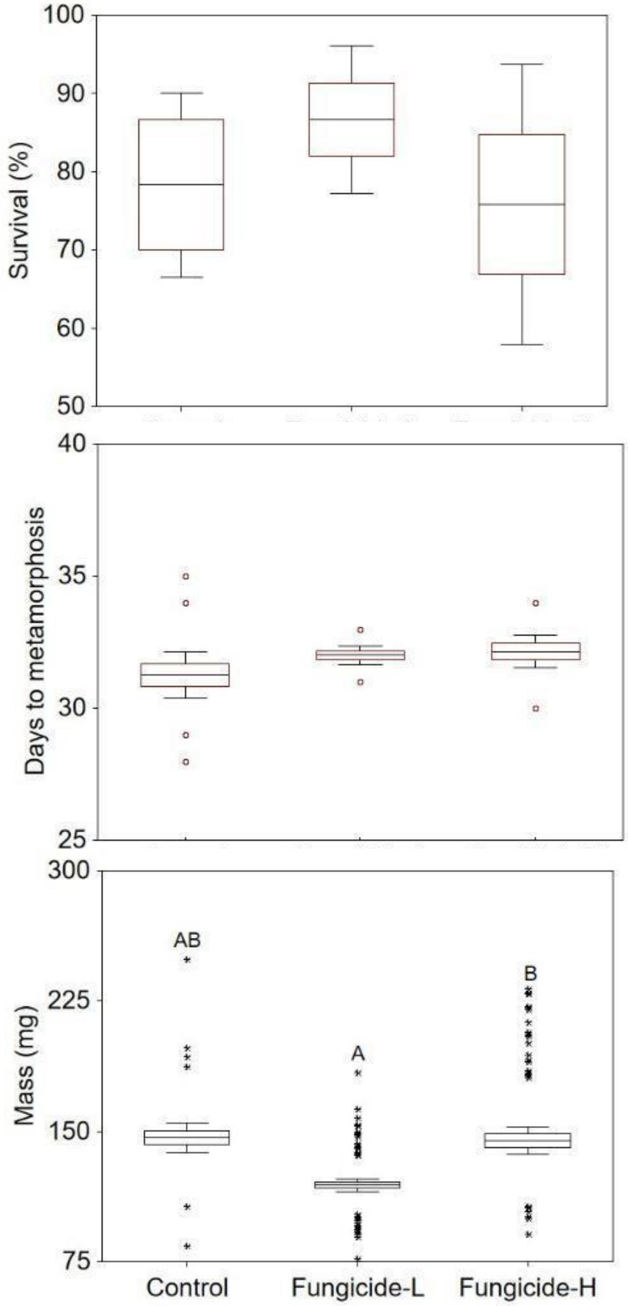

Figure 5. Mean (line), standard error (box) and range (whiskers) survival, days to metamorphosis and mass of American toad larvae raised in control or low/high fungicide treatments in a mesocosm setting. Upper case letters represent statistical significance.

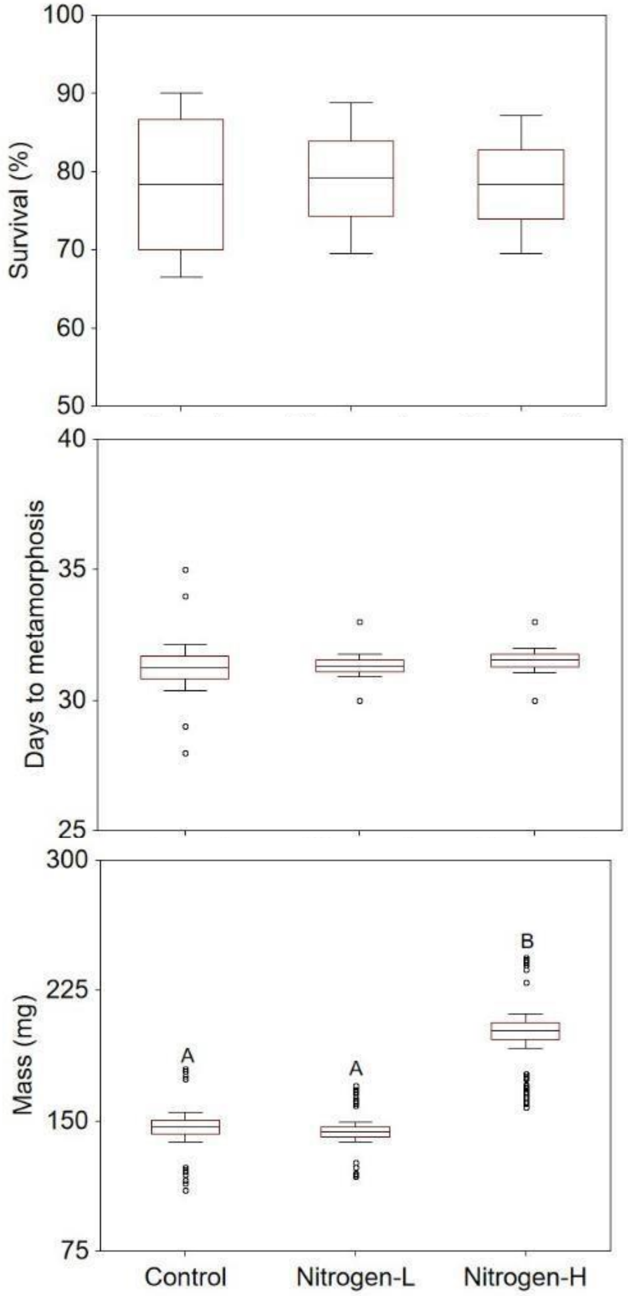

Figure 6. Mean (line), standard error (box) and range (whiskers) survival, days to metamorphosis and mass of American toad larvae raised in control or low/high nitrogen treatments in a mesocosm setting. Upper case letters represent statistical significance.

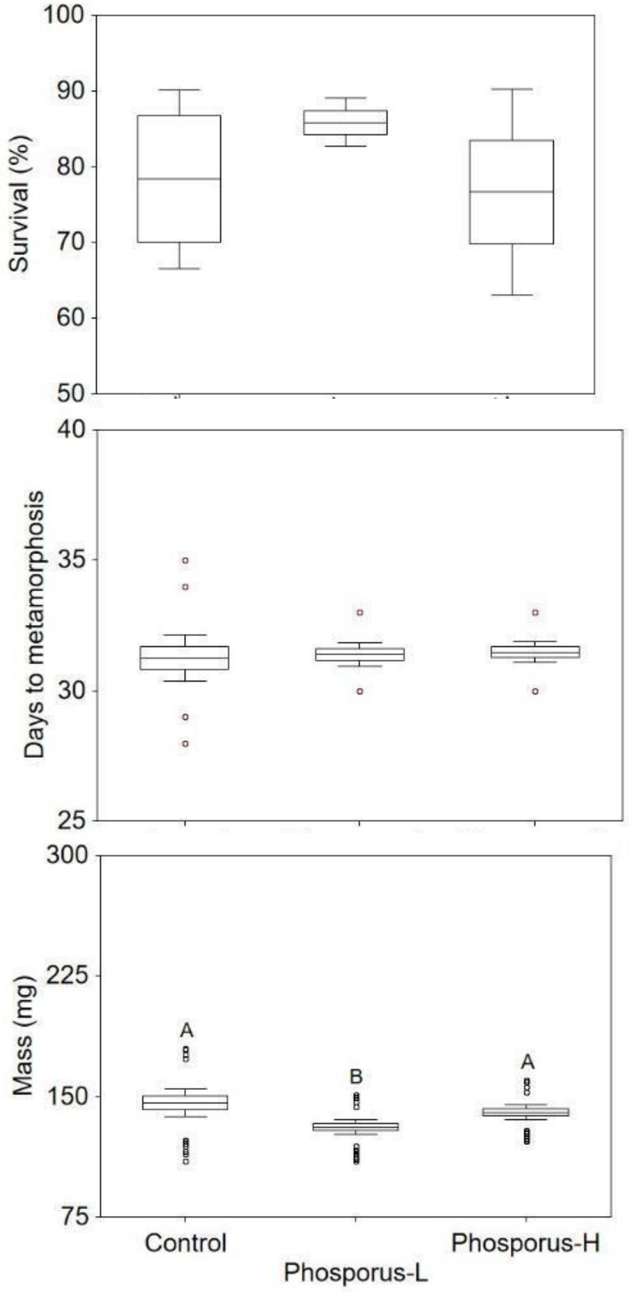

Figure 7. Mean (line), standard error (box) and range (whiskers) survival, days to metamorphosis and mass of American toad larvae raised in control or low/high phosphorus treatments in a mesocosm setting. Upper case letters represent statistical significance.

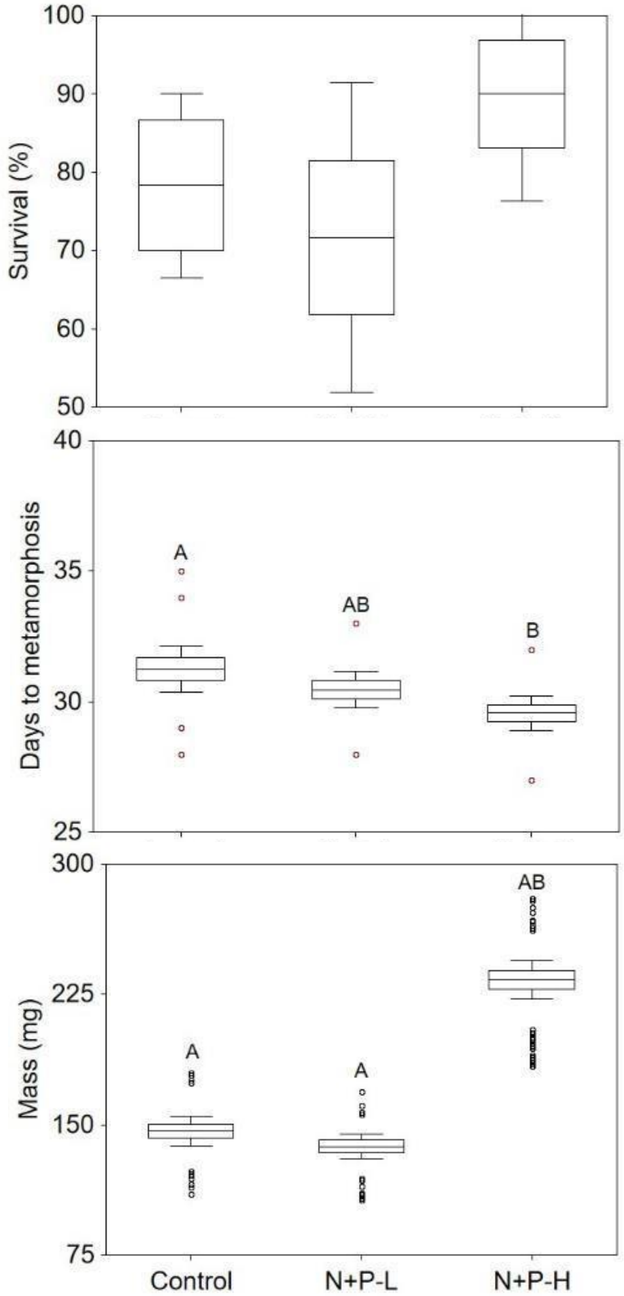

Figure 8. Mean (line), standard error (box) and range (whiskers) survival, days to metamorphosis and mass of American toad larvae raised in control or low/high nitrogen + phosphorus treatments in a mesocosm setting. Upper case letters represent statistical significance.

USGA ID#: 2018-19-669

Title: Simulation of Nitrous Oxide Emissions and Carbon Sequestration in Zoysiagrass Fairway

Project Leaders: Mu Hong[1], Dale J. Bremer[1], and Ross Braun[2]
Affiliation: [1]Kansas State University; [2]Purdue University

Objectives:

1. Calibrate the DAYCENT model to predict emissions of nitrous oxide (N2O), a greenhouse gas (GHG) implicated in climate change, from fairway zoysiagrass.
2. Predict the long-term impacts of N fertilization and irrigation management practices on N2O emissions and C sequestration in fairway zoysiagrass.
3. Estimate long-term impacts of N fertilization and irrigation management on global GHG inventories by estimating energy (e.g. mowing and irrigation) expenses associated with turfgrass maintenance.

Start Date: 2018
Project Duration: 2 years
Total Funding: $76,812

Summary Points:

- The DAYCENT model will be parameterized and calibrated for zoysiagrass during 2019.
- Field measurements of N2O flux measurements from zoysiagrass from a previous study (Lewis and Bremer, 2013) will be used to validate the model after initial calibration with data from Braun and Bremer (2018a).
- Zoysiagrass turf from the same sward as the initial study by Braun and Bremer (2018a) remains in the field, and clipping data from those plants will be collected to determine biomass production rates similar to Hamido et al. (2016), and will be used for DAYCENT model calibration.

Summary Text:

Nitrous oxide (N2O) and carbon dioxide (CO2) are important greenhouse gases that have been implicated in global climate change. Turfgrass systems are typically fertilized with nitrogen (N) and irrigated, which may result in significant N2O emissions (Braun and Bremer, 2018b). Turfgrass also has the capacity to sequester CO2 from the atmosphere (Braun and Bremer, 2019).

A previous USGA-funded study at K-State revealed significant effects of N fertilizer type and irrigation management on N2O emissions in zoysiagrass over two years and C sequestration over three years (Braun and Bremer, 2018a, 2019; Figs. 1-4). The acquisition of these data provides a unique opportunity to calibrate the DAYCENT model to zoysiagrass turf; specifically, to predict long-term impacts of N fertilization and irrigation management on N2O emissions and C sequestration. Such model development is important because continuous long-term measurements are expensive and time consuming. DAYCENT is a powerful model developed and used widely to predict GHG fluxes in agricultural lands. DAYCENT has been applied to C3 but not C4 turfgrasses such as zoysiagrass, which must be calibrated separately because of different physiological characteristics (Zhang et al., 2013a).

The authors have already measured N2O emissions, soil organic carbon, soil organic nitrogen, and have estimated the energy costs (also referred to as hidden carbon costs), from inputs such as N fertilization, irrigation management, pesticides, etc., in a simulated 'Meyer' zoysiagrass fairway at the KSU Turfgrass Research Center near Manhattan, KS (Braun and Bremer, 2018a, 2019; Figs. 2-4). This experiment was conducted under an automated rainout shelter that allowed for precise control of irrigation in a field setting (Fig. 1).

PI Ross Braun, a post-doc who was to lead the DAYCENT model research project, recently departed from Kansas State University to accept a position at Purdue University. Therefore, Ross is no longer the lead researcher on the project although he remains a cooperator. His departure delayed implementation of the project. However, Mu Hong, a current PhD student, has agreed to conduct this project under the supervision of PI Dale Bremer. In August, 2018, Mu attended a week-long CENTURY/DAYCENT workshop at Colorado State University in Fort Collins, CO to receive necessary DAYCENT model training (https://www.nrel.colostate.edu/education/century-and-daycent-model-training-workshops/). The DAYCENT model will be parameterized for zoysiagrass and calibrated using field measurements of N2O fluxes obtained by Braun and Bremer (2018a). Thereafter, N2O fluxes measured from zoysiagrass in an earlier study at the KSU Turfgrass Research Center near Manhattan, KS (Lewis and Bremer, 2013) will be used to validate and modify, if necessary, the DAYCENT model parameters using the method of Zhang et al. (2013b).

Model simulation effectiveness will be evaluated through correlation analysis by comparing measured with simulated N2O emissions and C sequestration. Data analysis will be conducted using statistical analysis software.

The results from this study are expected to provide information about the long-term impacts of deficit irrigation and N-fertilization practices that reduce greenhouse emissions of N2O and are most likely to sequester carbon in zoysiagrass turf.

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Figure 1. Automated rainout shelter moving across plots activated by 0.01 inch of rain.

Figure 2. Plots received precise irrigation amounts based on daily ET during summer period.

Figure 3. Close-up of one of twelve static chambers used for sampling N2O.

Figure 4. N2O sampling in progress.

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5. REGIONAL GRANTS

USGA ID#: 2016-26-576

Title: The impact of putting green management on visible wear caused by golf cleat/sole designs

Project Leaders: Thomas A. Nikolai, Ph.D. [1] and Douglas Karcher, Ph.D.[2]
Affiliation: [1]Michigan State University; [2]The University of Arkansas

Objectives:

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.
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.

Start Date: 2016
Project Duration: 2 years
Total Funding: $57,162

Summary Points:

- Golf sole and cleat designs from the 20th century (including 8 and 6 mm metal spikes) consistently resulted among the most visible foot traffic at every site compared to the most aggressive of today's cleat/sole designs.
- In terms of visible foot traffic, when statistical difference occurred, topdressing on creeping bentgrass and annual bluegrass resulted in less visible wear.
- The higher rates of nitrogen on creeping bentgrass plots at MSU and UARK resulted in the most visible wear and ball mark depression measured with the Tru Firm.
- In general, cleated designs caused more visible traffic than cleatless outsoles.
- Ordinarily, as the number of studs on cleatless outsoles, and the number of cleats (and even prongs) on cleated outsoles increased, visible foot traffic decreased.
- Irrigation trials indicated that the greater the amount of moisture in the soil the greater the visible indentations from studs and cleats. Additionally, rolled plots resulted in firmer surfaces, but greater volumetric water content and, occasionally, more visible wear.

Summary Text:

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.

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 Results & Useful Interpretation

1. Golf sole and cleat designs from the 20th century (including 8 and 6 mm metal spikes) consistently resulted among the most visible foot traffic at every site compared to the most aggressive of today's cleat/sole designs. These results indicate that while many long for the better days of the past it is comforting to know that many things, like golf soles/cleats, are better today.

2. In terms of visible foot traffic, when statistical difference occurred, topdressing on creeping bentgrass and annual bluegrass resulted in less visible wear. Topdressing also resulted in firmer (less ball mark depression measured with the Tru Firm) on creeping bentgrass and annual bluegrass at MSU. Additionally, annual bluegrass plots that were not groomed or topdressed resulted in the greatest ball mark depression compared to all other treatments. These result stress the importance of maintaining and/or implementing a light frequent topdressing program to minimize traffic stress which results in optimal playing conditions for clientele.

3. The higher rates of nitrogen on creeping bentgrass plots at MSU and UARK resulted in the most visible wear and ball mark depression measured with the Tru Firm. Additionally, results from different sole/ cleat designs indicate:

- Cleatless designs with <u>rubber outsoles</u> generally caused less visible traffic than cleatless designs with <u>thermoplastic polyurethane outsoles</u>.
- In general, cleated designs caused more visible traffic than cleatless outsoles, and those made with <u>thermoplastic polyurethane</u> resulted in less visible traffic than outsoles made with a

combination of polyurethane and thermoplastic polyurethane while those made with thermoplastic elastomer outsoles caused the most visible traffic.
- Ordinarily, as the number of studs on cleatless outsoles, and the number of cleats (and even prongs) on cleated outsoles increased, visible foot traffic decreased.

Combining results indicate that following a putting green grow-in golfers should be encouraged to use cleatless sole designs, preferably of rubber soles, or possibly thermoplastic polyurethane outsoles, to minimize damage on immature plants and maximize playing conditions.

4. Irrigation trials indicated that the greater the amount of moisture in the soil the greater the visible indentations from studs and cleats. Additionally, rolled plots resulted in firmer surfaces, but greater volumetric water content and, occasionally, more visible wear. It is important to consider that the trafficked research plots were all under identical irrigation regimes. It is also worthy to consider that past USGA funded lightweight rolling research plots has indicated that rolling does leads to greater moisture retention which most likely results in less dollar spot. Putting this all together, along with the fact that topdressing decreased VMC among the treatments, results indicate the significant role todays soil moisture measuring devices can play in determining the proper soil moister for individual putting greens.

The above mentioned results, and other findings from this research, should be helpful in bridging communication gaps among golf course superintendents, agronomist, golfers, and green committees regarding the importance of following sound management practices and utilizing soil moisture sensors to maintain firm and smooth putting surfaces.

Figure 1. Golf cleat/sole traffic studies were performed at 20 locations (Michigan, Arkansas, Florida and Scotland) with over 20 cleat/sole designs.

Figure 2. Plots were trafficked with different cleat/sole designs. Following traffic, golfing clientele rated the putting surface smoothness using a defined scale.

USGA ID#: 2017-24-634

Title: Impact of Management Strategies on Plant Health and Playability During Tournament Preparation

Project Leaders: Timothy L. Lulis and John E. Kaminski
Affiliation: The Pennsylvania State University

Objectives:

1. Determine the influence of various cultural and chemical practices on golf course putting green playability.
2. Elucidate the impact of these cultural practices on turfgrass quality.
3. Correlate the influence of various cultural programs with green speed from data collected from golf course superintendents.

Start Date: 2017
Project Duration: 2 years
Total Funding: $10,000

Summary Text:

Putting greens are the most critical playing surface on golf courses. During a typical round of golf, a large percentage of a player's strokes will be on the playing surface of a green. Ball roll distance, often referred to as green speed by golfers, and trueness of the ball's roll across a green have a major impact on the game of golf. Green speed is the most requested information on golf course conditions by players (Nikolai, 2005). Golf course managers strive for consistently fast and smooth playing surfaces on putting greens while endeavoring to maintain quality in the turfgrass stand. Research involving green speed has mostly focused on quantifying individual cultural practices on ball roll distance as opposed to a specific set of cultural practices. Additionally, the goal of most research focused on ball roll distance has been to identify cultural practices that maintain a reasonable ball roll distance while lowering the stress caused to turfgrass through standard cultural practices such as mowing frequently at a low height of cut (Gilhuly, 2006; Soller, 2013).

Turfgrass managers are often required to prepare for a golf course tournament during which relatively high or fast green speeds are expected by the golfers. 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. Quantifying and comparing the effects of several tournament preparation programs on the playability of greens would provide a great resource to golf course managers in an effort to maximize speeds with the least possible negative impact on plant health.

A common practice to achieving faster green speeds is the lowering of mowing heights. Research has indicated that a decrease in mowing height by .031 inch can be expected to produce a gain in ball roll of six inches (Richards, 2008). As mowing height is further lowered, however, increases in ball roll distances diminish. Reducing mowing heights from 0.156 inch to 0.125 inch may increase ball roll by as much as six inches, while an additional increase of six inches in ball roll would require dropping the mower height twice the previous increment to 0.063 inch (Nikolai, 2005).

In addition to height of cut, mowing frequency adjustments are commonly used by golf course managers as they intensify their management leading up to the start of a tournament. Most research on frequency of mowing and ball roll distance has been in the effort of identifying procedures that reduce the frequency of mowing while maintaining an acceptable greens speed. A variety of mowing frequencies are utilized by different turfgrass managers in an effort to increase speed. Some of these include: single mowing in the morning, single mowing in the morning and evening, and integrating double cutting into either/both morning or evening mowing events. Double cutting while maintaining a consistent height of cut has been shown to increase ball roll distance (Nikolai, 2004). Many factors remain unknown, however, as it relates to the timing of these increased mowing frequencies on green speed and plant health. For example, how long do these practices need to be implemented prior to the start of an event before any additional benefits are noticed?

Although a number of factors have been shown to improve green speeds, little research is available that investigates the influence of multiple factors on increasing speeds. There is also limited information on the law of diminishing returns of these practices as it relates to increasing green speed at the expense of plant health.

MATERIALS AND METHODS

Mowing Pattern x Cultural Practices. In 2017, a field study was repeated investigating the influence of mowing patterns in combination with nitrogen and trinexapac-ethyl was conducted. The study was conducted on a stand of 98% “Penn A-4” creeping bentgrass with approximately 2% annual bluegrass. The green was constructed with a sand based rootzone in 2003 and at the start of the study had 1.2% organic matter and a pH of 7.2.

The study was arranged as a randomized complete split-plot design with 3 replications. Main plots consisted of three mowing pattern with split-plots consisting of four fertilizer/plant growth regulator (PGR) regimes. Mowing patterns consisted of a standard single pass (S) pattern, a double cut (DC) pattern up and back along the same line, and a criss-cross (CC) pattern in which the individual plots were mowed twice at opposite angles. Height of cut (HOC) for all treatments was 0.100”. All mowing was done utilizing a John Deere E-Cut 220 with an 11-bladed reel and a 2.0 mm bedknife. All mowing treatments were initiated at 630 hours. Mower HOC and quality of cut were checked daily and adjusted as needed. The four fertilizer/PGR treatments consisted of: 1) urea (0.1 lb N 1000ft^{-2}, 14-day); 2) trinexepac-ethyl (0.125 fl oz 1000ft^{-2}, 14-day), 3) urea (0.1 lb N 1000ft^{-2}, 14-day) + Trinexepac-ethyl (0.125 fl oz 1000ft^{-2}, 14-day); and 4) a nontreated control receiving no fertilizer or PGR applications. A treatment outline is shown in Table 2.

Mowing Frequency x Brushing. In 2017 a study was repeated involving mowing frequency x brushing was conducted on a separate stand of 98% “Penn A-4” creeping bentgrass with approximately 2% annual bluegrass. The green was constructed to USGA putting green specifications in 2005 and at the start of the study had 1.4% organic matter and a pH of 7.3.

The study was arranged as a 3 x 4 factorial arranged in a randomized complete block design with 3 replications. Main effects consisted of four brushing treatments and three mowing frequencies. Height of cut (HOC) for all treatments was 0.100”. All mowing was done utilizing three John Deere E-Cut 220 with an 11-bladed reel and a 2.0 mm bedknife. For the main effect of mowing frequency, individual plots were mowed according to the following schedule. Single cut (SC) treatments involved one single pass with the mower. Double cut (DC) treatments consisted of two passes of the mower along the same line. Double-double cut (DD) treatments consisted of a DC cut in the morning and again in the afternoon. All mowing treatments were initiated at 630 hours followed by an afternoon mowing at 1430 hours on DD treatments. Mower HOC and quality of cut were checked daily and adjusted as needed. Brushing treatments included: 1) a powered rotary brush; 2) a soft bristle push brush; 3) a stiff bristled push brush; and 4) a nontreated control (i.e., no brush). Brush components and equipment were supplied by John Deere. All brushes were mounted to the mowers as per manufacturer specifications. A summary of all treatments is presented in Table 3.

Data was collected one to three times per week for the duration of the 10-week *Mowing Pattern x Cultural Practices* study. For all other experiments, data was collected twice daily for the 14-day duration of each study. Data collected included: Air temperature (AT) and relative humidity (RH), ball roll distance (BRD) using a USGA Stimpmeter, putting green trueness (PGT) using a Greenstester, soil moisture (SM) at 1.5” and 3.0” using a Fieldscout TDR 300 meter, NDVI using a Fieldscout TCM 500 meter, chlorophyll content (CM) using a Fieldscout CM 1000 meter, surface firmness (TF) using a Fieldscout TruFirm True Firmness Meter, and ball roll physics (BRP) characteristics using the Sphero Turf Research app from Turf Informatics and a Sphero robotic ball. The first set of data was collected immediately after the morning mowing. Immediately prior to the afternoon mowing, data was collected to ascertain AT, RH, BRD, PGT, and BRP. Following afternoon mowing treatments, data again was collected to ascertain BRD, PGT, and BRP on the experimental units that received the afternoon mowing. Turfgrass quality and color were also visually assessed on a 1 to 9 scale where 1 = entire plot brown or dead and 9 = optimum greenness and/or density. All data were subjected to analysis of variance and means were separated at $P \leq 0.05$ according to Fisher’s Protected least significant difference test.

RESULTS & DISCUSSION

Mowing Frequency x Brushing. Results were similar to the 2016 trial. Out of fourteen rating dates, eight dates had significant differences in BRD. On seven dates that were statistically significant, plots mowed with No Brush + Double Cut had among the greatest BRD (Table 3). Plots mowed with Soft Brush + Double Cut had among the greatest BRD on five of the statistically significant rating dates (Table 3). While No Brush + Single Cut and Rotary Brush + Double Cut had among the greatest BRD four of the statistically significant rating dates (Table 3). Plots mowed with Stiff Brush + Single Cut had the least BRD on eight of eight statistically significant rating dates, while Stiff Brush + Double mow plots had among the least BRD’s on seven of eight significant rating dates (Table 3). This data indicates that beginning any brushing program may reduce BRD in the short term when compared to not introducing brushing. It also reinforces previous data that indicates increasing mowing frequency will increase BRD.

Mowing Pattern x Cultural Practices. There was a significant difference in BRD on seven of twelve rating dates. On those rating dates plots mowed with either Double Cut or Cross Cut consistently had among the statistically greatest BRD, while plots mowed with a Single Cut were consistently among the plots with the statically least BRD (Table 4). Nitrogen and PRG main effects produced few significant differences on any rating dates (Table 4). This data suggests that spoon-feeding fertility programs and normal rates of growth regulator management may have little effect on ball roll distance. It also reinforces previous data that indicates increasing mowing frequency will increase BRD.

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Soller, D. 2013. Putting greens: It's time to set a speed limit. USGA Green Section Record. 51(16): 1-4.

Table 1. Treatments to evaluate the influence of brushing and mowing frequency on green speed and turfgrass quality on a creeping bentgrass putting green.

Main Effect (treatment)
Mowing patterns
Single cut
Double cut (up and back)
Double double cut (up and back)
Brushing practices
Rotary brush
Stiff bristled push brush
Soft bristled push brush
Nontreated

Table 2. Treatment list for mowing pattern in combination with Primo and/or nitrogen treatments.

Main Effect (treatment)
Main Plots (mowing patterns)
Single cut
Double cut (up and back)
Double cut (crisscross)
Sub Plots (cultural practices)
Primo
Nitrogen
Primo + Nitrogen
Nontreated

Table 3. Ball roll distance (BRD) after morning operations on a creeping bentgrass putting green during 14 days of tournament preparation brushing and mowing practices, 2017.

	Ball roll distance (cm)[z]				
Height of cut and mow	7 Jul	8 Jul	9 Jul	10 Jul	11 Jul
Soft Brush Single Cut............	333.6 a[x]	333.6 a	307.4 a	333.6 a	323.4 bc
Soft Brush Double Cut..........	309.9 abc	321.7 a	323.4 a	321.7 a	321.7 bc
Stiff Brush Single Cut............	303.1 bcd	303.1 a	298.0 a	277.7 a	309.9 c
Stiff Brush Double Cut..........	284.5 d	294.6 a	310.7 a	305.6 a	309.9 c
Rotary Brush Single Cut.........	286.2 cd	301.4 a	307.3 a	292.9 a	315.0 bc
Rotary Brush Double Cut.......	326.8 ab	342.1 a	318.3 a	315.8 a	309.9 c
No Brush Single Cut..............	304.8 bcd	331.9 a	313.3 a	314.1 a	326.8 b
No Brush Double Cut............	308.2 bcd	297.2 a	327.7 a	336.1 a	342.1 a

[z] Ball roll distance was assessed using a USGA Stimpmeter. To limit the ball roll to within the plots dimensions the "2x" notch on the Stimpmeter was used. Results were multiplied by a factor of 2 and converted to feet.

[y] Mowing treatments were initiated on 7 Jul 2017.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to the Fisher's Protected least significant difference test.

Table 3 (cont.). Ball roll distance (BRD) after morning operations on a creeping bentgrass putting green during 14 days of tournament preparation brushing and mowing practices, 2017.

	Ball roll distance (cm)[z]				
Height of cut and mow	12 Jul	13 Jul	14 Jul	15 Jul	16 Jul
Soft Brush Single Cut............	318.3 a-d[x]	320.9 b	325.1 a	299.7 bc	317.5 bc
Soft Brush Double Cut..........	338.7 ab	326.8 b	320.9 a	321.7 ab	325.1 ab
Stiff Brush Single Cut............	291.3 cd	291.2 d	291.3 a	291.2 c	301.4 c
Stiff Brush Double Cut..........	306.5 bcd	303.1 bcd	309.9 a	294.6 c	299.7 c
Rotary Brush Single Cut.........	289.6 cd	294.6 cd	308.2 a	290.4 c	301.4 c
Rotary Brush Double Cut.......	313.3 cd	316.7 bc	331.9 a	298.0 c	326.0 ab
No Brush Single Cut..............	323.4 bc	318.3 bc	311.6 a	328.5 a	343.8 a
No Brush Double Cut............	340.3 a	359.0 a	348.8 a	335.3 a	335.3 ab

[z] Ball roll distance was assessed using a USGA Stimpmeter. To limit the ball roll to within the plots dimensions the "2x" notch on the Stimpmeter was used. Results were multiplied by a factor of 2 and converted to feet.

[y] Mowing treatments were initiated on 7 Jul 2017.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to the Fisher's Protected least significant difference test.

Table 3 (cont.). Ball roll distance (BRD) after morning operations on a creeping bentgrass putting green during 14 days of tournament preparation brushing and mowing practices, 2017.

	Ball roll distance (cm)[z]			
Height of cut and mow	17 Jul	18 Jul	19 Jul	20 Jul
Soft Brush Single Cut............	331.1 ab[x]	318.4 a	323.4 bc	325.1 a
Soft Brush Double Cut..........	313.3 bc	302.3 a	332.7 ab	353.9 a
Stiff Brush Single Cut............	303.1 c	291.2 a	303.1 c	324.3 a
Stiff Brush Double Cut..........	315.0 bc	297.2 a	320.0 ab	320.1 a
Rotary Brush Single Cut........	324.3 abc	309.9 a	334.4 ab	336.1 a
Rotary Brush Double Cut.......	331.9 ab	309.9 a	334.4 ab	323.4 a
No Brush Single Cut..............	343.7 a	320.0 a	352.2 a	342.1 a
No Brush Double Cut............	345.4 a	335.3 a	355.6 a	367.5 a

[z] Ball roll distance was assessed using a USGA Stimpmeter. To limit the ball roll to within the plots dimensions the “2x” notch on the Stimpmeter was used. Results were multiplied by a factor of 2 and converted to feet.

[y] Mowing treatments were initiated on 7 Jul 2017.

[x] Means in a column followed by the same letter are not significantly different at *P* ≤ 0.05 according to the Fisher’s Protected least significant difference test.

Table 4. Ball roll distance (BRD) after morning operations on a creeping bentgrass putting evaluating the effects of PGR, nitrogen, and mowing patterns, 2017.

	Ball roll distance (cm)[z]					
Height of cut and	11 Jul	14 Jul	18 Jul	21 Jul	25 Jul	28 Jul
Single Cut + N + PGR.........	299.7 cd[x]	316.6 a	311.6 a	300.6 b	304.8 bc	306.5 a
Single Cut + N	290.4 d	309.9 a	308.2 a	304.8 b	289.6 c	304.0 a
Single Cut + PGR..............	299.7 cd	306.5 a	296.4 a	303.1 b	309.9 ab	318.4 a
Single Cut	308.2	302.3 a	310.7 a	305.7 b	304.8 bc	313.3 a
Double Cut + N + PGR.	308.2 bcd	314.1 a	335.3 a	331.9 a	310.7 ab	329.3 a
Double Cut + N	309.9 bcd	303.9 a	326.8 a	303.1 b	318.4 ab	309.9 a
Double Cut + PGR............	330.2 bc	327.6 a	330.2 a	312.4 b	321.7 ab	335.3 a
Double Cut	314.1 a	319.2 a	340.4 a	311.6 b	315.8 ab	326.8 a
Cross Cut + N + PGR.	318.4 abc	306.5 a	323.4 a	342.1 a	318.3 ab	326.8 a
Cross Cut + N	325.1 ab	330.2 a	345.4 a	335.3 a	318.3 ab	316.7 a
Cross Cut + PGR...............	326.8 ab	322.6 a	340.4 a	331.9 a	325.1 a	327.7 a
Cross Cut	316.7 abc	308.2 a	328.5 a	331.9 a	316.6 ab	318.3 a

[z] Ball roll distance was assessed using a USGA Stimpmeter. To limit the ball roll to within the plots dimensions the "2x" notch on the Stimpmeter was used. Results were multiplied by a factor of 2 and converted to feet.

[y] Mowing treatments were initiated on 11 Jul 2017.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to the Fisher's Protected least significant difference test.

Table 4 (cont.). Ball roll distance (BRD) after morning operations on a creeping bentgrass putting evaluating the effects of PGR, nitrogen, and mowing patterns, 2017.

	Ball roll distance (cm)[z]					
Height of cut and	1 Aug	4 Aug	8 Aug	11 Aug	16 Aug	18 Aug
Single Cut + N + PGR.........	303.1 ef[x]	298.0 d	291.3 a	301.4 d	298.0 c	299.7 a
Single Cut + N	292.9 f	298.0 d	294.6 a	308.2 cd	299.7 c	284.5 a
Single Cut + PGR..............	318.3 cde	292.9 d	309.9 a	301.4 d	313.3 abc	287.9 a
Single Cut	315.0 de	308.2 cd	299.7 a	300.6 d	294.7 c	297.2 a
Double Cut + N + PGR.	335.3 ab	324.3 abc	313.3 a	325.1 a	318.3 abc	303.1 a
Double Cut + N	326.8 a-d	317.5 bc	298.0 a	313.3 bc	315.0 abc	294.6 a
Double Cut + PGR............	331.1 abc	331.9 ab	313.2 a	331.9 a	320.0 abc	317.5 a
Double Cut	328.5 a-d	337.0 a	305.6 a	331.9 a	335.3 ab	299.7 a
Cross Cut + N + PGR.	331.0 abc	334.4 ab	323.4 a	322.6 ab	337.0 b	309.0 a
Cross Cut + N	326.0 a-d	321.7 abc	313.3 a	329.4 a	309.9 bc	311.6 a
Cross Cut + PGR...............	338.7 a	335.3 a	317.5 a	329.3 a	316.7 abc	320.9 a
Cross Cut	320.1 bcd	331.9 ab	307.3 a	313.3 bc	326.8 ab	307.3 a

[z] Ball roll distance was assessed using a USGA Stimpmeter. To limit the ball roll to within the plots dimensions the "2x" notch on the Stimpmeter was used. Results were multiplied by a factor of 2 and converted to feet.

[y] Mowing treatments were initiated on 11 Jul 2017.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to the Fisher's Protected least significant difference test.

Figure 1. The *Mowing Pattern x Cultural Practices* field study was arranged as a randomized complete split-plot design with 3 replications. Main plots consisted of three mowing pattern with split-plots consisting of four fertilizer/plant growth regulator (PGR) regimes. Mowing patterns consisted of a standard single pass (S) pattern, a double cut (DC) pattern up and back along the same line, and a criss-cross (CC) pattern in which the individual plots were mowed twice at opposite angles.

USGA ID#: 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

Objective: To evaluate spent coffee grounds for golf course turf applications.

Start Date: 2017
Project Duration: 2 years
Total Funding: $10,000

Summary Points:

- Shoot growth responses following application of spent coffee grounds do not differ from the untreated check.
- When spent coffee grounds are incorporated into sand-based rootzones, no significant improvements in 0-2 inch soil moisture have been detected over the first year.

Summary Text:
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 (SCG) 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, SCG could offer an opportunity for use of a more sustainable, renewable resource in many regions.

Over the past year field studies have been initiated at Texas A&M University to explore the agronomic potential of SCG in turf systems. Evaluations of both direct application of fresh and composted spent coffee grounds, as well as SCG-derived organic and bridge fertilizers have been evaluated against other commercially available organic, synthetic, and bridge-type fertilizers in the field. Greenhouse studies have been conducted to evaluate SCG in comparison to sphagnum peat moss for water and nutrient retention in sand-based root zones (Figure 1). An initial round of both field and greenhouse studies have also been conducted to evaluated pre-emergence herbicide potential of SCG (Figure 2).

Field studies were initiated in September 2017 on Celebration bermudagrass turf plots. The study is arranged as a completely randomized block design with 3 replicates. Fertilizer treatments are applied to plots 4x annually from May through October at a rates of either 0.5 or 1 lb. N/ 1000 sq. ft. Fertilizer treatments and associated analyses being tested include:

-Untreated check
-Fresh SCG (2.3-0.1-0.5)
-Composted SCG (2.9-0.1-0.5)
-Sigma Agriscience poultry litter-based organic fertilizer (4-2-2)
-Sigma Agriscience bridge containing poultry litter + ammonium sulfate (12-2-6)
-GeoJava poultry litter + SCG organic fertilizer (4-2-1)

-GeoJava bridge containing poultry litter + SCG + ammonium sulfate (12-2-6)
-Milorganite (5-2-0)
-Ammonium sulfate (21-0-0)
-Sulfur coated urea (SCU) (21-7-14)

Turfgrass and soil health effects are being monitored through evaluations of turf quality, percent green cover, soil moisture, and chemical/microbial analysis of soils to determine changes over time. Shoot growth curves have also been generated to characterize growth responses from spent coffee grounds and SCG-containing fertilizers in relation to other industry organic and synthetic fertilizers. Some of the field study results-to-date suggest the following:

- All fertilizer treatments in the study have provided acceptable levels of turf quality. However, overall mean turf quality from direct application of both fresh and composted SCG has not provided improved turf quality relative to the untreated control.
- SCG-containing GeoJava (4-2-1) has shown significantly improved turf quality compared to that of the untreated check, fresh and composted SCG, GeoJava (Bridge), ammonium sulfate, and SCU treatments.
- Shoot growth responses following application of SCG do not differ from the untreated check, which combined with turf quality data, suggest that N within SCG is tightly bound and/or slowly mineralized.
- Although a layer of SCG can be seen accumulating within the thatch/mat layer of SCG treatments, no significant improvements in 0-2 inch soil moisture have been detected over the first year.

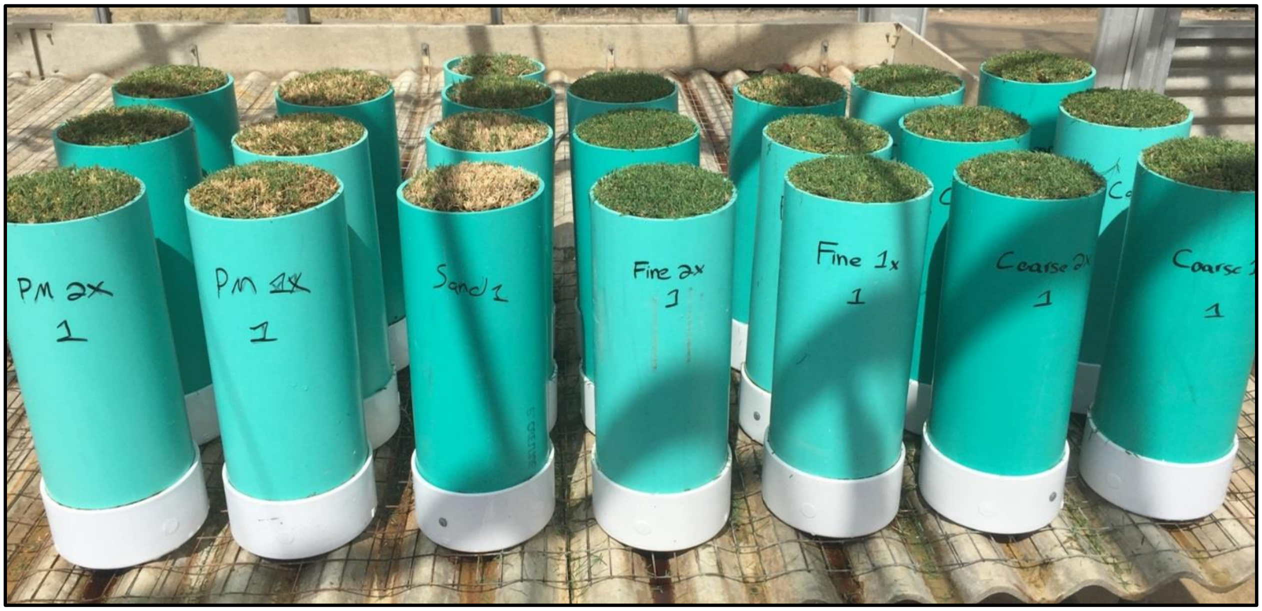

Figure 1. Image of greenhouse root zone amendment study evaluating nutrient and water retention in root zones amended with either sphagnum peat moss or spent coffee grounds at two rates and two particle size distributions.

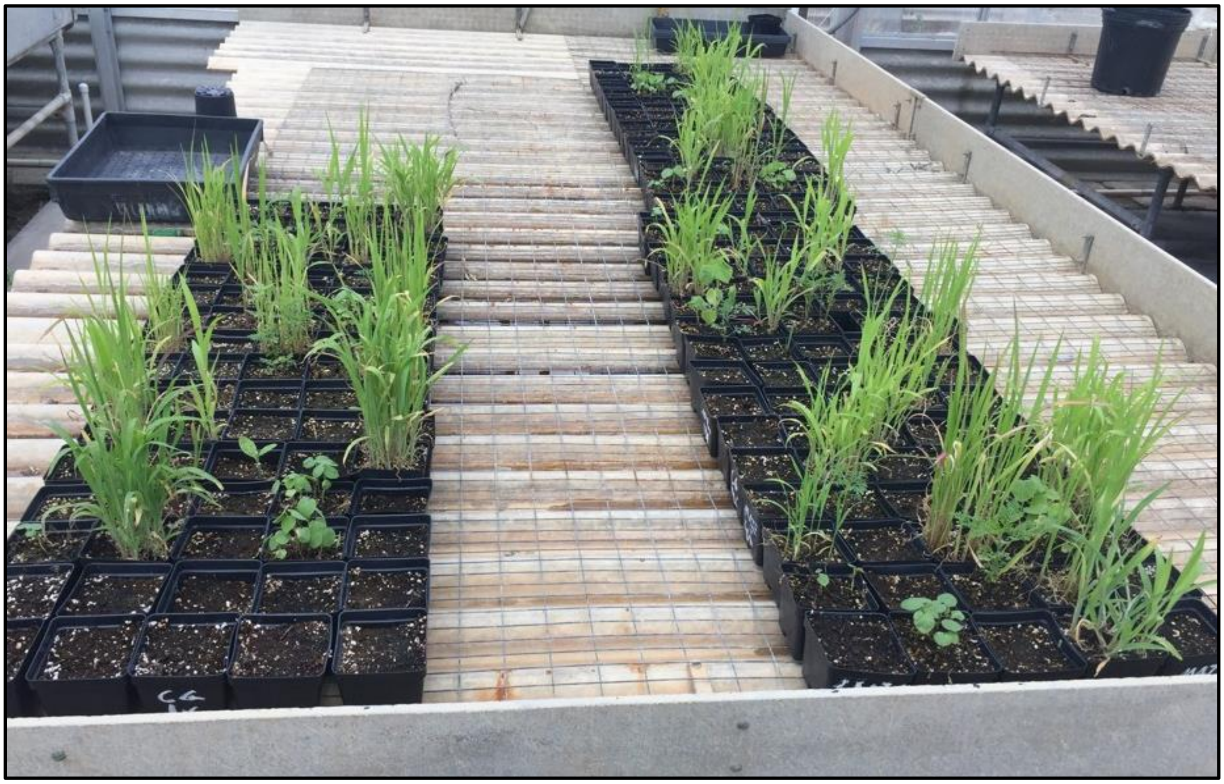

Figure 2. Image of greenhouse pre-emergence herbicide studies evaluating spent coffee grounds versus other organic and synthetically derived pre-emergence herbicides on germination and growth of multiple weed seedlings.

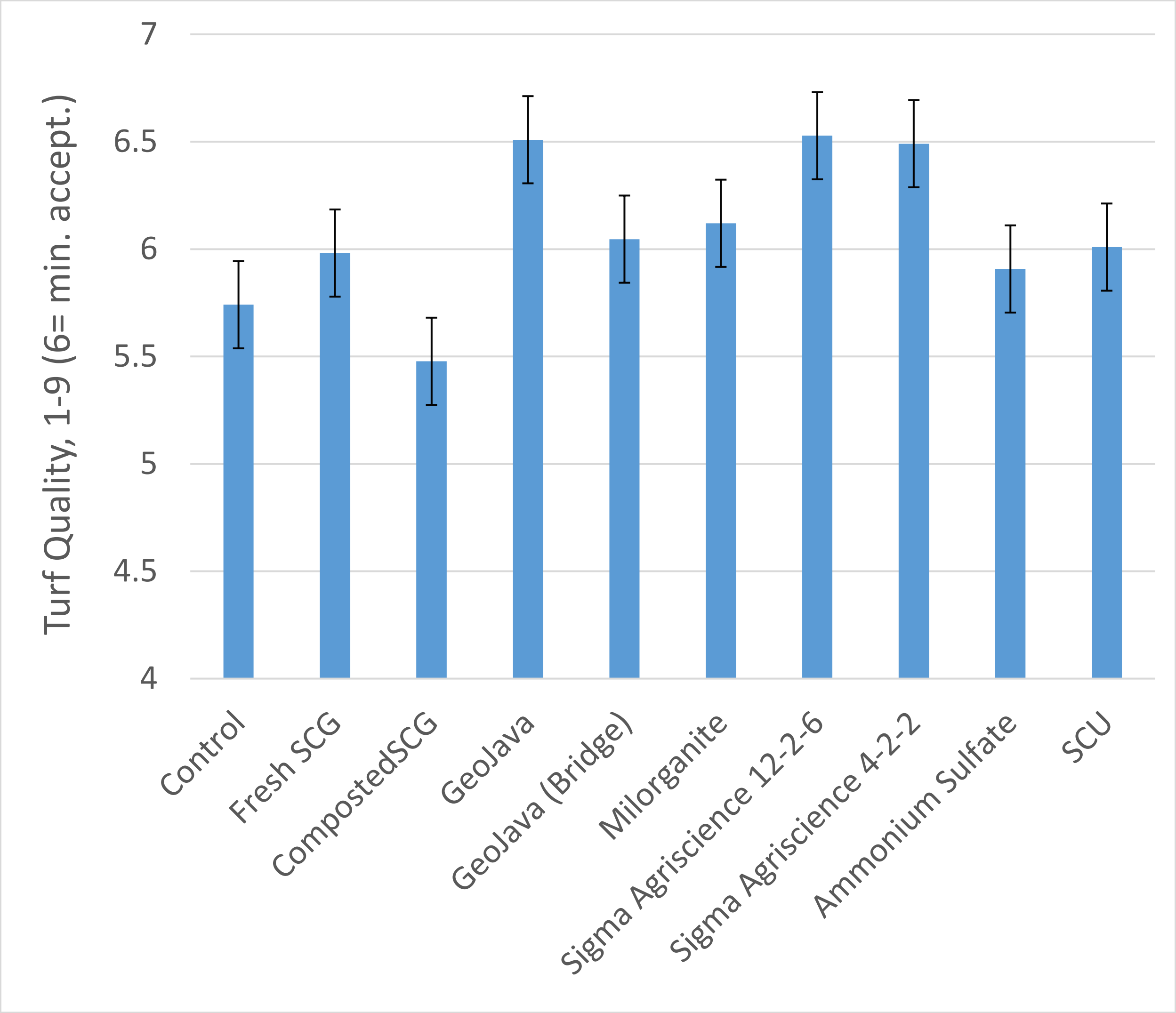

Figure 3. Celebration bermudagrass Turf Quality (5= minimally acceptable) in response to the various fertilizer treatments at the 1 lb. N/1000 sq. ft. application rate, averaged across all dates of the 2017-2018 seasons. Error bars denote Fisher's LSD at *P* = 0.05.

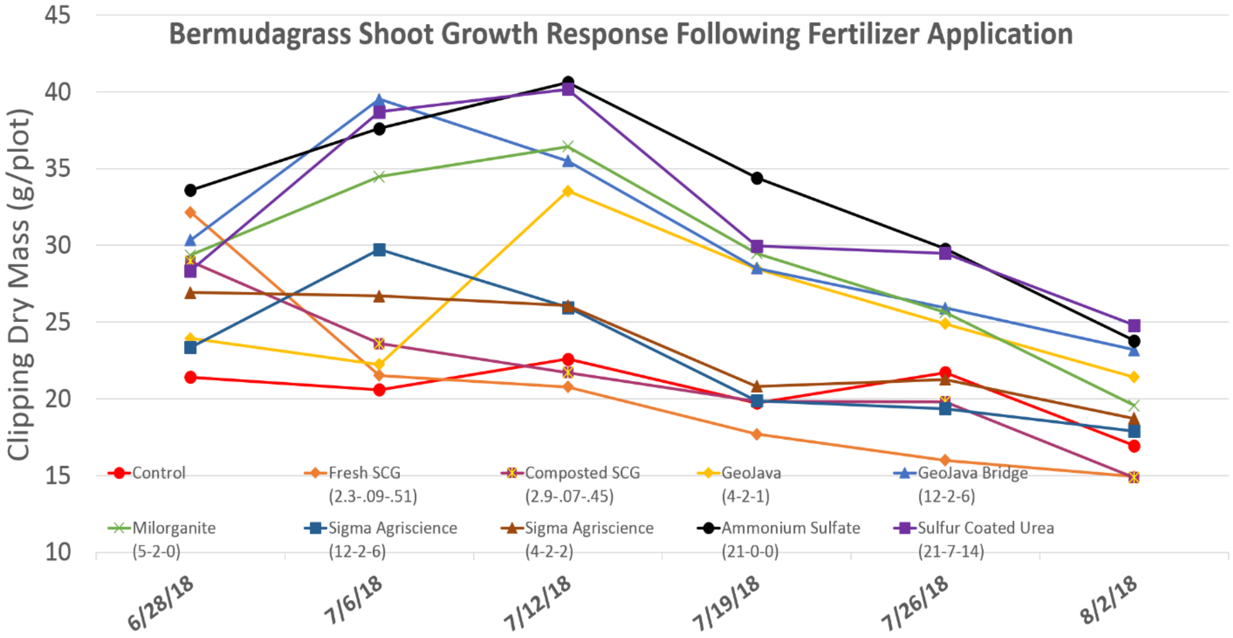

Figure 4. Shoot growth responses of spent coffee grounds and various fertilizer treatments over a six-week period following fertilizer application. Data are for the 1 lb. N/ 1000 sq. ft. application rate.

USGA ID#: 2017-26-636

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

Objectives:

1. Identify effective insecticides to control frit fly in golf course field trials.
2. Disseminate findings to golf/turf/landscape industries in Hawaii and beyond.

Start Date: 2017
Project Duration: 2 years
Total Funding: $10,000

Summary Points:

- Triple Crown resulted in the best frit fly control, as indicated by frit fly damage rating, turfgrass greenness, and overall turfgrass quality.
- Provaunt was the second best treatment identified.
- No injury to turfgrass from any of the treatments was observed during this project.

Summary Text:
Frit fly (*Oscinella frit*) is a relatively new turfgrass insect pest in Hawaii. All species of turfgrass are susceptible. In Hawaii, Bermudagrass is the most susceptible to frit fly injury. Frit fly larvae tunnel in the turfgrass stems near the surface of the soil, causing the upper portion of the grass to turn brown and die. Damage is common on golf putting greens and fairways. Injury usually appears first on the collars of the greens and moves in toward the center. The high, or upper, sections of grass are usually the first to show the symptoms, usually a general yellow (chlorotic) appearance. Greens with high organic matter content appear to be most susceptible. Further, the adult fly is a nuisance to golfers because they are attracted to white objects, including golf balls and golf carts. Relatively less researched, especially in Hawaii, frit fly continues to be a management challenge to many golf courses in Hawaii. In recent communications, quite some golf courses expressed interest in identifying effective control methods against frit fly. Therefore, we proposed this study to develop an IPM program to control frit fly with effective insecticides to be identified in field trials.

Field trial was conducted May through August, 2018 on Bermudagrass fairways at Kapalua Bay Course, Maui, Hawaii (Figure 1). Five treatments and untreated control were included (Table 1). There were 4 replications (plots) per treatment and control, arranged using a Randomized Complete Block Design (RCBD). Each plot was 7 ft by 7 ft, and there was a buffer area between any adjacent plots. All treatments were applied 3 times in total, 21 days between applications. Frit fly damage, turfgrass greenness, and overall turfgrass quality were measured, by 2 people, prior to the first application, approximately 21 days after first and second applications (immediately prior to the next application), and 2 weeks and 4 weeks after the third/last application. Frit fly damage was on 1 to 9 rating scale with 1 equaling no injury, and 9 equaling 100% injury. Turfgrass greenness was on 1 to 9 scale with 1 being straw brown and 9 being dark green. Overall turfgrass quality was on 1 to 9 scale with 9 being outstanding or ideal turf and 1 being poorest or dead.

Among the 5 treatments tested, Triple Crown resulted in the best frit fly control, as indicated by frit fly damage rating, turfgrass greenness, and overall turfgrass quality (Figures 2 to 4). Provaunt treatment was the second best treatment identified, as shown in Figures 5 to 7. Divanem (either high or low rate) or Talstar did not have obvious control effect on frit fly. No injury to turfgrass from any of these 5 treatments was observed during this project.

To fulfill the second objective of this project, PI Z. Cheng has scheduled to conduct a workshop on Maui (remotely available to neighbor islands and beyond) on December 13, 2018, targeting turf / golf / landscape industries and other interested parties, to disseminate the research findings, and make them more aware of this turfgrass pest, and how to control it.

Figure 1. Trial site at Kapalua Bay Course.

Table 1. Details of treatments.

TRT	PRODUCT	FORMU	RATE/A	Frequency
1.	Divanem + Adjuvant	0.7 SC (L)	6.1 fl oz + 0.25%v/v	3
2.	Divanem + Adjuvant	0.7 SC (L)	12.2 fl oz + 0.25%v/v	3
3.	Provaunt + Adjuvant	30 WG (S)	12 oz + 0.25%v/v	3
4.	Triple Crown	L	15 fl oz (no adju)	3
5.	Talstar S Select	L	15 fl oz (no adju)	3
6.	Untreated Control			

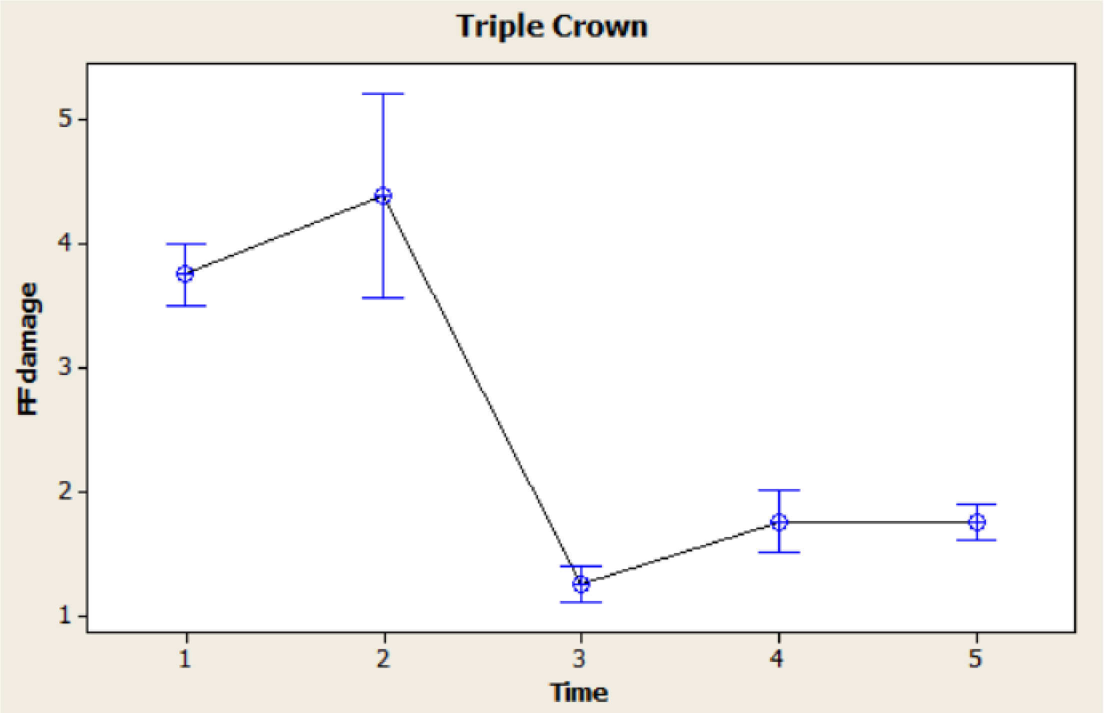

Figure 2. Frit fly damage rating under Triple Crown treatment. 1 to 9 rating scale with 1 equaling no injury, and 9 equaling 100% injury.

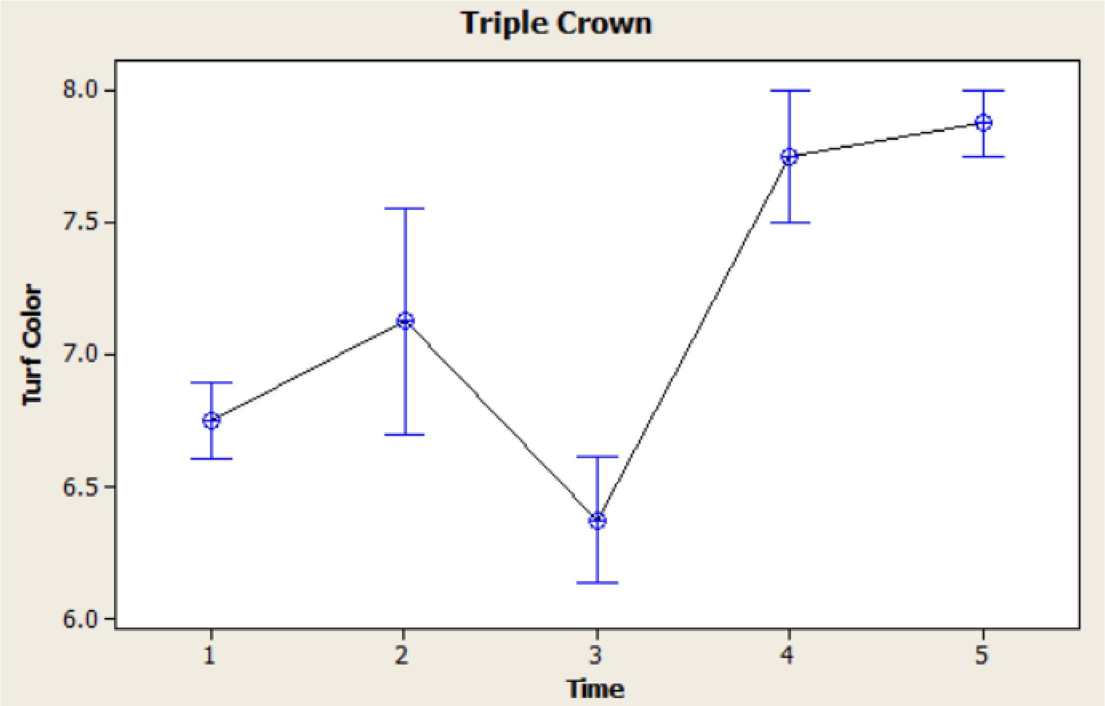

Figure 3. Turfgrass greenness rating under Triple Crown treatment. 1 to 9 scale with 1 being straw brown and 9 being dark green.

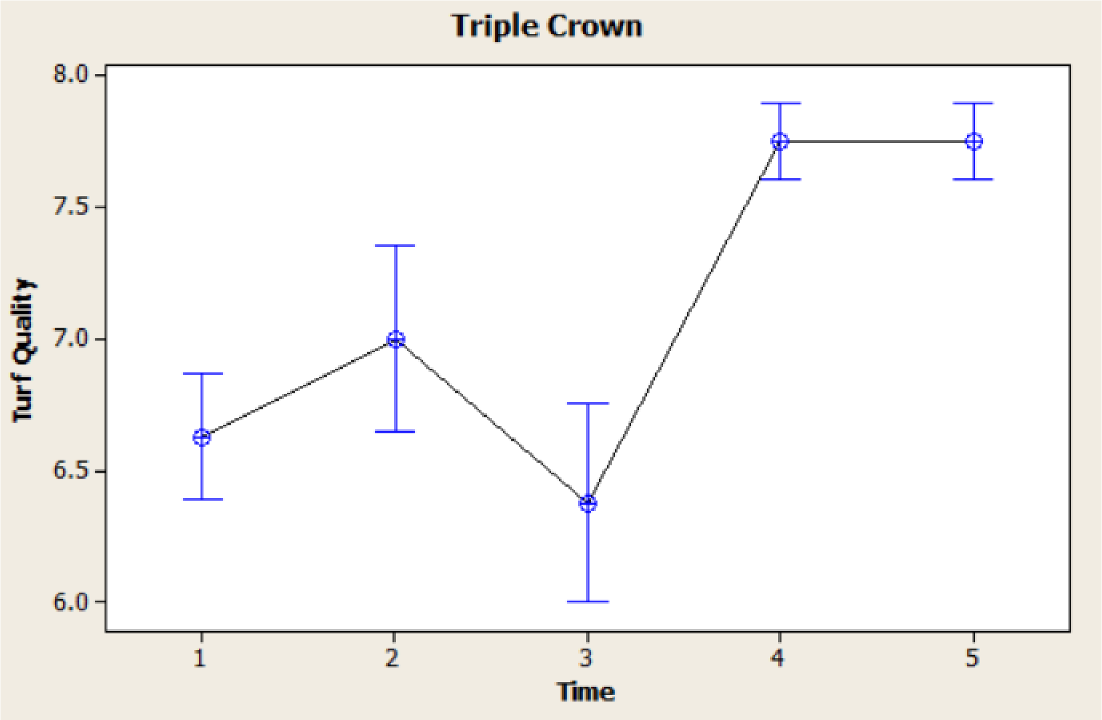

Figure 4. Overall turfgrass quality rating under Triple Crown treatment. Quality is based on 9 being outstanding or ideal turf and 1 being poorest or dead.

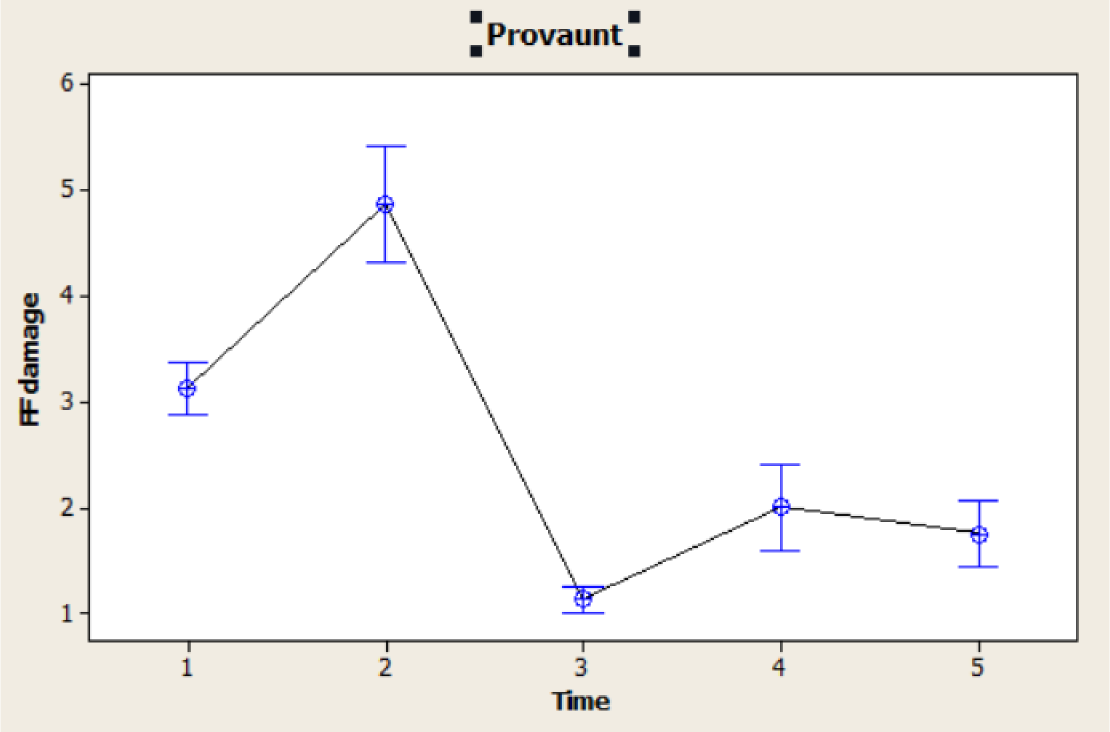

Figure 5. Frit fly damage rating under Provaunt treatment. 1 to 9 rating scale with 1 equaling no injury, and 9 equaling 100% injury.

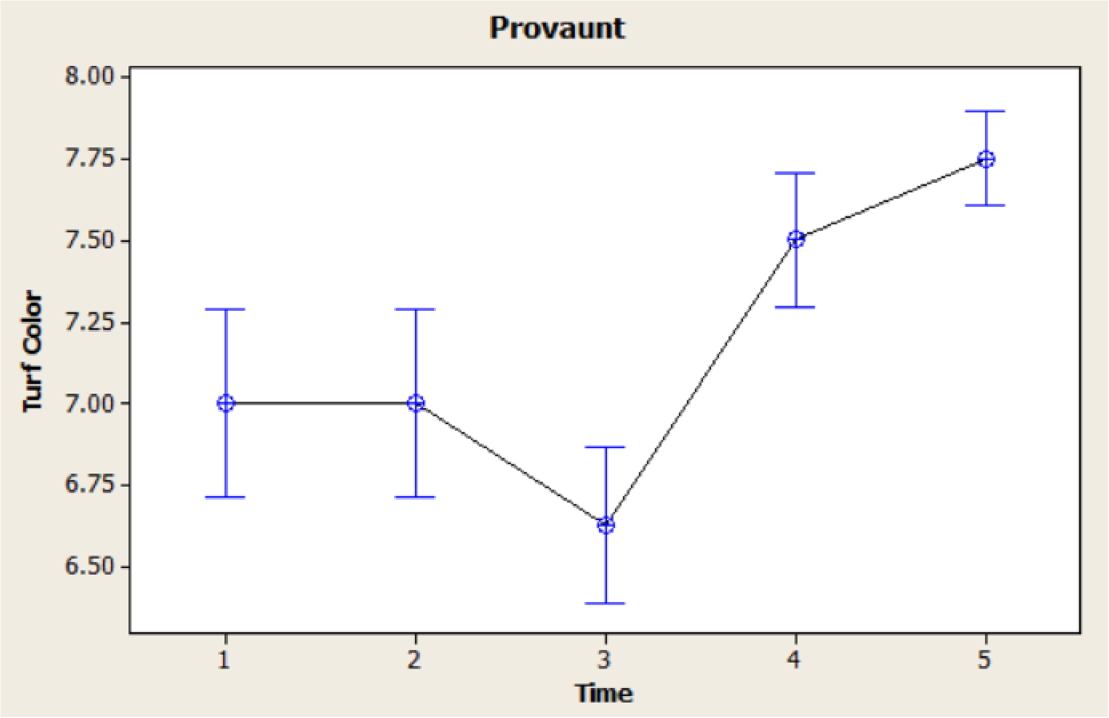

Figure 6. Turfgrass greenness rating under Provaunt treatment. 1 to 9 scale with 1 being straw brown and 9 being dark green.

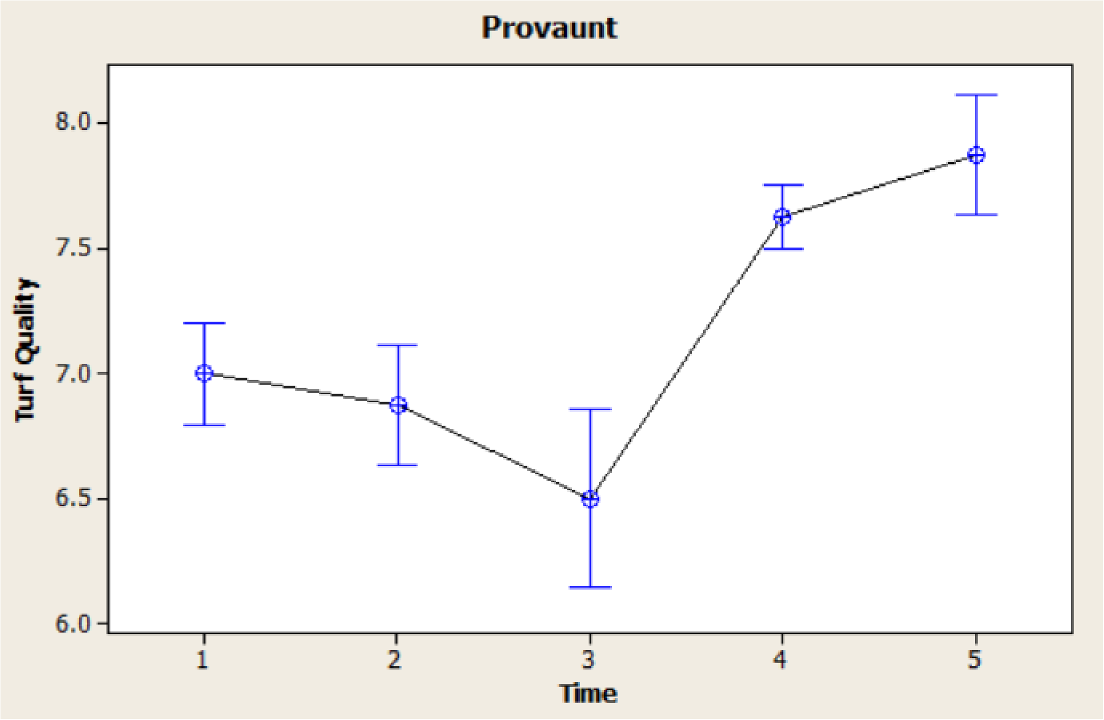

Figure 7. Overall turfgrass quality rating under Provaunt treatment. Quality is based on 9 being outstanding or ideal turf and 1 being poorest or dead.

USGA ID#: 2017-31-641

Title: Geographic Distribution, Characterization, and Epidemiology of Pythium-Associated Turfgrass Diseases in Pennsylvania and Mid-Atlantic United States and Identification of an Unknown Potential Pythium Disease of Putting Greens

Project Leaders: John E. Kaminski and Travis R. Russell
Affiliation: The Pennsylvania State University

Objectives:

1. Determine the geographic distribution and causal agents of Pythium-related diseases throughout Pennsylvania and mid-Atlantic region.
2. Identify and confirm the causal agent of an emerging disease “Pythium patch” on annual bluegrass putting greens.
3. Investigate epidemiology of Pythium-associated diseases across Pennsylvania and mid-Atlantic region.
4. Optimize cultural and chemical management strategies for “Pythium patch” and other Pythium pathogens causing disease on turfgrass in the mid-Atlantic region.

Summary Text:

During stressful periods of high heat and humidity, outbreaks of Pythium foliar blight can wreak havoc on turfgrass throughout the mid-Atlantic region of the United States. The signs and symptoms of Pythium foliar blight on turfgrass are well documented and can be diagnosed by a trained pathologist. However, there are over 200 species within the Pythium genus and many plant pathogenic species have been identified as the causal agent of Pythium foliar blight and other turfgrass diseases such as Pythium root dysfunction, Pythium root rot, and damping off of seedlings. Each of these diseases and associated pathogen species can vary in signs, symptoms, epidemiology, and proper control strategies. Due to the diverse nature of the Pythium diseases in turfgrass and the potential devastating damage they cause, there is a need to identify the causal agent of Pythium-associated turf diseases and their geographic distribution across Pennsylvania and throughout the mid-Atlantic region. This information will prove beneficial to understanding the unique biology, epidemiology, and control strategies of the different Pythium species in the region.

In 2016, an outbreak of a previously minor and relatively unknown disease displaying Pythium-like characteristics was observed on putting greens in 5 states on 13 golf courses in the mid-Atlantic and northeastern United States. This disease, termed “Pythium patch” due to displaying similar signs of other Pythium diseases in turfgrass, was first observed in Connecticut in 2005. However, the symptoms of this disease are unique. The disease progresses slowly compared to traditional Pythium diseases and is most unique for the selective targeting of annual bluegrass in mixed populations of creeping bentgrass putting greens. With symptoms similar to summer patch, this disease is often misdiagnosed. There is currently no scientific literature on this potentially new Pythium disease and the causal agent, epidemiology, and management options remain unknown.

No overall assessment of Pythium-related diseases on turfgrass relative to their geographic distribution, causal agent, epidemiology, and specific control measures in the mid-Atlantic has been conducted. This would be the first insight into developing management plans for turf practitioners tailored to unique Pythium species pathogens.

Methods

Objective 1: Geographic Distribution of Pythium-Associated Diseases across Pennsylvania and the Mid-Atlantic Region

Turfgrass samples will be collected across the state of Pennsylvania and neighboring states in the mid-Atlantic region that are suspected of being infected with a Pythium-related disease. Information regarding each sample such as location, environmental conditions, turfgrass species, management situation (rough, fairway, green), rootzone composition, etc. will be recorded to categorize and asses the distribution of the disease and causal pathogen in the region. Pathogens will be isolated from the diseased plant tissue and grown in pure culture. DNA isolation and analysis will be performed on the pathogen cultures to determine the causal agent of the disease in each sample. Identity confirmation from DNA techniques paired with corresponding sample information will be analyzed to produce insight into the geographical distribution of Pythium-related diseases in the mid-Atlantic and their respective casual agents, host specificity, and environmental preferences.

Objective 2: Identify and Confirm the Causal Agent of an Emerging Disease on Annual Bluegrass Putting Greens

In 2016, samples of annual bluegrass putting greens exhibiting symptoms similar to those described as “Pythium patch” were collected from 20 golf courses across 6 states in the mid-Atlantic and northeastern United States. From those samples 14 isolates were cultured for further analysis of the causal agent. DNA from these isolates is currently being extracted to determine the pathogen species identity. From these isolates, Koch’s postulates will be performed to confirm the causal agent responsible for this plant disease. Additionally, further samples will be collected 2019 and 2020 as disease symptoms occur to create a more robust collection of isolates to document pathogen diversity and epidemiology.

Objective 3: Investigate Epidemiology of Pythium-Associated Diseases across Pennsylvania and mid-Atlantic region

Pathogen isolates from Pythium-associated diseases on turfgrass acquired from locations across the mid-Atlantic region will be subjected to controlled environment and field evaluations to document the environmental factors that contribute to spread of the disease over time and space. Healthy turfgrass will be inoculated with the unique Pythium species and evaluated in growth chamber experiments to determine the cardinal environmental conditions (i.e. temperature, relative humidity, leaf wetness period, etc.) for disease development. Additionally, validation of the obtained environmental parameters will be assessed in a field research study on established turfgrass.

Objective 4: Optimize Cultural and Chemical Strategies for Pythium species-related turfgrass diseases in the mid-Atlantic and northeastern United States.

Due to the variation in environmental parameters, host specificity, and pathogenicity of the different species of Pythium that infect turfgrass, it is imperative to optimize the control strategies for each causal agent. *In vitro* fungicide assays will be used to determine sensitivity of each pathogen isolate to chemical control options at varying serial volumes. Further, fungicide efficacy trials in field research studies on established turfgrass infected with the pathogen will be utilized to determine optimal chemical control strategies. Furthermore, field research trials to evaluate cultural controls such as dew removal, mowing height adjustment, rolling, aerification, etc. to minimize disease severity will be developed.

Conclusions

Pythium-associated turfgrass diseases can cause significant turfgrass loss due to the quick infection and colonization of certain Pythium species. Due to the large number of Pythium species that are pathogenic and cause several turfgrass diseases, the specific causal agent is not always evaluated or known during diagnosis. These unique Pythium species vary in preferred environmental conditions, host specificity, disease symptoms, and optimum control strategies. There has previously been no characterization, geographic distribution, and evaluation of the Pythium diseases that affect turfgrass in Pennsylvania and the mid-Atlantic region. Findings from this sort of investigation would benefit turf managers through development of pathogen specific management and control recommendations.

Figure 1. The symptoms of “Pythium patch” are unique. The disease progresses slowly compared to traditional Pythium diseases and is most unique for the selective targeting of annual bluegrass in mixed populations of creeping bentgrass putting greens. With symptoms similar to summer patch, this disease is often misdiagnosed.

USGA ID#: 2017-35-644

Title: Winter Survival of Experimental Bermudagrasses in the Upper Transition Zone

Project Leaders: Mingying Xiang[1], Jack Fry[1], and Yanqi Wu[2]
Affiliation: [1]Kansas State University; [2]Oklahoma State University

Objective: To compare new, experimental bermudagrasses to existing cultivars for winter survival in Kansas.

Start Date: 2017
Project Duration: 2 years
Total Funding: $7,000

Summary Points:

- Progeny showed a wide range of variability in cold hardiness.
- Tifway had 0% survival in May 2018, whereas Latitude 36 and NorthBridge had winter survival of 20% and 25%, respectively.
- Several new, experimental progeny exhibited > 90% winter survival on the same rating date.

Summary Text:

Winter survival is the limiting factor in developing and selecting new bermudagrass cultivars for use in the transition zone.

Methods

On 19 July, 2016, vegetative plugs of 60 new bermudagrass progeny along with standards cultivars Latitude 36, NorthBridge, DT-1, Tifway, and Patriot were planted at the Rocky Ford Turfgrass Research Center in Manhattan, KS. Bermudagrass progeny came from the turfgrass breeding program at Oklahoma State University. Plots measured 4 ft. by 4 ft. and were replicated 3 times. The soil type was a silty clay loam (fine, smectitic, mesic, Aquertic Argiudoll) with a pH of 7.3. Plots were mowed 3 times per week at 5/8” mowing height. Nitrogen from urea was applied twice during the summer to provide 1 lb. of N at each application. Ronstar was applied in April to prevent annual grassy weeds, and Trimec was applied at the same time to remove broadleaves.

The first freezing temperature occurred on 27 Oct., 2017, and bermudagrasses started to lose color. After 25 Dec., there were 17 days on which the low temperature was < 10 °F; the lowest temperature occurred on 1 Jan. 2018 (- 8 °F).

Data were collected on winter injury on a 0 to 100% scale on 25 May 2018. Data were analyzed using PROC GLM, and results are presented in Table 1.

Table 1. Winter survival of bermudagrass progeny and standard cultivars on 25 May 2018 in Manhattan, KS.

Entry	Survival (%)[z]	Entry (*cont.*)	Survival (%)[z] (*cont.*)
OSU1656	98.3	OSU1617	28.3
OSU1666	96.7	OSU1423	26.7
OSU1675	93.3	OSU1605	26.7
OSU1680	93.3	OSU1412	25.0
OSU1629	90.0	OSU1640	23.3
OSU1406	88.3	OSU1425	21.7
OSU1337	86.7	OSU1634	21.7
OSU1433	86.7	OSU1669	21.7
OSU1649	86.7	OSU1607	20.0
OSU1657	85.0	OSU1610	20.0
OSU1682	83.3	OSU1606	18.3
OSU1664	81.7	OSU1420	15.0
OSU1687	80.0	OSU1615	15.0
OSU1673	78.3	OSU1611	13.3
OSU1257	75.0	OSU1603	8.3
OSU1628	73.3	OSU1612	8.3
OSU1639	73.3	OSU1417	5.7
OSU1662	71.7	OSU1310	5.0
OSU1601	68.3	OSU1616	3.3
OSU1620	68.3	OSU1418	2.7
OSU1625	63.3	OSU1415	0.7
OSU1641	63.3	Patriot	30.0
OSU1695	63.3	NorthBridge	25.0
OSU1435	61.7	DT-1	22.7
OSU1636	60.0	Latitude 36	20.0
OSU1439	56.7	Tifway	0.0
OSU1644	53.3	LSD[y]	23.6
OSU1631	51.7		
OSU1696	50.0		
OSU1604	46.7		
OSU1674	46.7		
OSU1403	43.3		
OSU1691	43.3		
OSU1402	38.3		
OSU1409	38.3		
OSU1318	36.7		
OSU1614	36.7		
OSU1408	35.0		
OSU1645	35.0		

[z] Winter survival was rated visually on a 0 to 100% scale; results are averaged over three replicates.

[y] 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 ($P < 0.05$).

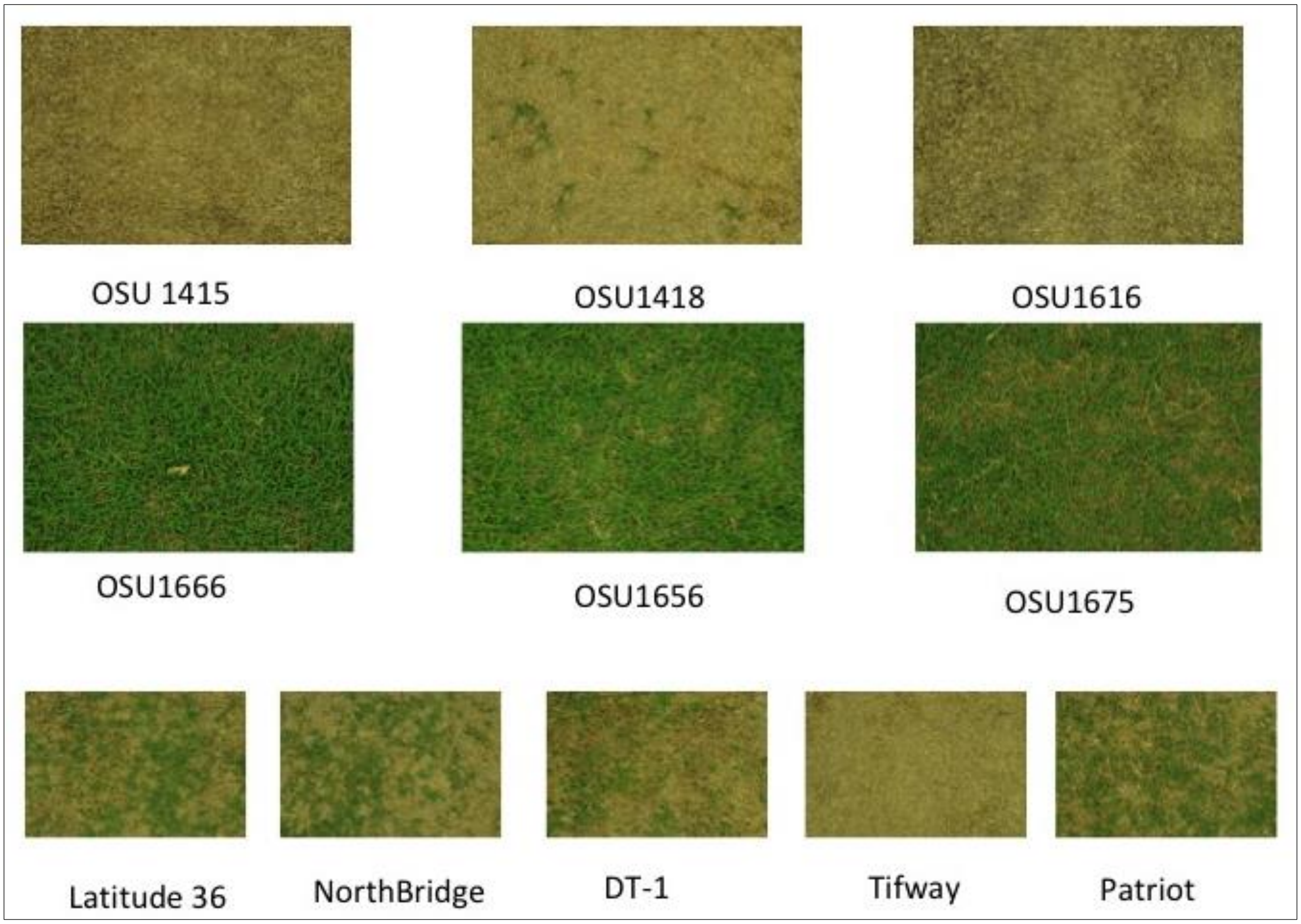

Figure 1. Overhead photos of new bermudagrass progeny and standard cultivars taken above a single, representative plot on 28 May, 2018 in Manhattan, KS.

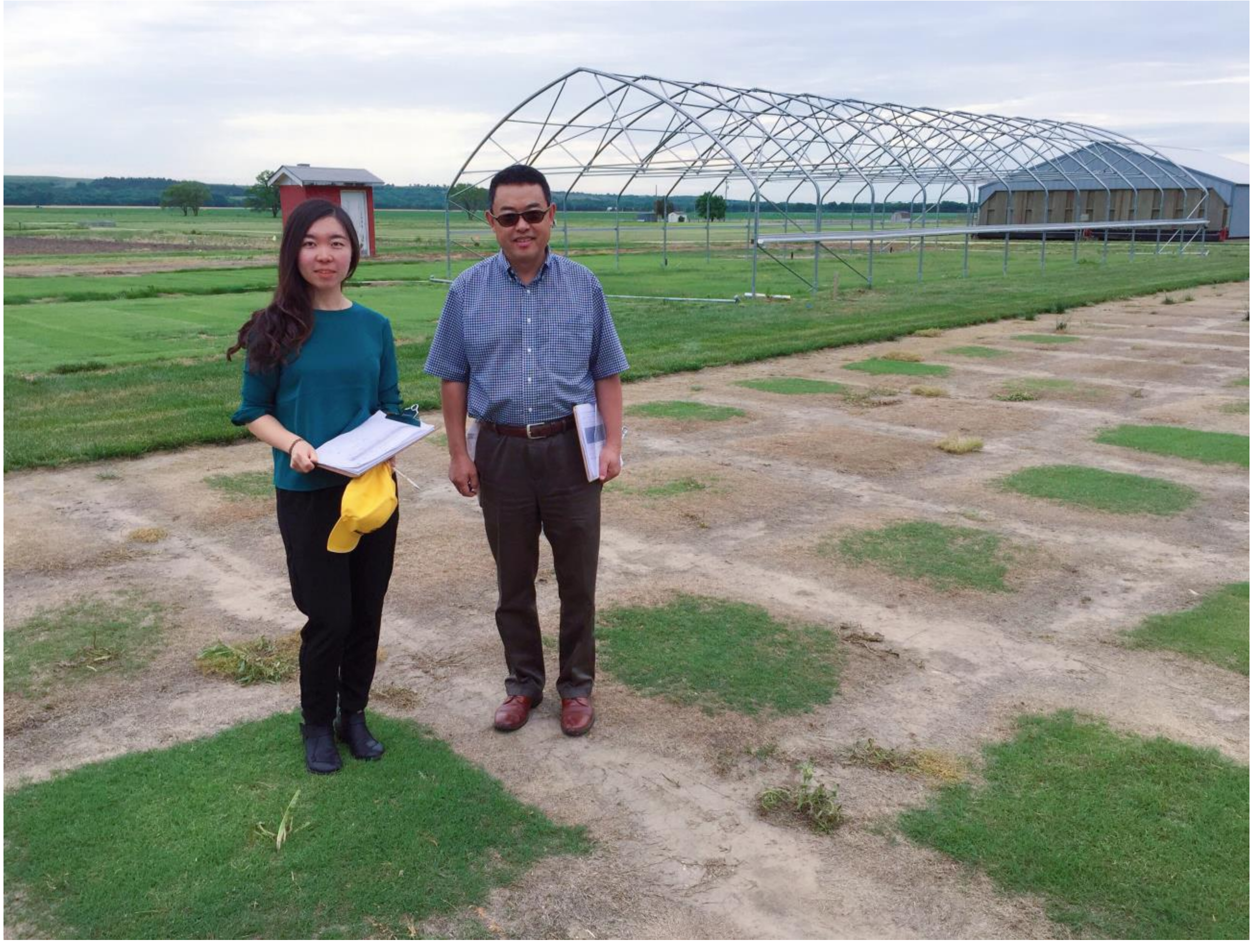

Figure 2. Dr. Yanqi Wu, turfgrass breeder at Oklahoma State University, and Mingying Xiang, Ph.D. student at Kansas State University, rate plots in Manhattan, KS in May 2018 (Credit: Dr. Jack Fry).

USGA ID#: 2017-35-645

Title: Effects of Ethylene Inhibition on Creeping bentgrass and Annual bluegrass Survival of Ice Cover Stress

Project Leader: Emily Merewitz Holm
Affiliation: Michigan State University

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.

Start Date: 2017
Project Duration: 2 years
Total Funding: $10,000

Summary Points:

- Ethylene evolution from annual bluegrass plots was enhanced due to ACC and ethephon treatments. Ethylene inhibition treatments did not significantly lower ethylene evolution rates when compared to the untreated control.
- Effective ethylene treatments reduce turf quality and NDVI and reduced recovery of annual bluegrass after 0 and 20 d following simulated low temperature and ice cover conditions.
- Ethylene inhibition treatment Retain, increased ABG recovery after 40 and 80 d after low temperature treatment.
- Ethylene inhibition treatments increased CAT and APX activity and had lower saturated FA and greater unsaturated FA content when compared to the untreated control.
- Ethylene treatment products increased malondialdehyde content and greater saturated FA content while having lower POD and SOD activity when compared to the untreated control.

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. 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 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 which can be associated with antioxidant activity and membrane fatty acid content. 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). Ethylene inhibition treatment Retain increased ABG recovery after 40 and 80 d of low temperature treatment. This can be correlated to an increase in antioxidant scavenging activity and an increase in unsaturated fatty acid content when compared to the untreated control. Ethylene inhibition treatments AVG or Retain improved ABG recovery while ethephon treatment decreased recovery which could be associated with turf quality, NDVI, and respiration in the field after treatments during acclimation. This is an important step in determining why ABG may be more susceptible to winterkill when compared to CBG while also trying to find a treatment method that could be a viable option for golf course superintendents to use on putting green surfaces to alleviate the probability of winterkill to their ABG.

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Yu XM, Griffith M, and Steven B. Wiseman. 2001. Ethylene induces antifreeze activity in winter rye leaves Plant Physiology 126:1232-1240.

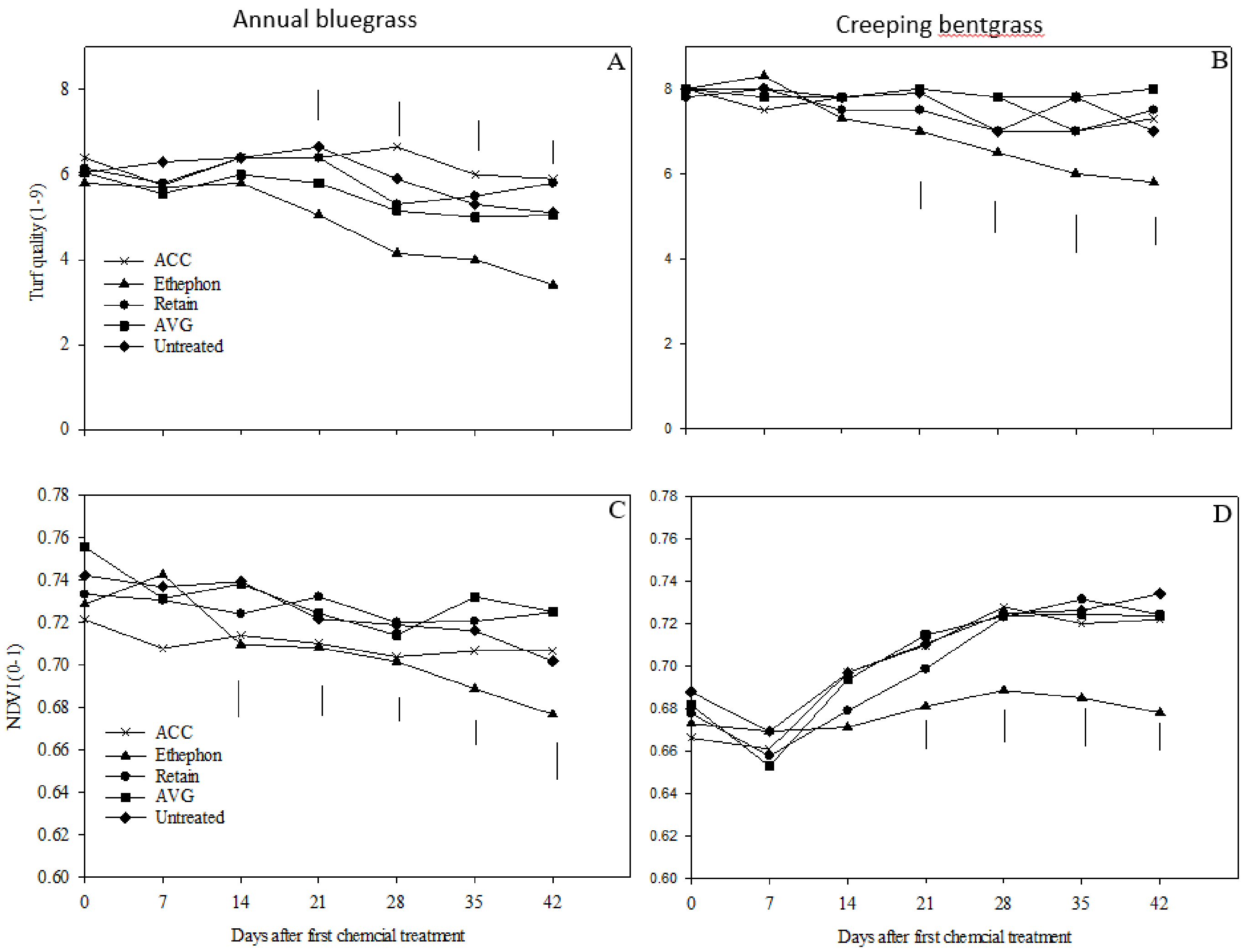

Figure 1. Visual turfgrass quality (scale of 1-9 with 9 = healthy, 1 = necrotic) of A) annual bluegrass and B) creeping bentgrass, and normalized difference vegetation index (NDVI) of C) annual bluegrass and D) creeping bentgrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated. Means from both 2016 and 2017 are pooled together. Least significant difference (LSD) values are indicated by vertical bars ($P \leq 0.05$) for treatment comparisons on a given day of treatment.

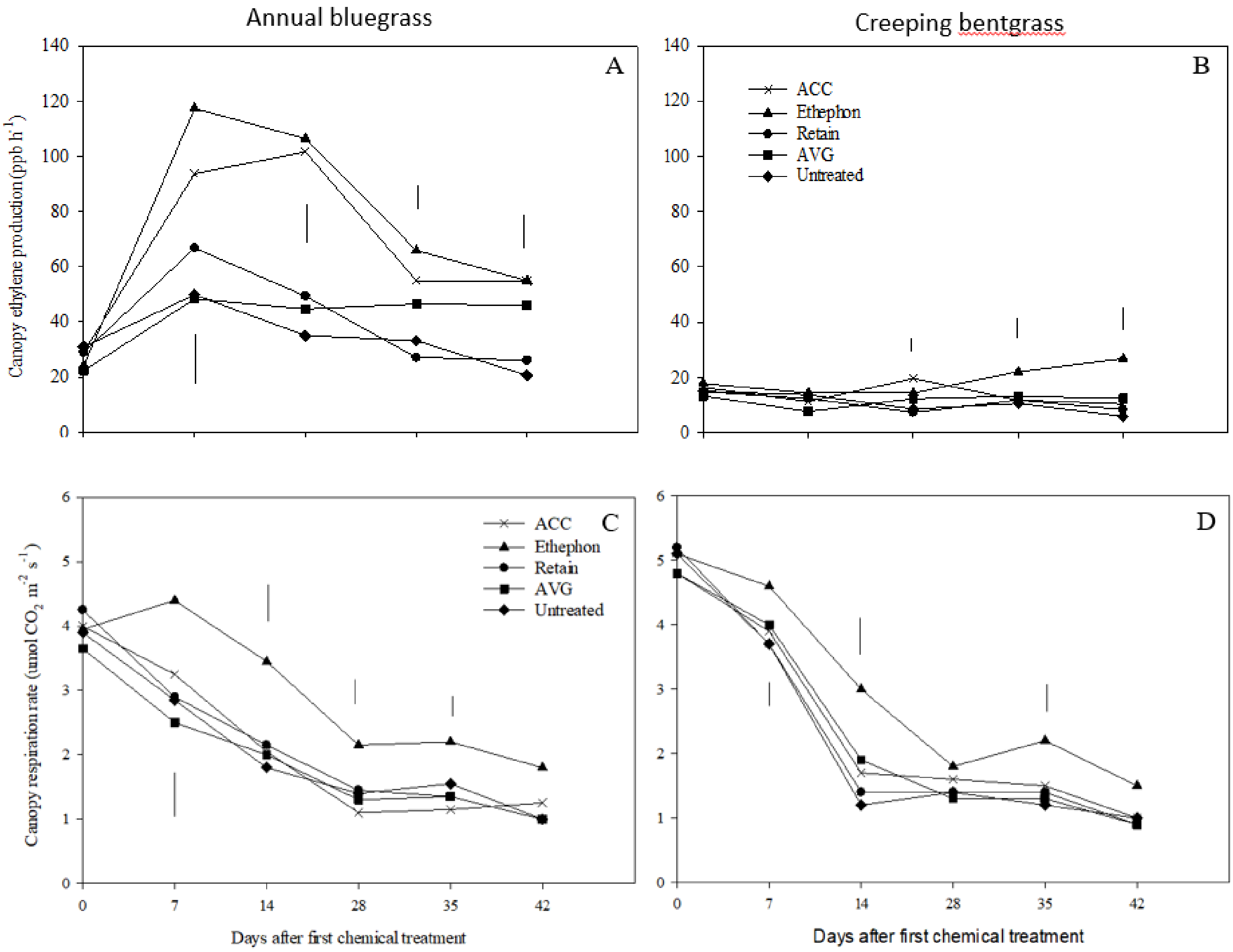

Figure 2. Ethylene gas production of A) annual bluegrass and B) creeping bentgrass and turfgrass whole plant respiration of C) annual bluegrass and D) creeping bentgrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated. Means from both 2016 and 2017 are pooled together. Least significant difference (LSD) values are indicated by vertical bars ($P \leq 0.05$) for treatment comparisons on a given day of treatment.

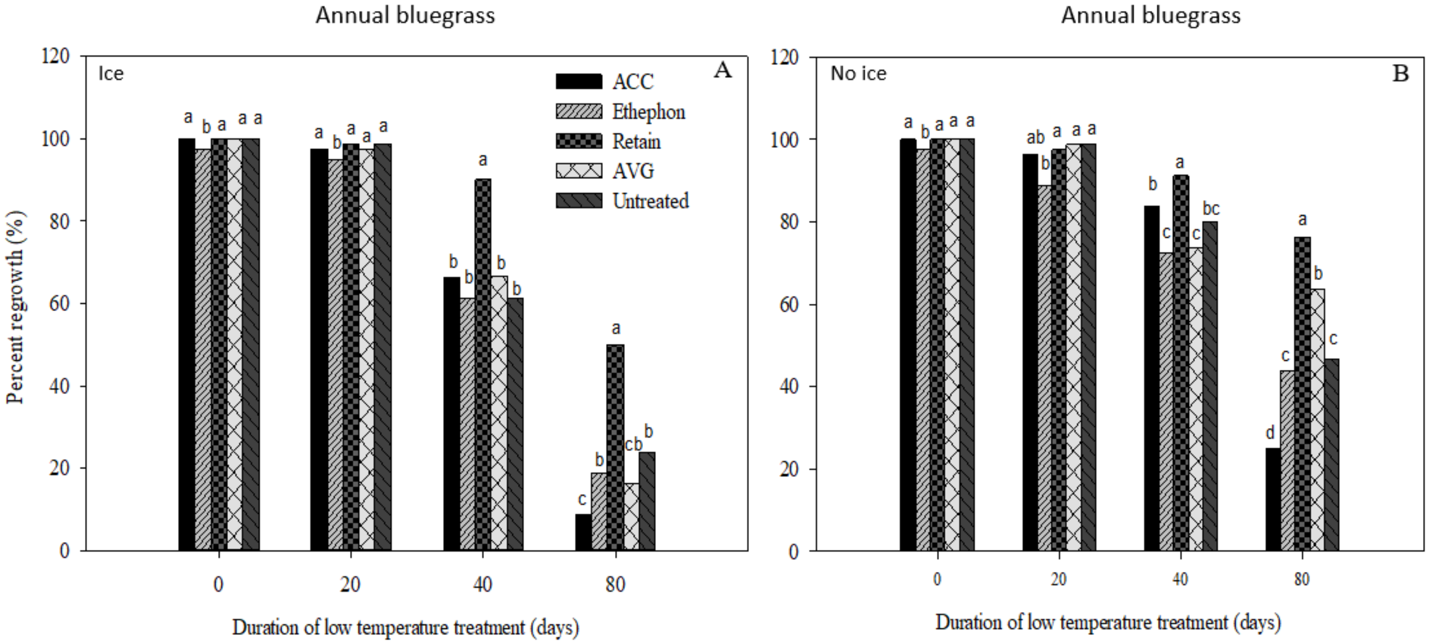

Figure 3. Regrowth of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated after 0, 20, 40 and 80 days at -4ºC in A) Ice cover or B) non-ice-covered treatments. Means from both 2016 and 2017 are pooled together. Least significant difference (LSD) values are indicated by vertical bars (P ≤ 0.05) for treatment comparisons on a given day of treatment.

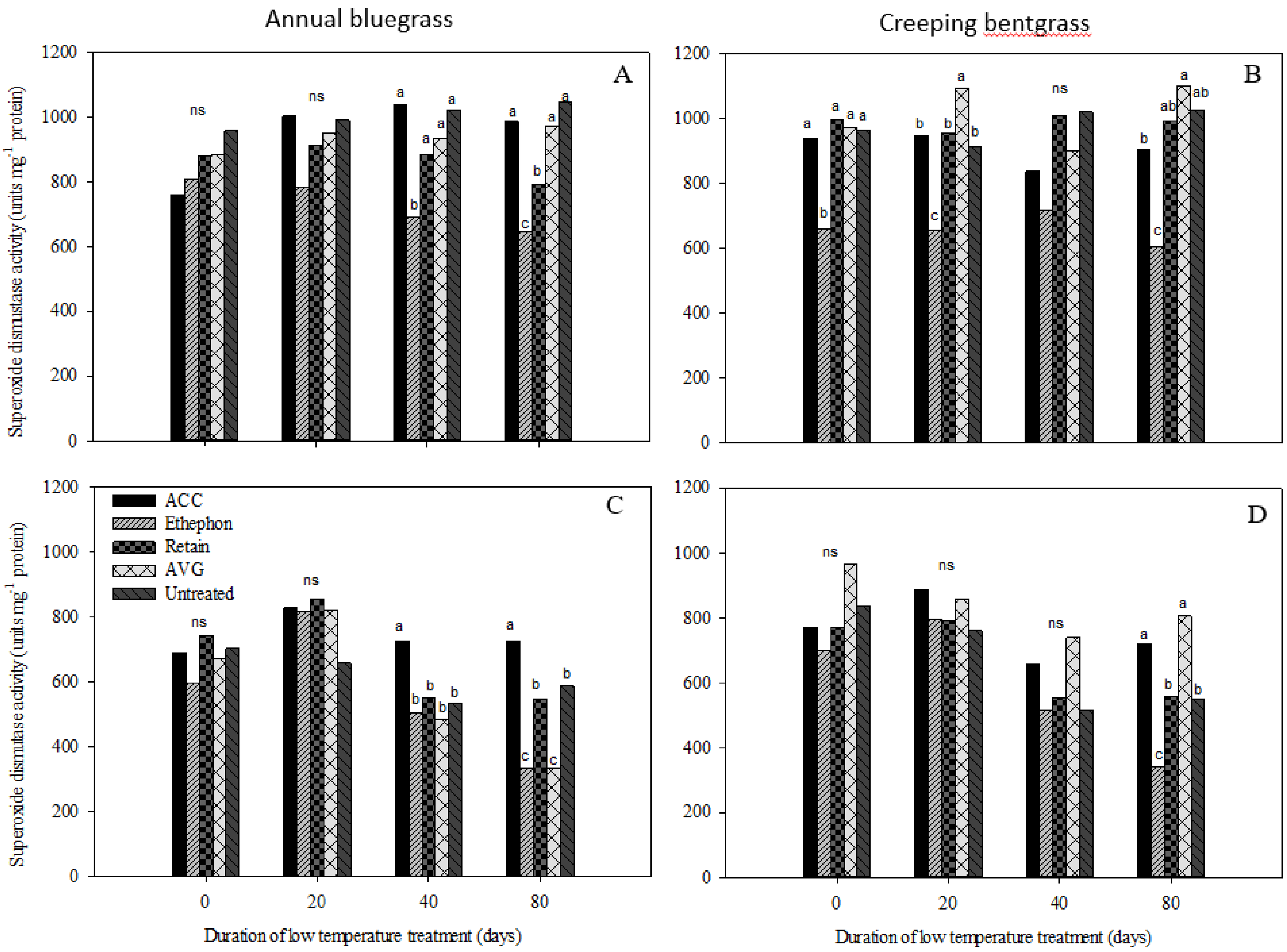

Figure 4. Malondialdehyde (MDA) content of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated after 0, 20, 40 and 80 days at -4ºC in leaf tissue under ice cover (A) or no ice cover (B) and in crown tissue under ice cover (C) or no ice cover (D). Means from both 2016 and 2017 are pooled together. Bars with different letters are significantly different (P ≤ 0.05) due to treatment within a given day.

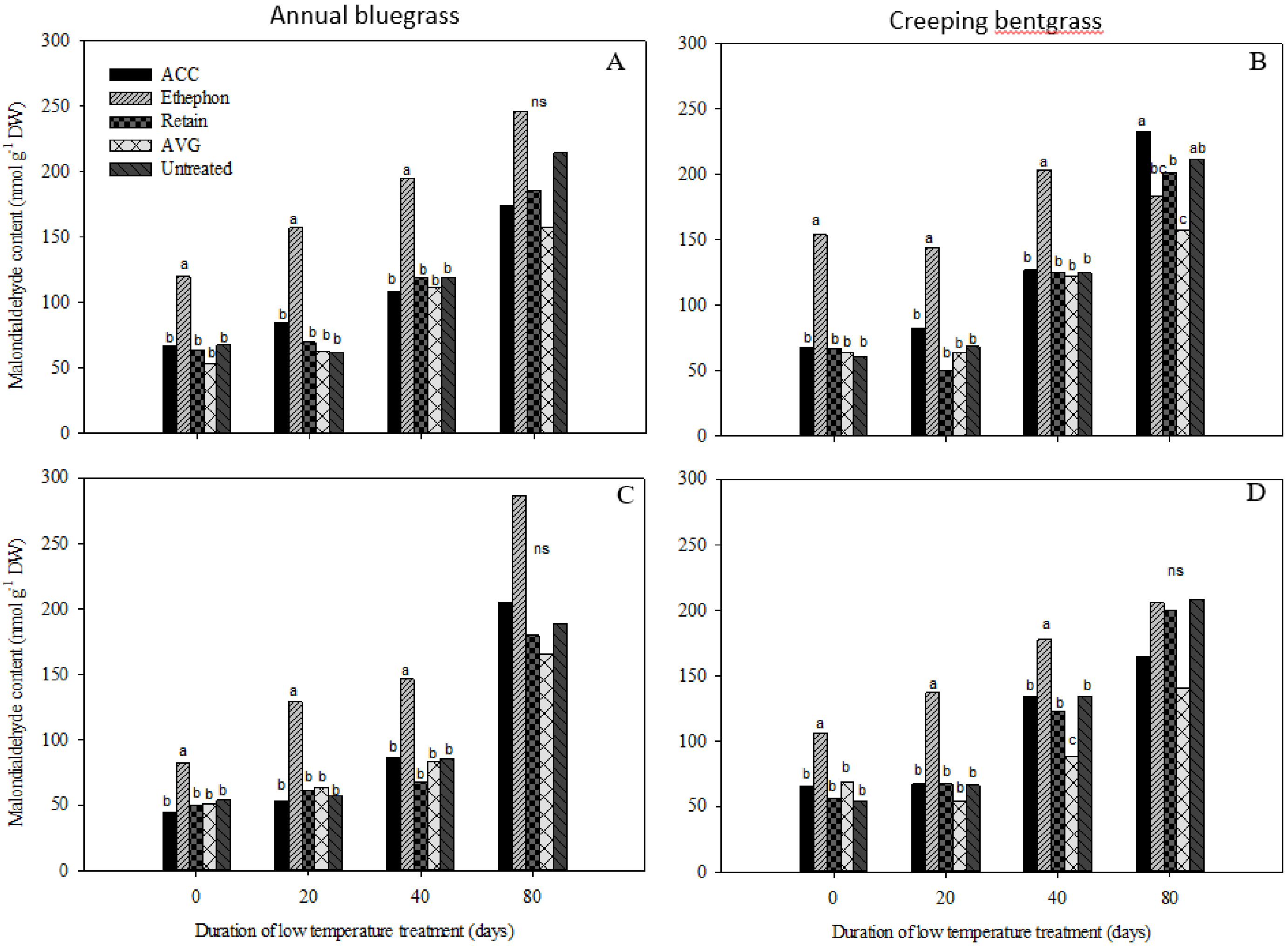

Figure 5. Catalase (CAT) activity of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated after 0, 20, 40 and 80 days at -4ºC in leaf tissue under ice cover (A) or no ice cover (B) and in crown tissue under ice cover (C) or no ice cover (D). Means from both 2016 and 2017 are pooled together. Bars with different letters are significantly different (P ≤ 0.05) due to treatment within a given day.

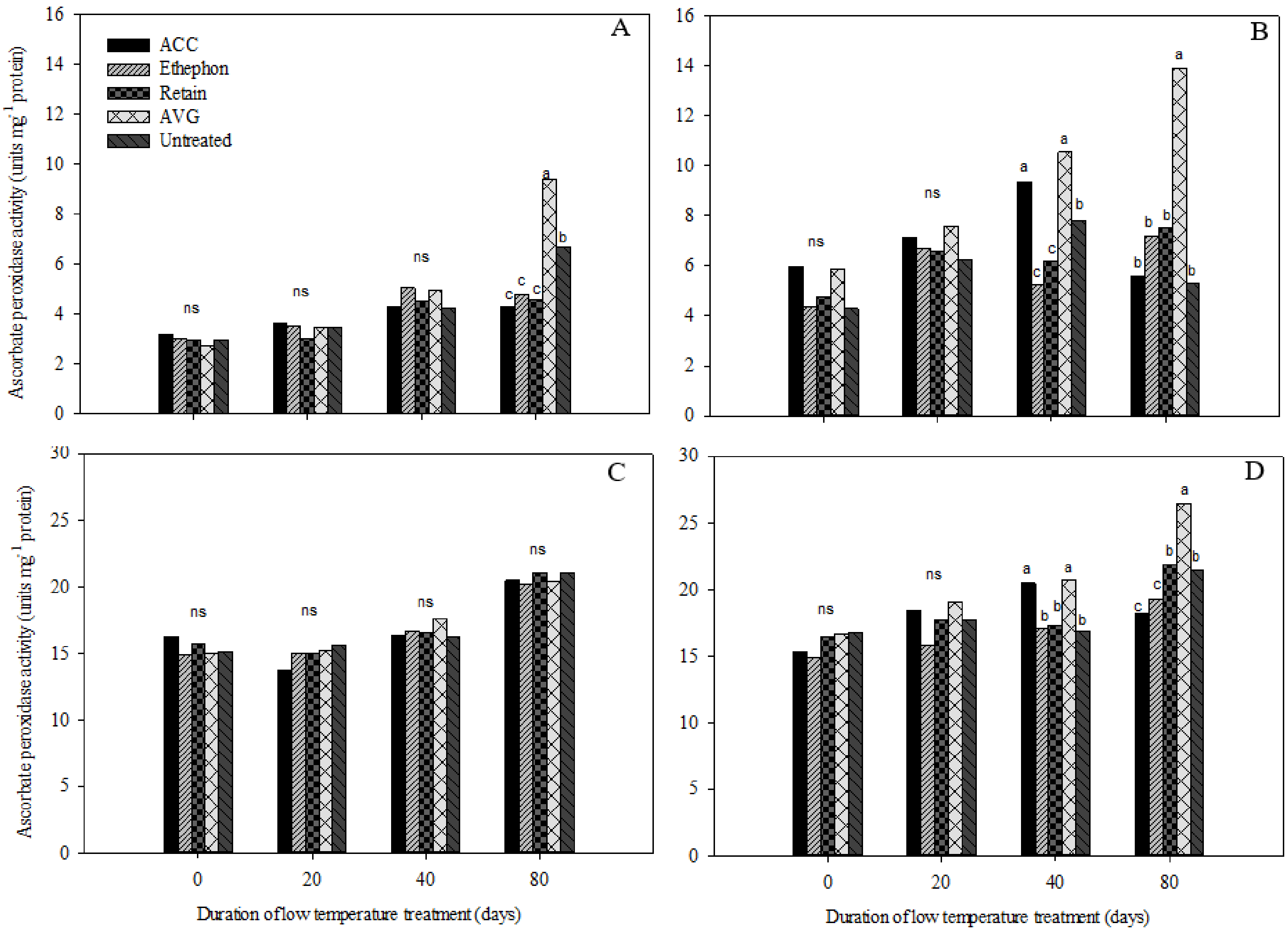

Figure 6. Superoxide dismutase (SOD) activity of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated after 0, 20, 40 and 80 days at -4ºC in leaf tissue under ice cover (A) or no ice cover (B) and in crown tissue under ice cover (C) or no ice cover (D). Means from both 2016 and 2017 are pooled together. Bars with different letters are significantly different (P ≤ 0.05) due to treatment within a given day.

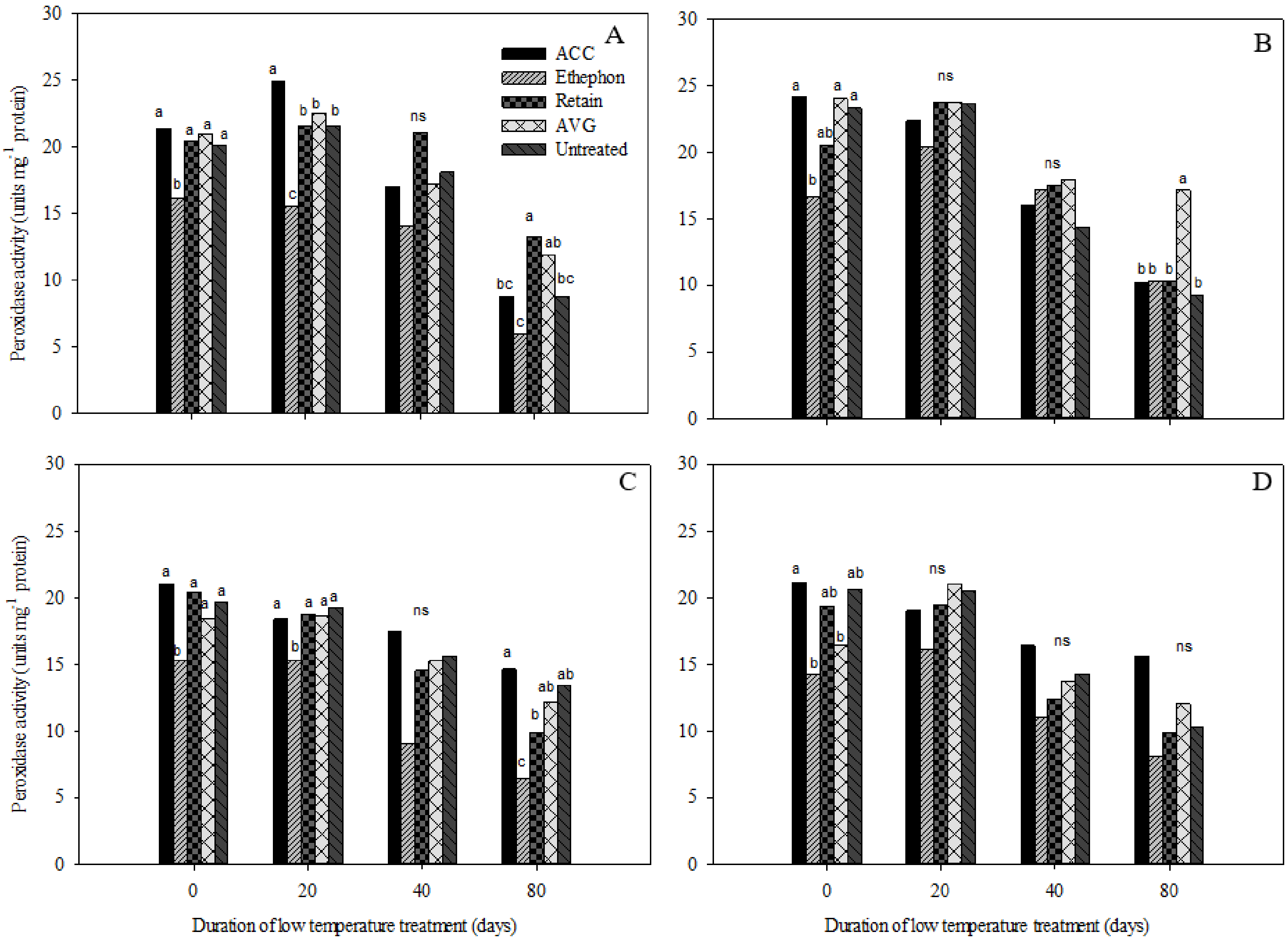

Figure 7. Peroxidase activity of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated after 0, 20, 40 and 80 days at -4ºC in leaf tissue under ice cover (A) or no ice cover (B) and in crown tissue under ice cover (C) or no ice cover (D). Means from both 2016 and 2017 are pooled together. Bars with different letters are significantly different (P ≤ 0.05) due to treatment within a given day.

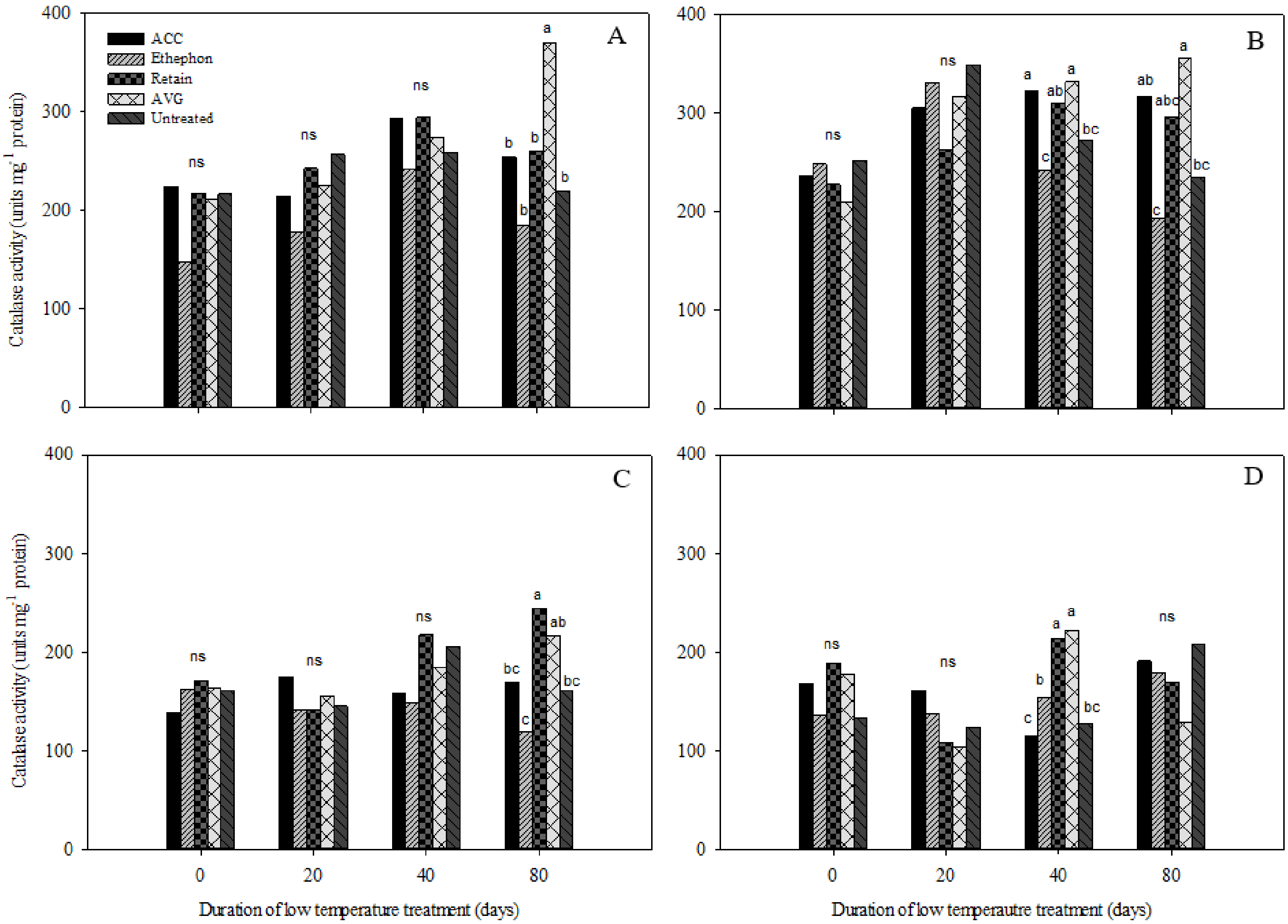

Figure 8. Ascorbate peroxidase activity of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated after 0, 20, 40 and 80 days at -4ºC in leaf tissue under ice cover (A) or no ice cover (B) and in crown tissue under ice cover (C) or no ice cover (D). Means from both 2016 and 2017 are pooled together. Bars with different letters are significantly different ($P \leq 0.05$) due to treatment within a given day.

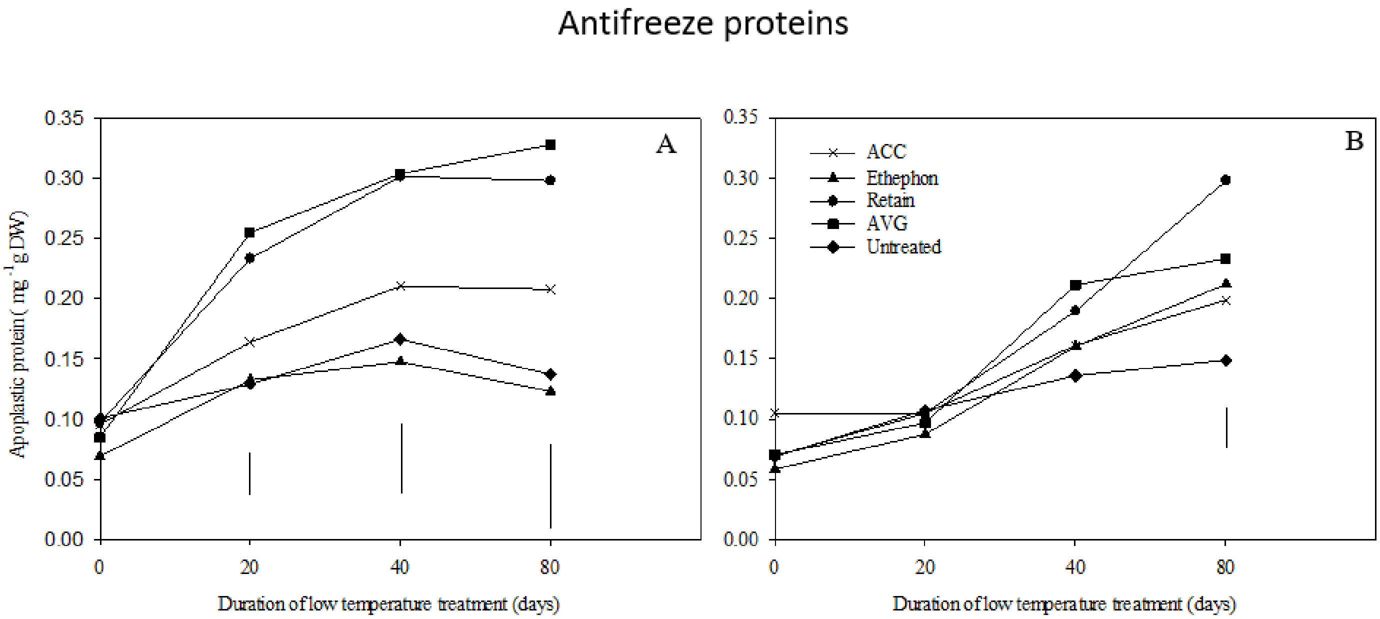

Figure 9. Antifreeze protein concentration of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated after 0, 20, 40 and 80 days at -4ºC in leaf tissue (A) and in crown tissue (B). Means from both 2016 and 2017 and from ice cover treatments are pooled together. Least significant difference (LSD) values are indicated by vertical bars (P ≤ 0.05) for treatment comparisons on a given day of treatment.

Table 1. Changes in the saturated fatty acid contents of A) leaf B) crown and C) root tissue of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated and then exposed to 20 days in a low temperature growth chamber (-4 °C) in. Means from both 2016 and 2017 are pooled together. Ice and no ice cover treatment means are pooled together. Within each column for each fatty acid, means followed by the same letter are not significantly different (P ≤ 0.05). Columns with no letters indicate no significant differences among chemical treatments.

	Leaf				Crown				Root			
	Stress treatment period (d)				Stress treatment period (d)				Stress treatment period (d)			
	0	20	40	80	0	20	40	80	0	20	40	80
16:0ʅ	Molar percentage (mol %)											
ACC	14.2	18.1	21.3	19.5 a	41.6 a	41.9 a	40.4 bc	39.1 bc	27.5	30.5	32.6 a	31.0
Ethephon	10.3	16.6	19.2	25.0 a	37.8 ab	39.9 a	45.8 a	43.2 ab	27.3	29.1	30.7 abc	28.7
Retain	14.0	16.6	17.8	16.2 b	32.3 b	36.9 b	36.4 c	35.5 c	25.4	25.5	24.6 c	27.3
AVG	11.9	16.9	17.5	14.6 b	42.7 a	40.7 a	39.5 bc	35.1 c	28.7	27.6	26.4 bc	25.5
Untreated	11.9	17.6	21.8	23.6 a	38.5 ab	42.4 a	44.4 ab	42.0 ab	28.9	30.0	32.9 a	31.6
18:0												
ACC	3.8 ab	4.0	3.2 b	2.8 bc	21.6 a	19.1	36.2 a	21.1 bc	3.7	7.1 a	6.4	5.8
Ethephon	3.2 b	4.3	5.1 a	5.5 a	22.1 a	13.6	25.4 b	28.5 a	3.3	6.4 a	5.7	6.6
Retain	2.5 b	5.0	3.7 ab	3.4 b	17.2 b	13.8	25.7 b	19.1 c	3.1	6.3 a	5.8	5.7
AVG	3.2 b	4.6	3.6 ab	3.6 b	19.3 ab	13.3	23.6 bc	22.3 bc	2.3	5.8 a	6.2	7.0
Untreated	2.3 b	4.0	3.1 b	2.9 bc	21.4 a	13.0	24.3 bc	23.3 b	3.1	6.5 a	6.7	7.3

Table 2. Changes in the saturated fatty acid contents of A) leaf, B) crown and C) root tissue of annual bluegrass treated with 1-aminocyclopropane-1-carboxylic acid (ACC), ethephon, Retain, aminoethoxyvinylglycine (AVG), or untreated and then exposed to 40 days in a low temperature growth chamber (-4 °C). Means from both 2016 and 2017 are pooled together. Ice and no ice cover treatment means are pooled together. Within each column for each fatty acid, means followed by the same letter are not significantly different ($P \leq 0.05$). Columns with no letters indicate no significant differences among chemical treatments.

	Leaf				Crown				Root			
	Stress treatment period (d)				Stress treatment period (d)				Stress treatment period (d)			
	0	20	40	80	0	20	40	80	0	20	40	80
16:1ʅ	Molar percentage (mol %)											
ACC	4.7	4.9	6.2	5.6 ab	2.1	11.4c	1.8 bc	2.0	3.5	0.8	0.9	0.9
Ethephon	3.4	4.5	5.3	5.1 b	2.0	10.4 d	1.8 bc	1.8	3.6	0.7	0.8	1.0
Retain	5.1	4.2	6.3	6.4 a	1.4	12.3 ab	2.3 b	2.0	2.6	0.9	1.0	0.9
AVG	5.0	3.7	4.5	5.1 b	2.3	11.9 bc	1.6 c	1.5	3.2	0.7	0.6	0.8
Untreated	4.3	3.6	5.0	4.5 b	1.9	12.6 a	1.7 c	1.6	3.4	0.8	0.7	0.8
18:1												
ACC	1.8 ab	2.0 bc	2.2	1.8	2.4	2.6 ab	2.7	2.2	10.8	11.0	9.7 a	9.9 a
Ethephon	1.9 ab	2.4 ab	2.3	2.2	2.3	2.1 b	2.3	2.7	8.4	11.5	6.8 b	9.3 ab
Retain	2.7 a	2.7 a	2.9	2.5	3.2	2.7 ab	2.3	2.6	12.1	11.2	10.4 a	11.8 a
AVG	2.2 a	1.6 c	1.9	1.1	3.3	3.4 a	3.4	3.4	9.3	11.5	11.0 a	9.7 ab
Untreated	1.8 ab	2.0 bc	2.4	1.8	2.8	2.7 ab	2.7	2.6	7.7	7.6	11.7 a	7.2 b
18:2												
ACC	12.0	15.0	16.5	16.3 a	19.5	21.0 a	21.2 a	20.5 ab	32.5 c	34.7	34.0	35.9
Ethephon	15.3	14.7	9.5	9.95 b	22.6	19.7 ab	15.0 b	16.7 c	33.6 bc	34.6	36.3	34.9
Retain	16.3	14.3	14.2	15.8 a	22.1	19.7 ab	16.7 ab	20.7 a	34.4 bc	35.2	34.4	36.0
AVG	13.6	14.4	13.8	7.1 b	19.6	18.7 ab	15.6 b	11.6 d	35.7 b	37.1	36.2	36.2
Untreated	15.4	13.1	9.4	10.6 b	19.3	17.1 b	15.3 b	16.8 b	34.7 bc	39.1	36.7	36.6
18:3												
ACC	44.2	44.7	46.9	43.8	14.0	14.7	13.8	13.3 cd	15.1	14.2	14.6 a	14.6
Ethephon	44.7	47.8	49.3	48.2	13.5	12.8	12.6	11.2 d	15.2	16.3	10.4 b	13.4
Retain	44.5	45.9	47.0	42.8	14.9	15.9	15.1	17.2 a	13.6	12.1	15.1 a	12.0
AVG	45.5	47.1	47.2	48.3	15.9	15.4	14.4	15.0 abc	14.8	15.3	15.1 a	15.6
Untreated	45.3	46.4	46.7	50.7	15.8	14.2	15.5	14.9 bc	14.9	14.7	15.3 a	14.3

USGA ID#: Donation

Title: Grass Roots Exhibit

Project Leader: Kevin Morris
Affiliation: National Turfgrass Federation

Objective: The 'Grass Roots' exhibit is a 1.3-acre exhibit at the US National Arboretum and consists of 12 interactive educational turfgrass displays. The primary objective of the 'Grass Roots' Initiative is to promote and educate the general public, horticultural community, and policymakers about the environmental, recreational, economic, and aesthetic benefits of turfgrass.

Start Date: 2014
Project Duration: 5 years
Total Funding: $125,000

Summary Points:

- The US National Arboretum will co-host the American Public Gardens Association conference in June, 2019. We expect 'Grass Roots' to play a significant role in this hosting as the conference provides a special opportunity to outreach to public garden professionals.
- The Arboretum 'Grass Roots' exhibit hosted an estimated 25.000-30,000 visitors in 2018.
- 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 state turfgrass extension education websites.
- Geoff Rinehart conducted four lawn care workshops and hosted tours for multiple groups visiting the exhibit.

Summary Text:

The 2018 season was the fourth 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 co-hosting the national meeting of the American Public Garden Association June 17-21, 21019 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 remained as the coordinator in a part-time capacity, managing the 'Grass Roots' social media accounts, supervising part-time workers, and overseeing the exhibit's agronomic program. In October, 2018 Israel Orellana, a long-time part-time employee at 'Grass Roots', took over as coordinator; Geoff remains with 'Grass Roots' in a reduced part-time role continuing to manage the social media accounts and providing technical guidance for the agronomic program of the exhibit. In 2018 there were three other individuals who worked part-time on 'Grass Roots' totaling ~1 FTE/week during the growing season.

We estimate 'Grass Roots' attendance was 25,000-30,000 in 2018, similar to previous 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. Outreach and education to horticultural groups is an important aspect of the 'Grass Roots' mission and we were pleased that Geoff presented an hour-long presentation about fundamental cultural practices and the functionality of turfgrass in the landscape at an event sponsored by the Smithsonian Institution Gardens on February 21 and on August 22 hosted a ‘Grass Roots’ tour for the DC chapter of the American Society of Landscape Architects.

We continue to publicize the exhibit and its contributions to communicating the importance of turfgrass benefits to the public. Because of Geoff’s reduced role, this aspect of the Initiative has not been as robust in the past. However, Geoff did give a presentation about the exhibit at the ASA meeting in Baltimore and provided a brief update to the C-5 Turfgrass Science section business meeting at the ASA meetings in Baltimore. In addition, Geoff is scheduled to speak at the Mid-Atlantic Turfgrass Expo in Virginia in January, 2019 about ways that sports facilities can implement a public outreach/education display using the ‘Grass Roots’ model.

As in the past, Geoff conducted a total of four homeowner lawn care workshops (two in each spring and fall, respectively). In addition to conducting homeowner-oriented events, we also hosted several professional/academic meetings/events this year. On March 17, we hosted the Mid-Atlantic Sports Turf Managers Association (MASTMA) spring meeting and in August, Geoff co-hosted a tour of the Maryland SoccerPlex ‘Grass Roots’ exhibit for the MASTMA field day event. Geoff also provided a tour for a turfgrass management class from Northern Virginia Community College on June 11. The National Turfgrass Federation organized the “C-5 Turfgrass Tour” for the American Society of Agronomy on November 4 and included 30 agronomists from around the country. In addition to Arlington Cemetery and the National Mall, participants were led on a guided tour of the ‘Grass Roots’ exhibit.

In 2018, ‘Grass Roots’ again collaborated with the National Cherry Blossom Festival, the National Park Service, and BicycleSPACE to conduct the 4th annual National Greenscape Corridor Bike Ride. This year ~40 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. Although we added a new display featuring a USDA study on *Danthonia spicata*/fine fescue mixes in 2017, that display will be “decommissioned” during Winter 2018-19 since the study is no longer active. Last year, we also established a “mini-display” of TifTuf™ bermudagrass sod in a 4’ x 4’ “turf module”, but it died over the winter of 2017-18. In late summer, 2018 we installed a module of the new release ‘Tahoma 31’ bermudagrass, but because of limited availability installed it via plugs. Our intention is to create interpretive signage for this “mini-display” once it is grown in during the 2019 season.

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 continues to be maintained on a full-time basis by the Maryland SoccerPlex maintenance staff and serves as an example of “transporting” the ‘Grass Roots’ exhibit concept to other sites.

Figure 1. The Washington D. C. chapter of the American Society of Landscape Architects toured the 'Grass Roots' exhibit in August 2018.

Figure 2. A putting green at the 'Grass Roots' Arboretum.

Figure 3. Estimated 'Grass Roots' attendance was 25,000-30,000 in 2018, similar to previous 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.

Figure 4. Turfgrass management students from Northern Virginia Community College toured the ‘Grass Roots’ exhibit in June 2018.