United States Golf Association
Green Section Research
PO Box 2227, Stillwater, OK 74076
T 405.743.3900 F 405.743.3910
mkenna@usga.org www.usga.org

Turfgrass and Environmental Research Program

2015 Research Summaries

CONFIDENTIAL – NOT FOR PUBLICATION

Table of Contents

Annual Report - 2015

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

William A. Meyer and Stacy A. Bonos
Rutgers University

Objectives:

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

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

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

Start Date: 1982

Project Duration: Continuous

Total Funding: $10,000 per year

As of October 30, 2015 over 2,256, promising turfgrasses and associated endophytes were collected in Poland, Bosnia, Croatia, Italy ,Greece Norway, Finland, Latvia, Denmark, Lithuania and Norway. These are having seed produced in the Netherlands and will be evaluated in New Jersey. Over 11,948 new turf evaluation plots, 95,995 spaced-plant nurseries and 6,680 mowed single-clone selections were established in 2015.

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 12,850 tall fescues, 4,000 Chewings fescues, 6,000 hard fescues 20,000 perennial ryegrasses and 7,000 bentgrasses were also screened during the winter in greenhouses and superior plants were put in spaced-plant nurseries. Over 90 new inter- and intra-specific Kentucky bluegrasses were harvested in 2015.

The following crossing blocks were moved in the spring of 2015: 8 hard fescues (312 plants), 6 Chewings fescues (253 plants), 18 perennial ryegrasses (1,720 plants), 6 strong creeping red fescues (151 plants), 19 tall fescues (498 plants), 8 creeping bentgrasses (125 plants) 8 velvet bentgrass (182 plants), 9 colonial bentgrasses (248 plants) and 6 *Deschampsia cespitosa* (118 plants) .

To enhance our breeding for resistance to gray leaf spot, a July 23, 2015 planting of 2,200 perennial ryegrasses were seeded. Excellent *Pythium* blight control was attained and a good gray leaf spot epidemic occurred. This data will be used to select future varieties of perennial ryegrass. Over 20,000 perennial ryegrasses were planted in the spring of 2015 as spaced-plants. They were allowed to develop seed heads in the late spring and selections were made for stem and crown rust resistance and heat tolerance.

The breeding program continues to make progress breeding for disease resistance and improved turf performance. New Promising varieties named and released in 2015 were Pacific Gem, Benchmark, Stamina, Expedite, Sea Biscuit, Man O War, Metolius and Xcelerator perennial ryegrasses; 4thMillenium, Bizem, Rebounder, Rowdy, Double Take, Firewall, Diablo, Technique, Temple, Avenger II, Thunderstruck, Thor, Raptor III, Dynamite and Bloodhound tall fescues. There was also one creeping red fescue fescue named Marvel and three hard fescues Minimus, Sword and Blue Ray. New Kentucky blugrasses were Legend, Unite, Fargo, Bolt, BlueBank, Malbec and Martha. There was one new creeping bentgrass named Luminary.

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
- Five perennial ryegrasses, 15 new tall fescues, 7 Kentucky bluegrasses and 4 fine fescue ,and 1 creeping bentgrass were released in 2015.
- Published or have in press over 2 referred journal articles in 2015

References

Refereed Research Publications:

Honig, J.H., J. Vaicunias, V. Avellero, C. Kubik, W.A. Meyer and S.A. Bonos. 2015. Classification of bentgrass (Agrostis) cultivars and accessions based on microsatellite (SSR) markers Genet Resour Crop Evol. DOI 10.1007/s10722-015-0307-6.

Koch, M. W. Meyer and S.A. Bonos. 2015. Heritability of salinity tolerance in perennial ryegrass. Crop Science 55(4): 1834-1842.

Abstracts:

Meyer, W., S. Bonos, E.N. Weibel, A. Grimshaw, H. Que, R. Bara, M. Mohr, D. Smith and T. Tate. 2015. Overcoming the challenges of breeding cool-season turfgrasses for low-input turf. p. 16. In Proceedings of the 24th Rutgers Turfgrass Symposium. January 16, 2015.

Jespersen, D., F. Belanger, J. Honig, W. Meyer, S. Bonos and B. Huang. 2015. Development and confirmation of candidate gene markers for selection of heat tolerance. p. 19. In Proceedings of the 24th Rutgers Turfgrass Symposium. January 16, 2015.

Grimshaw, A., W. Meyer and S.A. Bonos. 2015. Evaluation of hard fescue (Festuca brevipila) for summer patch (Magnaporthae poae). p. 35. In Proceedings of the 24th Rutgers Turfgrass Symposium. January 16, 2015.

Non-referred Publications:

Weibel, E.N., T.J. Lawson, J.B. Clarke, J.A. Murphy, B.B. Clarke, W.A. Meyer, and S.A. Bonos. 2015. Performance of bentgrass cultivars and selection in New Jersey turf trials. 2014 Turfgrass Proceedings 46:1-42.

Tate, T.N., A.L. Grinshaw, D.A. Smith, R.F. Bara, M.M. Mohr, E.N. Weibel, S.A. Bonos, and W.A. Meyer. 2015. Performance of fine fescue cultivars and selections in New Jersey turf trials. 2014 Rutgers Turfgrass Proceedings 46:43-68.

Grimshaw, A.L., T.M. Tate, M.M. Mohr, R.F. Bara, D.A. Smith, E.N. Weibel, J.A. Murphy, S.A. Bonos and W.A. Meyer. 2015. Performance of Kentucky bluegrass cultivars and selections in New Jersey turf trials. 2014 Rutgers Turfgrass Proceedings 46:69-129.

Qu, Y., E.D. Koch, M.M. Mohr, R.F. Bara, D.A. Smith, E. Szerszen, S.A. Bonos and W. A. Meyer. 2015. Performance of fine fescue cultivars and selections in New Jersey turf trials. 2014 Rutgers Turfgrass Proceedings 46:131-160.

Tate, T., R.F. Bara, D.A. Smith, M.M. Mohr, S.A. Bonos, and W.A. Meyer. 2015. Performance of tall fescue cultivars and selections in New Jersey turf trials. 2014 Rutgers Turfgrass Proceedings 46:161-188.

Title: Adaptation and Management of Fine Fescues for Golf Course Fairways

Project leaders: Eric Watkins and Brian Horgan

Affiliation: University of Minnesota

Objectives: (1) To determine if the plant growth regulator trinexapac-ethyl improves performance and divot recovery of fine fescue species and mixtures on low-input golf course fairways; (2) To determine if fine fescues can survive when managed as fairways under acute drought; and (3) To determine if fine fescue fairways require fungicides at currently-recommended application rates to survive winter snow mold pressure.

Start Date: 2012

Project Duration: four years

Total Funding (over entire project duration) $74,133

Summary text:

Golf course fairways in the north central region primarily consist of species that require high inputs of water, pesticides, and nitrogen fertilizer. Golf course superintendents continue to be affected by governmental regulations restricting the use of chemical and water inputs on managed turfgrass. Future restrictions will impact golf course management in a very significant way and the solution to the problem of inputs on golf course fairways could include the use of lower-input grasses. Low-input fine fescue species should be able to withstand the pressure from typical turfgrass stresses while producing acceptable turf and excellent playing quality—all with fewer overall inputs of pesticides, water, and fertilizer. Due to limited research on these species in fairway settings, superintendents are wary to begin using fine fescues. This research project is investigating a few key areas where research-based information is lacking.

Objective 1: The trial consists of 25 mixtures of single cultivars representing five fine fescue species (‘Radar’ Chewings, ‘Beacon’ hard, ‘Navigator II’ strong creeping red, ‘Shoreline’ slender creeping red, and ‘Quatro’ sheep). To this point, there has not been a significant effect of plant growth regulator application on plot performance (trinexapac-ethyl was applied every 200 growing-degree days at the label recommended rate to half of the plots). Traffic, which is applied 3 days each week during the summer using a golf cart traffic simulator, has had a significant effect on mixture performance; results to date suggest that the inclusion of slender creeping red or hard fescue is beneficial for turf performance. Mixtures with large proportions of strong creeping red fescue were very susceptible to dollar spot caused by *Sclerotinia homoeocarpa*. Divots were removed from this trial and no entries had full divot recovery within 12 months; this is a major weakness of fine fescues on fairways in the northern United States and will need to be addressed if these grasses are to be used on a wide scale.

Objective 2: The same species and mixtures as in Objective 1 were evaluated under acute drought for a 60-day period in August 2014 in St. Paul, MN and Madison, WI and received the

60 d drought treatment in July and August of 2015 (Fig. 1). Mixtures that included significant proportions of hard fescue and sheep fescue tolerated drought best and maintained adequate turf color (Fig. 2). Mixtures that contained higher proportions of strong creeping red fescue and slender creeping red fescue performed poorly at both locations.

Objective 3: The same fine fescue species and mixtures as in Objective 1 are also being evaluated on three golf course in Minnesota: Northland Country Club (Duluth, MN); The Cragun's Legacy Courses (Brainerd, MN) (Fig. 3); and Theodore Wirth Golf Club (Minneapolis, MN). Since establishment in 2013, we have seen little disease pressure in untreated plots (no fungicide). These grasses may be resistant to snow mold pathogens; however, our observations in higher cut fine fescue suggest that snow mold and snow scald disease can be a problem in these grasses.

Summary Points

- Use of a plant growth regulator does not appear to have a significant effect on performance of fine fescues in a fairway trial.
- Hard fescue and slender creeping red fescue were present in mixtures that performed well under traffic stress.
- Hard fescue and sheep fescue were present in mixtures that performed well under acute drought stress.
- Snow mold and snow scald damage was minimal on golf course trials.
- Results from this project should assist in developing optimized mixtures for use on golf courses in the northern United States, ultimately leading to overall reduced inputs of water, fertilizer, and pesticides

Figure 1: Drought trials were established under a rainout shelter in St. Paul, MN (pictured) and Madison, WI. The rainout shelter was used to withhold precipitation for 60 days. (photo credit: Maggie Reiter)

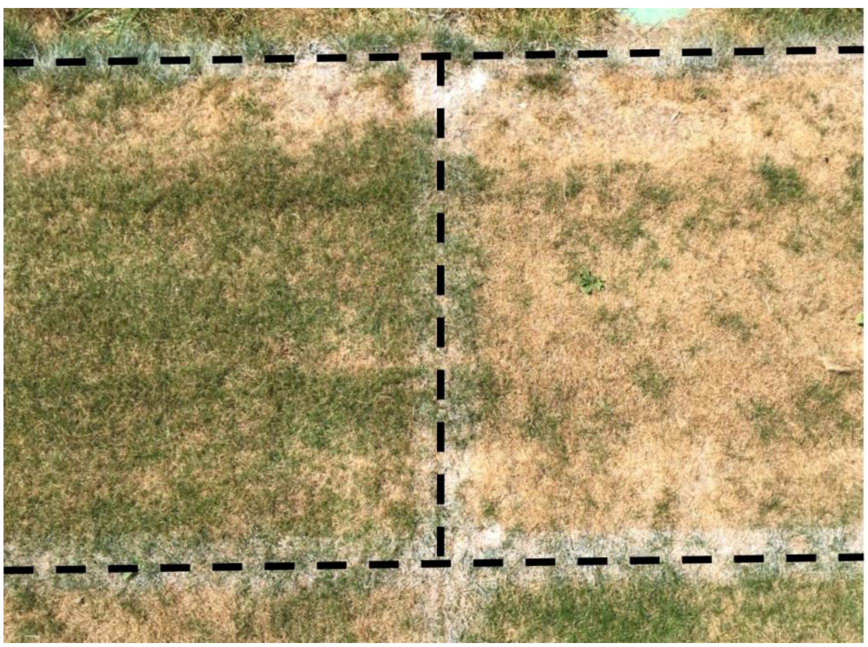


Figure 2: This photo shows a comparison of a 50:50 hard fescue:sheep fescue mixture (left) and a 100% strong creeping red fescue plot (right). This photo was taken after 30 days of drought in Madison, WI. Plots with hard and sheep fescue performed better than plots with strong creeping red fescue. (photo credit: Maggie Reiter)

Figure 1. Plots at each golf course site were covered to increase disease pressure. (photo credit: Maggie Reiter)

Characterization and Validation of Molecular Markers Linked to Heat and Drought Tolerance for Marker Assisted Selection of Stress-tolerant Creeping Bentgrass

Principal Investigators: Bingru Huang, Stacy Bonos, Faith Belanger, and Paul Raymer

Objectives:
1) Validate SSR markers linked to six known heat/drought tolerance QTLs and gene-based markers that were developed in previous USGA-funded projects in a bentgrass breeding population with a wide range of variation in drought and heat tolerance in two different environments or locations.
2) Determine the stability of known QTLs over a range of test cross parents and environments.
3) Assess physiological traits (phenotypes) linked to these molecular markers in drought and heat tolerance.
4) Identify and characterize phenotypes of newly developed drought and heat tolerant lines using validated markers to facilitate marker assisted selection in creeping bentgrass breeding programs.

Drought and heat are two major abiotic stresses which cause damage to cool-season turf areas. Creeping bentgrass (*Agrostis stolonifera*) is a high value turfgrass which is particularly susceptible to the stresses of drought and heat. Damages caused by these stresses include reductions in photosynthesis, the production of reactive oxygen species, damage to membranes and degradation of proteins. Ultimately these cellular damages reduce plant growth and canopy density, induce premature senescence and eventual result in plant death. The development cool-season turfgrass species with improved heat and drought tolerance is indispensible for maintaining high quality turf areas during summer months with elevated temperatures or when irrigation is limited. Our previous projects have identified and developed molecular markers linked to drought or heat tolerance in bentgrass species using both quantitative trait loci (QTLs) and candidate-gene based markers. Candidate gene markers include previously identified genes which play important roles in stress tolerance such as anti-oxidant genes, chaperones involved in protein stabilization, and photosynthesis genes. The current project will further confirm the relationship between these molecular markers and important stress tolerance related traits.

In the current project our aim is to validate previously developed SSR markers associated with drought or heat related QTLs and gene-based markers associated with important tolerance related genes in a genetically diverse population. Screening this population for important physiological characteristics related to abiotic stress tolerance in two locations will allow for the confirmation of markers related to important drought or heat tolerance mechanisms. Once the utility of these markers is confirmed they can be used for marker assisted selection (MAS) for the development of bentgrass lines with improved abiotic stress tolerance.

Two populations of 144 creeping bentgrass germplasm, including several commercial cultivars (Penncross, Crenshaw, Declaration, Penn A-4, Luminary) and new experimental lines from both UGA and Rutgers were planted in two locations, at the University of Georgia in Griffin, GA in fall 2012, and at Rutgers University in New

Brunswick, NJ in fall 2013. These populations represent a diverse collection of germplasm from both Rutgers and University of Georgia breeding programs to be used for the confirmation of previously developed markers. Both locations are equipped with rainout shelters which were used in the spring or fall to exclude rainfall and induce drought stress. Turf plots have been assessed for both heat tolerance during the summer months, and drought tolerance at both the University of Georgia and Rutgers; giving multiple years of phenotypic data at both locations. Parameters measured to estimate plant health during heat or drought include visual ratings, NDVI (normalized difference vegetation index), chlorophyll content, membrane stability, use of light boxes to take photos for digital image analysis, in additional to leaf water content during drought periods as well as canopy temperature depression during summer heat stress.

A large range of genotypic variations in for both drought and heat tolerance were found at both locations. In 2015 average turf quality ratings ranged from 1 – 6.3 during drought, and 1.3 – 6.2 during summer heat stress at UGA, while at Rutgers ratings ranged from 2.2 – 6.7 during summer heat stress, and 1 – 4.7 during the fall drought period (Fig. 1) Similar distributions can be see for membrane stability demonstrating a large range of stress tolerance in population (Fig. 2). Many experimental lines performed better than standard commercial cultivars which ranged from 17% of lines ranking better than the best commercial cultivars for the Georgia drought trial to 42% of lines ranking better than the best commercial cultivar during the Rutgers heat trial. Several lines performed extremely well across both locations for both heat and drought stress such as S11-8675-2 and S11-8712-10 which were always ranked in the top 10%.

Additionally tissue samples from 144 new lines/cultivars have been collected and DNA has been extracted from them. These samples are being used to screen 54 SSR markers in the QTL regions associated with drought or heat tolerance. In addition, 13 previously developed candidate gene markers are also examined in the new lines/cultivars. Over 22 markers have been fully screened and tested for associations between markers and physiological traits linked to drought or heat tolerance in different years and locations.

Summary Points:

- A total of 144 new lines/cultivars were evaluated for summer heat tolerance and drought tolerance in both Georgia and New Jersey giving multiple years of field data at both locations to use for molecular marker analysis
- Genetic variations for both heat and drought tolerance were found at both locations, with several elite lines outperforming standard commercial cultivars at both locations under both heat and drought conditions.
- Screening of DNA markers continues with a large number of markers already being screened and shown to be polymorphic within the population, demonstrating that genetic difference for the previously selection markers exist.
- Top performing lines are being selected for more in depth characterization of mechanisms responsible improved drought or heat tolerance.

Figure 1:
Distributions of turf quality ratings for the University of Georgia drought stress sampling in June of 2015 (A), Rutgers drought stress sampling in September of 2015 (B), University of Georgia heat stress sampling in August of 2015 (C) Rutgers heat stress sampling in August of 2015 (D).

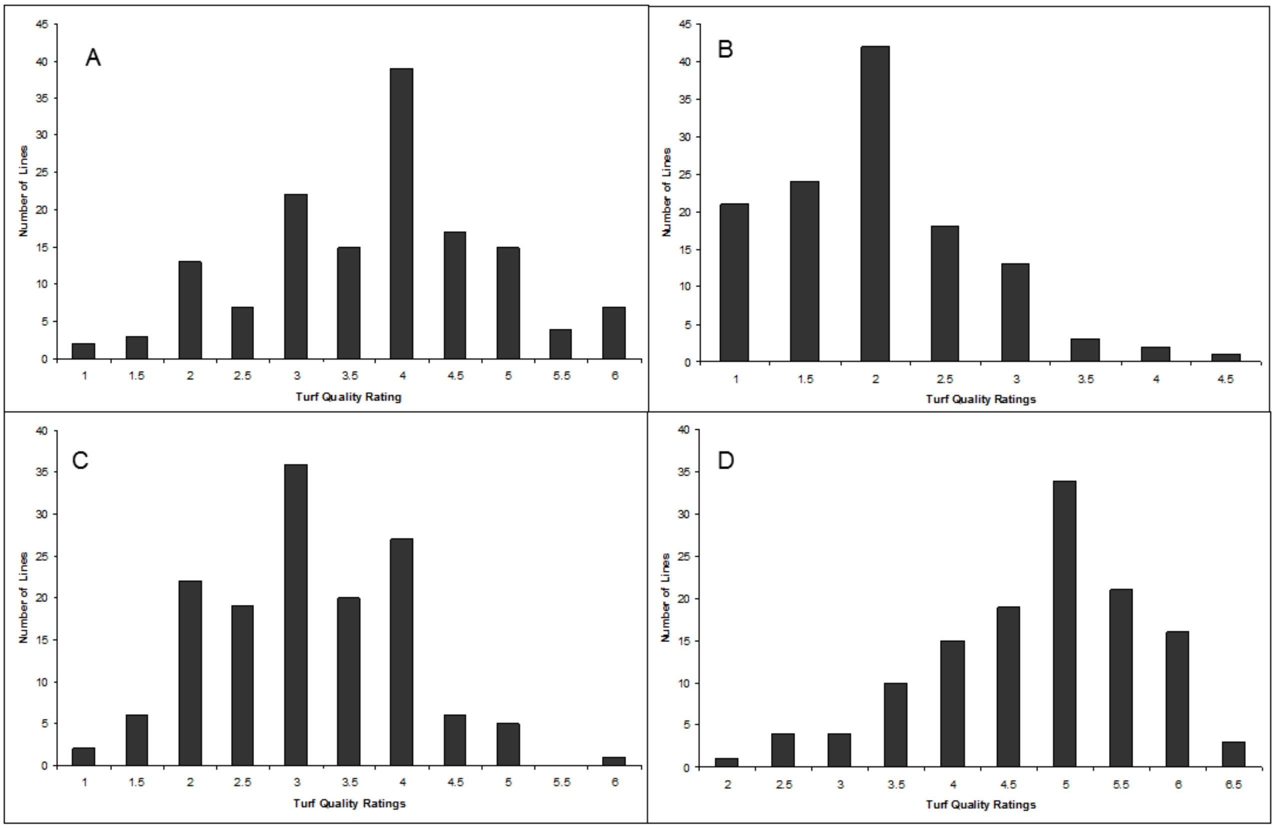


Figure 2:
Distributions of membrane stability as estimated by electrolyte leakage for the University of Georgia drought stress sampling in June of 2015 (A), Rutgers drought stress sampling in September of 2015 (B), University of Georgia heat stress sampling in August of 2015 (C) Rutgers heat stress sampling in August of 2015 (D).

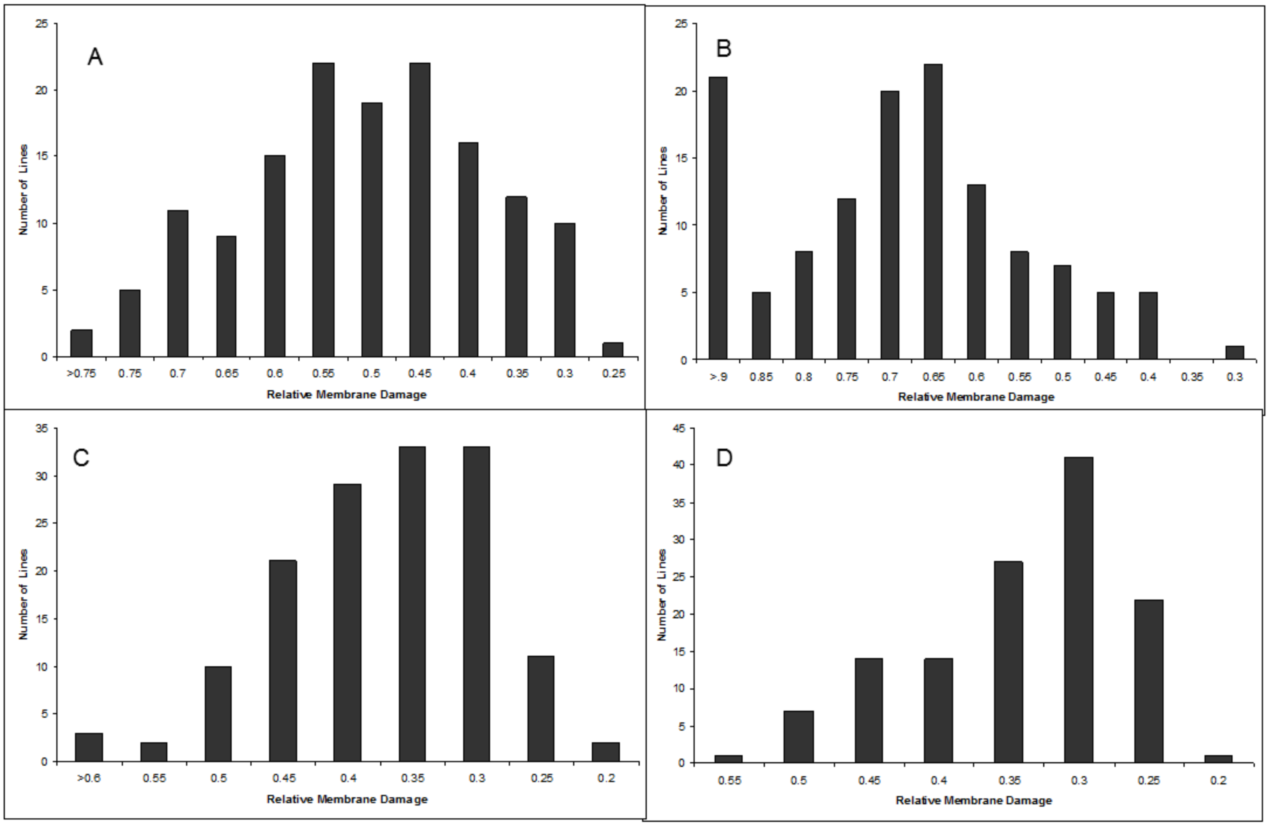


Figure 3:
Image taken at the University of Georgia during the 2015 drought stress period demonstrating the range of responses to drought stress with in the population.

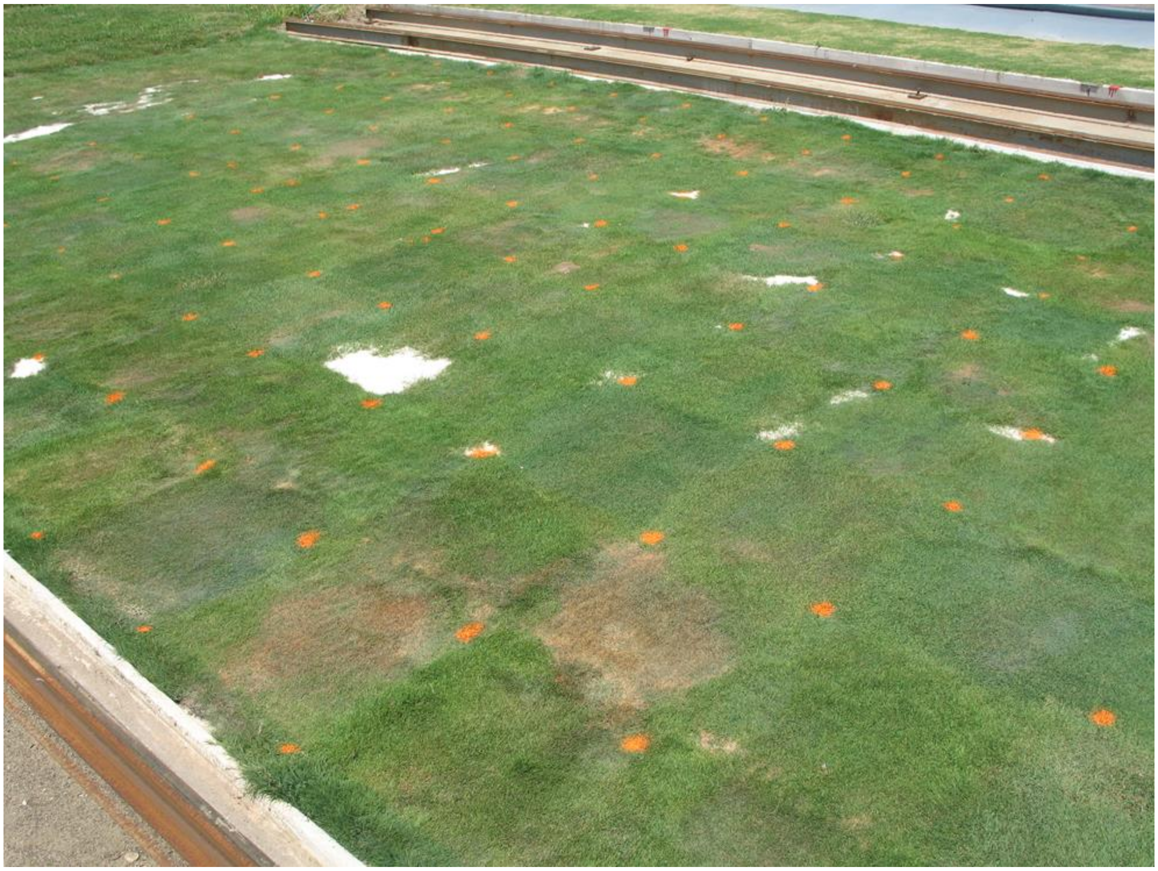
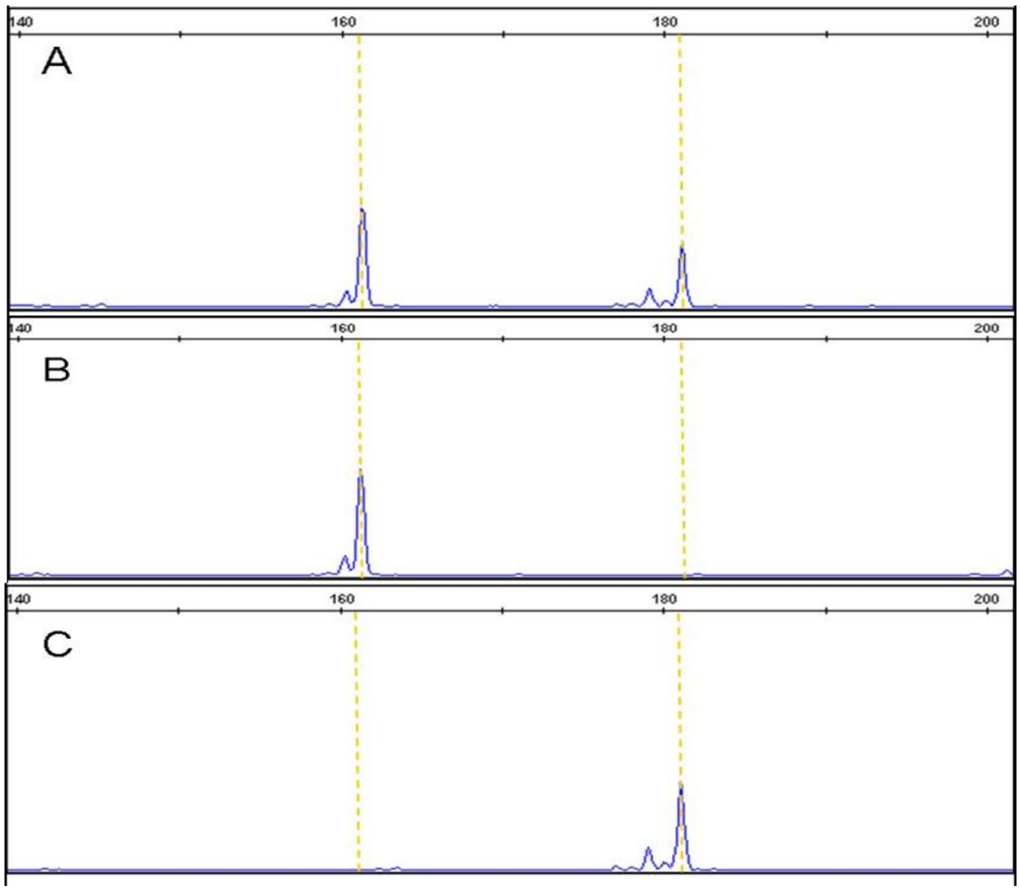


Figure 4:
Representative results from SSR marker screening using a capillary electrophoresis system, showing polymorphisms among three genotypes (A, B, C) for a heat-tolerance marker. Peaks are SSR marker products and orange dotted lines represent potential product sizes for the marker.



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

Project leader: Eric Watkins

Affiliation: University of Minnesota

Objective:

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

Start Date: 2012
Duration: three years
Total Funding: $30,000

This project provides matching funds for a five-year USDA-NIFA project funded by the Specialty Crops Research Initiative (grant number 2012-51181-19932). The project involves 10 scientists, along with graduate students and support staff, from three Universities (University of Minnesota, Rutgers University, and the University of Wisconsin). The project has four objectives: Objectives 1 and 2 involve social science research that will determine what consumers desire in new low-input fine fescue varieties; Objective 3 is focusing on identifying breeding material that is tolerant of stresses common to low-input turf environments; Objective 4 is addressing the challenges of educating end-users about the use of fine fescues in parks, lawns, and golf courses.

The fine fescue species have great potential to be functional grasses in sustainable landscapes including lawns, parks, and golf courses. A major concern for turfgrass managers considering increasing their use of fine fescues is the ability of these grasses to withstand wear and traffic; this is especially of concern to golf course superintendents who might want to use fine fescues on fairways (Fig. 1). For this part of the overall project, our objectives were to 1) evaluate the performance of fine fescues under abrasive applied with Rutgers Wear Simulator (RWS) and trampling forms of traffic applied with Cady Traffic Simulator (CTS); and 2) assess the seasonal effect of abrasive wear (using RWS) on fine fescues in different seasons. Eight passes (one pass per week for eight weeks) were applied to lawn height fine fescue for each form of traffic during three traffic periods per year (April to June, July to August, and September to October) from September 2013 to August 2015. Ten cultivars were evaluated (2 each from the primary fine fescue species representing one each of a newer and older cultivar). As expected, the uniformity of turf cover and fullness of turf cover (FTC) was greatest in the non-trafficked check plots. All newer varieties had improved traffic tolerance than older varieties. In order to improve this trait in new cultivars, we have begun screening for wear tolerance in both Minnesota and New Jersey by applying wear to mowed spaced plants (Fig. 2).

As part of our social science research, we have conducted surveys of homeowners throughout Canada and the United States to discover which traits they desire in a turfgrass. We have completed choice experiments with homeowners using both online surveys (analysis complete) and on-site experiments (analysis ongoing) with real plots (Fig. 3). Generally speaking, many consumers are willing to pay premiums for turfgrasses with lower maintenance requirements. Among the three maintenance attributes, mowing requirement is the most predominant attribute affecting consumers' purchasing decision. Water usage, followed by fertility requirement, is also considered as one of the most influential attributes for consumers. Fertility requirements are found to be affecting consumers' choices to some extent. Although this research is not directly applicable to golf courses, it does show that the general public is moving in a direction of desiring more sustainable turfgrass management.

Other projects that are ongoing include determining heat stress tolerance levels in fine fescues, screening fine fescues for summer patch and snow mold resistance, identifying fine fescues with increased weed-suppressive ability (Fig. 4), and additional social science research associated with our first two objectives.

Summary Points

- Fine fescues have shown potential for use on lower-input golf courses
- Traffic tolerance trials are ongoing and breeding work has been initiated
- Consumers prefer grasses that require less mowing, use less water, and have lower fertility requirements

Figure 1. Fine fescue fairway trail in St. Paul, Minnesota that includes entries from the 2013 National Turfgrass Evaluation Program Fine Fescue Test.

Figure 2. Individual fine fescue plants were planted in both New Jersey and Minnesota. These plants will be subjected to wear in order to identify top performing genotypes (photo credit: Austin Grimshaw).

Figure 3. Consumers visited turfgrass plots in both New Jersey and Minnesota to take part in surveys. (photo credit: Jingjing Wang)

Figure 4. Preliminary studies have found some fine fescues can suppress the growth of weeds. This figure shows the effect of a number of Chewings fescue germplasm collections on the growth of white clover in a laboratory study.

Figure 1. Fine fescue fairway trail in St. Paul, Minnesota that includes entries from the 2013 National Turfgrass Evaluation Program Fine Fescue Test.

Figure 2. Individual fine fescue plants were planted in both New Jersey and Minnesota. These plants will be subjected to wear in order to identify top performing genotypes (photo credit: Austin Grimshaw).

Figure 3. Consumers visited turfgrass plots in both New Jersey and Minnesota to take part in surveys. (photo credit: Jingjing Wang).

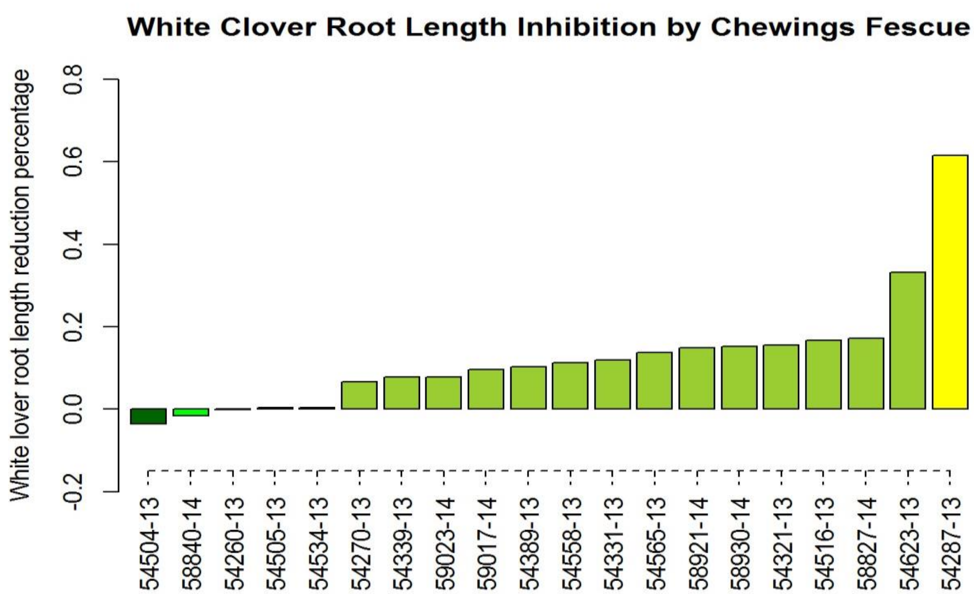


Figure 4. Preliminary studies have found some fine fescues can suppress the growth of weeds. This figure shows the effect of a number of Chewings fescue germplasm collections on the growth of white clover in a laboratory study.

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

Objectives:

Seed producing hybrids and checks were seeded in the fall and spring of 2014-15. The objectives were to evaluate the performance of the entries in a small scale National Turfgrass Evaluation Program (NTEP) trial for low and medium maintenance turf quality.

The fall medium- and low-trials were seeded on September 24 & 25, 2014. Entries varied for germination/%cover when rated on Nov 20th. Germination was slightly better in the medium trial for unknown reasons (Table 1 & 2). The checks (Kentucky and commercial hybrids) generally germinated well. Six hybrids in the low trial were detected that germinated well (> =5 score) (Table 1). After establishment, the low input trial was not watered, which eventually indicated which entries contained possible heat/drought tolerance, based on turf-quality ratings (Table 1; Figure 1 & 2). Between the 6/2 and 8/25 rating in the low maintenance trial, conditions were harsh on Kentucky checks, Bandera and some experimental hybrids moving them from the near top to near bottom of the rating scale (Table 1). This was also the time when pure Texas bluegrass and some experimental hybrids that were ranked lower in quality started to move up the quality scale. With the addition of irrigation in the medium maintenance trial, the Kentucky checks did not exhibit the level of stress seen in the low maintenance trial (Table 2). By the last rating date (11/24) in the low maintenance trial, there were several hybrids and Texas bluegrass that contained a turf quality rating similar to Solar Green (5.0), although they varied for % coverage. By the last rating on the medium maintenance trial (11/24), some of the hybrids that ranked high in the low maintenance trial also ranked high in the medium (Table 2). Similar to the Kentucky checks, some of the hybrids that did not perform well in the low maintenance trial did not exhibit the stress in the medium trial and ranked higher on the quality scale (Table 2; Figure 2). A spring seeding trial seeded on 4-15-15 did not result in successful establishment for most of the entries. Although most of the entries initially germinated and were watered throughout the summer, only the entries listed in Table 1 with an '*' in the germination column had plants remaining by the fall. On Oct 24, 2015 an additional fall seeding trial was seeded. The trial including new hybrid selections in addition to some of the better performing entries currently identified.

On the basis of first year performance data, several hybrid entries appear to contain greater heat/drought tolerance than the Kentucky checks; but, similar to the cultivars Solar Green and Thermal Blue. Due to low seed production, some of the entries only contained one or two replications. The experimental hybrids with heat tolerance varied for color, texture, density, and first year percentage ground cover (Figure 2). Although the pure Texas bluegrass population 'D4' performed well as conditions became more extreme, it currently requires prototype equipment to process the seed to a commercial grade. Further evaluation of the current hybrids, newly selected hybrids, and efforts to increase seed production are in progress.

Summary:

>A low and medium NTEP turf trial containing novel experimental hybrids derived from crosses between Texas and Kentucky bluegrass was seeded in the fall of 2014 in Woodward, Oklahoma.

>Several hybrids were identified that appeared to contain greater heat and drought tolerance than the Kentucky bluegrass checks; but, similar to the cultivars Solar Green and Thermal Blue.

>The hybrids with heat tolerance varied for texture, color, density, first year ground coverage and seed production.

>Further evaluation of the current hybrids, newly selected hybrids, and efforts to increase seed production are in progress.

Table 1. Characteristics and performance of hybrids and checks managed under low-input conditions

Low-Input				**Seeded 9-25-14**																	
	Germ	Texture	Color	**Turf Quality**														% Living Cover (2015)			
N	11/20/14	4/29/15	10/9/15	2/13/15		4/29/15		6/2/15		8/25/15		9/17/15		10/23/15		11/24/15		3/12	7/30	10/9	11/24
3	8.7*	6.0	4.3	#125 Tkiso	8.7	Absolute	7.0	Absolute	6.0	#28:20 Tki	5.0	TK24 SPS F	5.0	Texas D4-i	5.2	#35:24 TK	5.5	3.0	5.0	5.0	5.5
3	8.0	4.7	5.0	Absolute	8.3	Thermal B	7.0	Bandera	6.0	TK24 SPS F	4.7	#28:20 Tki	5.0	#35:24 TK	5.0	(TK43XTre	5.3	4.0	4.7	4.7	6.0
3	7.7*	3.0	3.3	Solar Green	7.7	Bandera	6.7	Thermal B	6.0	#67 TK24X	4.0	#35:24 TK	5.0	(TK43XTre	4.7	Texas D4-i	5.2	4.8	3.8	5.2	5.3
3	7.7	4.3	6.7	#67 TK24XHuntsville	7.3	Solar Gree	6.7	Solar Gree	5.7	#71 FS	4.0	(TK43XTre	4.3	TK24 SPS F	4.0	#67 TK24X	5.0	6.0	4.7	3.3	4.7
3	6.3*	7.3	5.0	#21 D4-10XPoland	7.3	#67 TK24X	6.3	#57 TK43X	5.7	#35:24 TK	4.0	Texas D4-i	4.3	Thermal B	4.0	Solar Gree	5.0	7.0	6.0	5.5	5.0
3	8.7*	3.7	5.0	Thermal Blue	7.0	Midnight	6.3	#67 TK24X	5.3	(TK43XTre	3.7	#71 FS	4.0	#71 FS	4.0	#71 FS	5.0	1.0	3.0	3.0	3.0
2	5.5	3.0	5.0	#56 WL63XRussian FS	6.5	#57 TK43X	6.0	Midnight	5.3	Solar Gree	3.3	#67 TK24X	3.7	#28:20 Tki	4.0	TK24 SPS F	4.7	2.7	3.7	3.3	3.7
3	7.3*	3.7	4.3	Bandera	6.3	#125 Tkisc	5.7	#17 TK43X	5.0	Texas D4-i	3.2	Texas WL-	3.7	Solar Gree	3.7	Thermal B	4.7	7.0	5.7	5.6	5.7
3	6.7	3.7	4.7	#50 TK43XTrenton	6.3	(TK43XTre	5.0	#21 D4-10	4.3	Thermal B	3.0	Solar Gree	3.3	Texas WL-	3.7	Texas WL-	4.0	2.3	3.7	3.7	4.7
2	5.5*	3.5	6.0	#71 TK24XHuntsville	6.0	#17 TK43X	5.0	(TK43XTre	4.0	Texas WL-	2.7	Thermal B	3.0	#67 TK24X	3.3	#71 TK24X	4.0	4.5	4.0	2.5	2.5
3	5.0*	4.0	5.7	(TK43XTrenton)XRus	5.0	#21 FS	4.7	#21 FS	4.0	#87 (WL63	2.0	#71 TK24X	2.5	#71 TK24X	2.5	#28:20 Tki	4.0	2.0	4.0	4.0	4.0
3	7.0*	5.3	3.3	Midnight	5.0	#21 D4-10	4.7	TK24 SPS F	4.0	#71 TK24X	2.0	#21 FS	2.3	#125 Tkisc	2.3	#21 FS	3.3	4.0	3.3	3.0	2.3
1	4.0	4.0	4.0	#17 TK43XTrenton	5.0	#71 TK24X	4.5	#56 WL63	4.0	#125 Tkisc	1.7	#125 Tkisc	2.0	#21 FS	1.7	#125 Tkisc	3.0	6.7	4.0	2.3	3.0
3	3.7	5.0	4.0	#57 TK43XTrenton	4.7	TK24 SPS F	4.3	#28:20 Tki	4.0	#21 FS	1.7	Absolute	2.0	#87 (WL63	1.5	Absolute	2.3	7.3	4.7	4.9	2.0
6	3.2*	3.8	5.2	Texas D4-iso	4.5	#28:20 Tki	4.0	#125 Tkisc	3.7	#56 WL63	1.5	#56 WL63	2.0	Absolute	1.3	#56 WL63	2.0	4.0	3.0	2.0	2.5
3	3.0	6.7	6.0	#21 FS	3.7	Texas D4-i	3.5	#50 TK43X	3.7	#21 D4-10	1.3	#87 (WL63	2.0	Bandera	1.0	#87 (WL63	2.0	2.0	2.5	3.2	2.0
2	2.0	4.0	6.0	#35:24 TK43XTrenton	3.0	#56 WL63	3.5	#71 TK24X	3.5	Midnight	1.3	Bandera	1.0	#21 D4-10	1.0	#21 D4-10	1.7	6.0	3.7	1.7	2.0
2	2.0	3.5	4.5	#87 WL63XRussian FS	2.5	#35:24 TK	3.5	#35:24 TK	3.5	Absolute	1.0	#21 D4-10	1.0	#50 TK43X	1.0	Bandera	1.3	6.0	4.0	4.5	1.0
3	2.0	2.7	4.0	Texas WL-iso	2.3	#50 TK43X	3.0	Texas D4-i	3.0	Bandera	1.0	Midnight	1.0	#57 TK43X	1.0	Midnight	1.3	5.7	4.0	4.1	1.3
3	1.7	2.3	6.3	TK24 SPS FS	2.0	#87 (WL63	3.0	#87 (WL63	3.0	#50 TK43X	1.0	#50 TK43X	1.0	#56 WL63	1.0	#50 TK43X	1.3	5.3	3.3	1.0	1.3
1	2.0	3.0	6.0	#28:20 Tkiso	2.0	#71 FS	3.0	#71 FS	3.0	#57 TK43X	1.0	#57 TK43X	1.0	#17 TK43X	1.0	#57 TK43X	1.3	5.3	4.3	1.3	1.7
1	1.0	4.0	6.0	#71 FS	1.0	Texas WL-	2.3	Texas WL-	2.3	#17 TK43X	1.0	#17 TK43X	1.0	Midnight	0.7	#17 TK43X	1.0	4.0	4.0	1.0	1.0

Low-input = 3.5” mowing height; 0.75 lb N/1000 ft^2/ Spring & Fall; no irrigation after establishment

Absolute, Midnight = Commercial *Poa pratensis* (Kentucky bluegrass); Solar Green, Thermal Blue, Bandera = Commercial Texas x Kentucky hybrids; Texas D4 & WL = *Poa arachnifera* (Texas bluegrass) experimental populations. Others = experimental hybrids. FS = fully shucked seed in which pure caryopsis were seeded.

N = # of plots

Germ = germination/%coverage (1 low -9 high), entries with an ‘*’ also germinated when seeded in the spring

Texture = (1 coarse – 9 fine); Color = (1 light – 9 dark); Turf Quality (1 low – 9 high); % Living Cover (1 low – 9 high)

Table 2. Characteristics and performance of hybrids and checks managed under medium-input conditions.

Medium-Input				**Seeded 9-24-14**																	
	Germ	Texture	Color	Turf Quality														% Living Cover (2015)			
N	11/20/14	4/29/15	10/9/15	2/13/15		4/29/15		6/2/15		8/25/15		9/17/15		10/23/15		11/24/15		3/12	7/30	10/9	11/24
1	7.0	4.0	5.0	#17 TK43XTrenton	8.0	Solar Gree	6.7	Midnight	6.3	#71 FS	6.0	Solar Gree	6.3	Solar Gree	7.0	#71 FS	7.0	1.0	3.0	3.0	3.0
3	7.0	6.0	5.3	#125 Tkiso	7.3	Midnight	6.3	Bandera	6.0	Solar Gree	5.3	Midnight	5.7	Midnight	6.7	TK24 SPS F	7.0	2.7	3.7	3.3	3.7
3	6.0	2.0	5.0	Solar Green	6.7	Thermal B	6.3	#57 TK43X	6.0	TK24 SPS F	5.0	#35:24 TK4	5.5	Thermal B	6.7	Solar Gree	7.0	5.0	7.0	6.6	7.0
3	5.3	6.0	4.7	#21 D4-10XPoland	6.3	#57 TK43X	6.3	#17 TK43X	6.0	#17 TK43X	5.0	Thermal B	5.3	#35:24 TK4	6.5	Midnight	6.7	5.7	5.7	6.7	5.0
3	4.7	4.0	4.7	Bandera	5.7	Bandera	6.0	Absolute	5.7	Midnight	4.7	#71 FS	5.0	#57 TK43X	6.0	#35:24 TK4	6.5	3.0	5.0	5.0	5.5
3	6.3	5.3	6.7	Midnight	5.7	#17 TK43X	6.0	Thermal B	5.7	#35:24 TK4	4.5	#57 TK43X	5.0	#17 TK43X	6.0	Thermal B	6.3	5.0	6.7	6.0	7.0
3	6.3	2.7	5.0	Thermal Blue	5.7	Absolute	5.7	Solar Gree	5.3	Absolute	4.3	#17 TK43X	5.0	Texas D4-i	5.8	Absolute	6.0	2.7	5.0	5.7	4.3
2	4.0	4.0	6.5	#71 TK24XHuntsville	4.5	#125 Tkisc	5.0	#67 TK24X	5.0	(TK43XTre	4.0	(TK43XTre	4.7	Absolute	5.7	Texas D4-i	6.0	2.8	5.2	4.9	6.0
3	3.0	3.3	6.7	#67 TK24XHuntsville	4.0	#67 TK24X	5.0	#87 (WL63	4.5	Thermal B	4.0	Absolute	4.3	#125 Tkisc	5.3	#17 TK43X	6.0	3.0	5.0	6.0	5.0
3	4.3	5.3	6.7	Absolute	3.7	#21 D4-10	5.0	#125 Tkisc	4.0	#87 (WL63	3.5	Texas D4-i	4.2	(TK43XTre	5.3	#125 Tkisc	5.7	6.0	5.7	5.2	5.7
3	4.3	3.3	3.7	#50 TK43XTrenton	3.7	#21 FS	4.3	(TK43XTre	4.0	#67 TK24X	3.3	#125 Tkisc	4.0	#71 FS	5.0	#57 TK43X	5.7	5.3	4.3	1.3	1.7
6	2.5	3.7	3.8	Texas D4-iso	3.3	#35:24 TK4	4.0	#21 FS	4.0	#21 FS	3.3	#87 (WL63	4.0	#71 TK24X	4.5	#87 (WL63	5.5	2.0	2.5	3.2	2.0
2	2.5	3.0	5.0	#35:24 TK43XTrenton	3.0	#50 TK43X	3.3	#21 D4-10	4.0	#57 TK43X	3.3	TK24 SPS F	4.0	#87 (WL63	4.5	(TK43XTre	5.3	4.0	4.7	4.7	6.0
3	2.7	3.7	6.0	(TK43XTrenton)XRus	2.7	#71 TK24X	3.0	#35:24 TK4	4.0	Texas D4-i	3.3	#71 TK24X	3.5	TK24 SPS F	4.5	#71 TK24X	5.0	3.0	4.0	3.5	3.0
3	1.3	5.3	5.3	#21 FS	2.3	#71 FS	3.0	#50 TK43X	3.7	#125 Tkisc	3.0	#67 TK24X	3.3	#21 FS	4.3	#67 TK24X	4.3	2.7	4.7	4.7	3.3
2	1.5	3.5	6.0	#87 (WL63XRussian) F	2.0	(TK43XTre	3.0	TK24 SPS F	3.5	#71 TK24X	2.5	#21 FS	3.3	Texas WL-	4.0	Texas WL-	4.3	2.3	3.7	3.7	4.7
2	1.0	2.5	4.0	TK24 SPS FS	2.0	#87 (WL63	3.0	#71 TK24X	3.0	Bandera	2.0	Bandera	3.0	#28:20 Tki	4.0	#28:20 Tki	4.0	2.0	4.0	4.0	4.0
3	2.3	4.3	4.7	#57 TK43XTrenton	2.0	Texas D4-i	3.0	#71 FS	3.0	#28:20 Tki	2.0	#28:20 Tki	3.0	#67 TK24X	3.7	Bandera	3.7	4.3	5.3	4.9	3.7
3	2.0	3.0	5.0	#56 WL63XRussian FS	2.0	TK24 SPS F	3.0	#28:20 Tki	3.0	Texas WL-	1.7	Texas WL-	2.7	Bandera	3.3	#21 FS	3.7	4.0	3.3	3.0	2.3
3	1.0	3.3	4.0	Texas WL-iso	1.3	#28:20 Tki	3.0	Texas D4-i	2.8	#50 TK43X	1.3	#50 TK43X	2.0	#21 D4-10	2.7	#21 D4-10	2.7	5.3	3.7	4.0	3.0
1	1.0	4.0	7.0	#71 FS	1.0	#56 WL63	1.7	#56 WL63	2.7	#21 D4-10	1.0	#21 D4-10	1.3	#50 TK43X	2.3	#50 TK43X	2.7	3.3	4.0	3.4	2.3
1	1.0	2.0	5.0	#28:20 Tkiso	1.0	Texas WL-	1.7	Texas WL-	2.0	#56 WL63	1.0	#56 WL63	1.0	#56 WL63	1.0	#56 WL63	1.3	4.0	3.0	2.0	2.5

Medium-input = 2.5” mowing height; 2 lb N/1000 ft^2 Spring and Fall; irrigation to prevent stress or dormancy

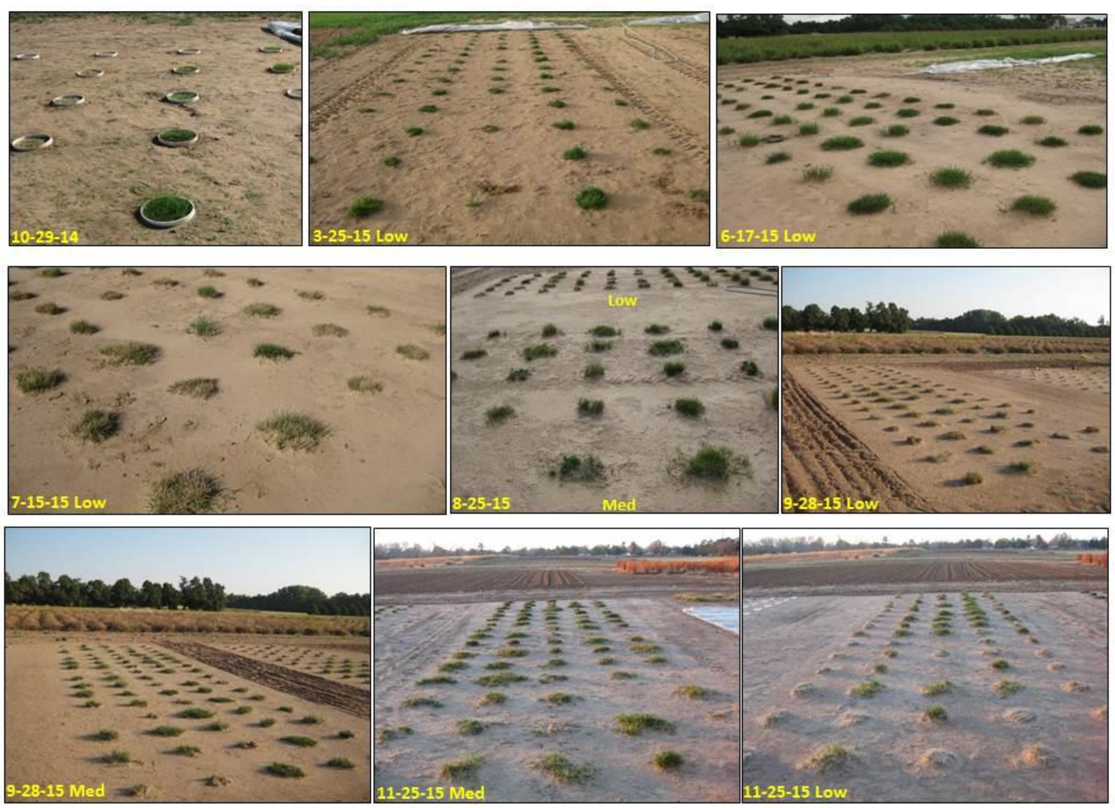


Figure 1. Photographs of the low and medium input seeded turf trial starting from approximately five weeks after seeding (10-29-14) to late November the following year.

Figure 2

Figure 2. All photos were taken on December 3, 2015. Names in the top left corner correspond to the entries in Table 1. The best plot, when there was a visible difference, within the low and medium trials was photographed for the figure.

Reduced Water Consumption of Perennial Ryegrass in the Western USA

Joseph G. Robins and B. Shaun Bushman

USDA-ARS, Logan, UT

Perennial ryegrass (*Lolium perenne* L.) is one of the more important cool-season turgrasses for golf courses. Unfortunately, in much of the Western USA perennial ryegrass requires high amounts of irrigation to maintain acceptable quality. With ongoing drought in several western states and the uncertainty of future precipitation patterns under climate change there is a need for turfgrasses with lower irrigation requirements. To facilitate the development of lower irrigation requiring perennial ryegrass cultivars, ARS researchers in Logan, UT initiated a study to evaluate a large collection of perennial ryegrass germplasm for turfgrass quality under limited irrigation.

In 2014, ARS researchers requested seed of perennial ryegrass cultivars with improved drought tolerance from North American and European turfgrass seed companies. Most of the companies responded by sending seed samples for their most drought tolerant cultivars. Several also included seed of non-drought tolerant cultivars to be used as comparisons in the evaluations. ARS researchers also requested perennial ryegrass seed of 66 accessions in the U.S. National Plant Germplasm System (NPGS). The objective of the seed request from the NPGS was to include a wide portion of the genetic variation present in perennial ryegrass originating from drier regions. Perennial ryegrass accessions in the NPGS predominate from some countries, for example Turkey, and thus countries are not equally represented.

The number of perennial ryegrass germplasm accessions requested from the NPGS according to country of origin.

Country	No. of Accessions
Afghanistan	4
Bolivia	1
Iran	10
Iraq	1
Russia	5
Former Soviet Union	6
Spain	1
Turkey	36
Turkmenistan	1
Uzbekistan	1

The original research plan was to establish replicated field trials of the perennial ryegrass germplasms at three sites in northern Utah (Millville, North Logan, and Kaysville) during fall 2015. Unfortunately, the NPGS was unable to supply sufficient seed for the seeding of the proposed evaluations. This necessitated the increase of the NPGS seed by the ARS researchers. During winter 2014-15, 30 seeds from each NPGS accessions were seeded to flats in the greenhouse at Logan, UT. After establishment of the plants, the plants of each accession were vernalized in growth chambers. In spring 2015, the vernalized plants from each NPGS accession were transplanted to isolated crossing blocks at a Millville, UT field site. Following pollination and seed maturation, the ripe seed was hand-harvested from each plant and bulked by accession. Seed was then threshed and cleaned in preparation for fall 2016 planting. Many accessions produced sufficient seed for the 2016 planting. However, to ensure sufficient seed supply, seed from the NPGS accession will also be harvested, threshed, and cleaned in 2016 in time for the fall planting.

Isolated seed production crossing blocks of the NPGS accessions at the Millville, UT field site in 2015.

Although the lack of necessary seed put the project timeline back one year, the ARS researchers felt the delay worthwhile to include a wider sample of perennial ryegrass variation in the evaluations. This will provide a more robust examination of the variation within perennial ryegrass for irrigation requirements and allow for a more informed selection process.

Summary Points

- **Obtained cultivars and accessions from seed companies and NPGS to be used in germplasm evaluation.**
- **Established seed production crossing blocks for the 66 NPGS accessions.**
- **Harvested seed from the 66 NPGS accessions.**

Evaluation of Crown Membrane Health and Gas Accumulation in Response to Ice Stress and Management Practices of Creeping Bentgrass and Poa Annua

Emily Merewitz and Kevin Frank
Michigan State University

Start date: 2015
Project duration 2 years
Total funding: $20,000

Objectives:

1. *Investigate whether crown membrane fatty acid ratios and composition may correlate to toxic gas accumulation and are they differentially accumulated between creeping bentgrass and poa annua under ice cover stress*
2. *Evaluate how lipid profiles and FFA change over a time course of ice cover*
3. *Use a simulated ice cover experiment to determine whether membrane health changes due to incubation of turf with specific ice cover associated gases*
4. *Evaluate whether chemical treatments commonly used in the turf industry reduce turf loss due to ice cover, particularly related to membrane disruption or FFA accumulation*

Creeping bentgrass and annual bluegrass are two important putting green species that are sensitive to ice cover damage. Creeping bentgrass is typically more tolerant to ice stress than annual bluegrass. A major cause of damage under prolonged ice cover is the accumulation of toxic gases and damage to grass crown tissue. Several management practices have been reported to improve turf survival of winter, but have not been investigated in controlled studies. This project aimed to determine whether commonly used plant growth regulators (PGRs) and an oil based product, Civitas, have an effect on turf survival of ice cover and is that survival related to membrane or crown health.

Separate creeping bentgrass and annual bluegrass fields were maintained at the Hancock Turfgrass Research Center at Michigan State University. Plots of both species were treated in late summer through fall of 2014 every two weeks with: Civitas, mefluidide, propiconazole, or trinexapac ethyl at label recommended rates. Turfgrass plots underwent natural acclimation to cold conditions in fall 2014. Turfgrass plugs were then taken on 11 Nov 2014 from each plot, planted in 4 inch plastic pots in native soil, and then transferred to an environmentally controlled low temperature growth chamber (-4^{o}C) where they underwent 1) no ice or 2) ice cover (0.5” thick) treatments. Turfgrass plugs were taken out of the low temperature growth chamber at 0, 20, 40, 60, and 100 days after temperature treatments. Plants were then destructively sampled by cutting the plants in half. Half of the plant went to gas chromatography mass spectroscopy (GC/MS) for analysis of free fatty acids while the other half went towards a percent regrowth assay in a greenhouse.

Ice covered plugs treated with mefluidide, propiconazol, and civitas all had significantly more regrowth than trinexapac-ethyl and untreated control plugs after 20, 40, and 60 days in the low temperature growth chamber. Exposure of plants to the low temperature chamber conditions and the regrowth assay results should not be directly correlated with number of days of survival in the field. The chamber conditions completely freeze the soil profile, which would not likely occur under field conditions. We are currently installing heating ribbons in the growth chamber in order to keep soil temperatures warmer and more closely aligned with field conditions for future projects.

At 20 days under ice cover, the majority of the fatty acids detected within annual bluegrass were linolenic acid, linoleic acid, oleic acid, stearic acid, palmitoleic acid, and palmitic acid. Plants that were treated with mefluidide, propiconazole, and Civitas have a greater percentage of polyunsaturated fatty acids, with linoleic acid being the most increased due to these chemical treatments, compared with trinexapac-ethyl and untreated samples (Table 1). The unsaturated fatty acid linoleic acid is a precursor to the plant hormone jasmonic acid, a hormone involved in stress responses and the induced systemic resistance pathway. Fatty acids greater than 18 carbons were detected in trace amounts primarily in Civitas treated samples. Further evaluation of these profiles is needed and is being performed.

Currently, field plots are being treated in the same manner as in 2014 in order for collection of turf plugs. Analysis on creeping bentgrass plants and the other objectives listed above are also on-going.

Summary Points

- Annual bluegrass regrowth after simulated ice cover in a growth chamber was significantly affected by plant growth regulator or civitas treatments.
- Enhanced survival of annual bluegrass after treatment with plant growth regulators or civitas could be related to shifts in fatty acid accumulation.
- More work is on-going to thoroughly investigate fatty acids and gas accumulation in both creeping bentgrass and annual bluegrass responses to chemical management practices and ice cover.

Figure 1 – Annual bluegrass plants treated with Civitas, mefluidide, propiconazole, trinexapac ethyl, or untreated under ice (0.5” thick) in a low temperature growth chamber (-4°C)

Figure 2 – Regrowth (%) of annual bluegrass plugs maintained under ice cover in a low temperature growth chamber (-4 °C) that were treated with different plant growth regulating compounds. Different letters indicate statistically significant differences within a sampling day ($P \leq 0.05$).

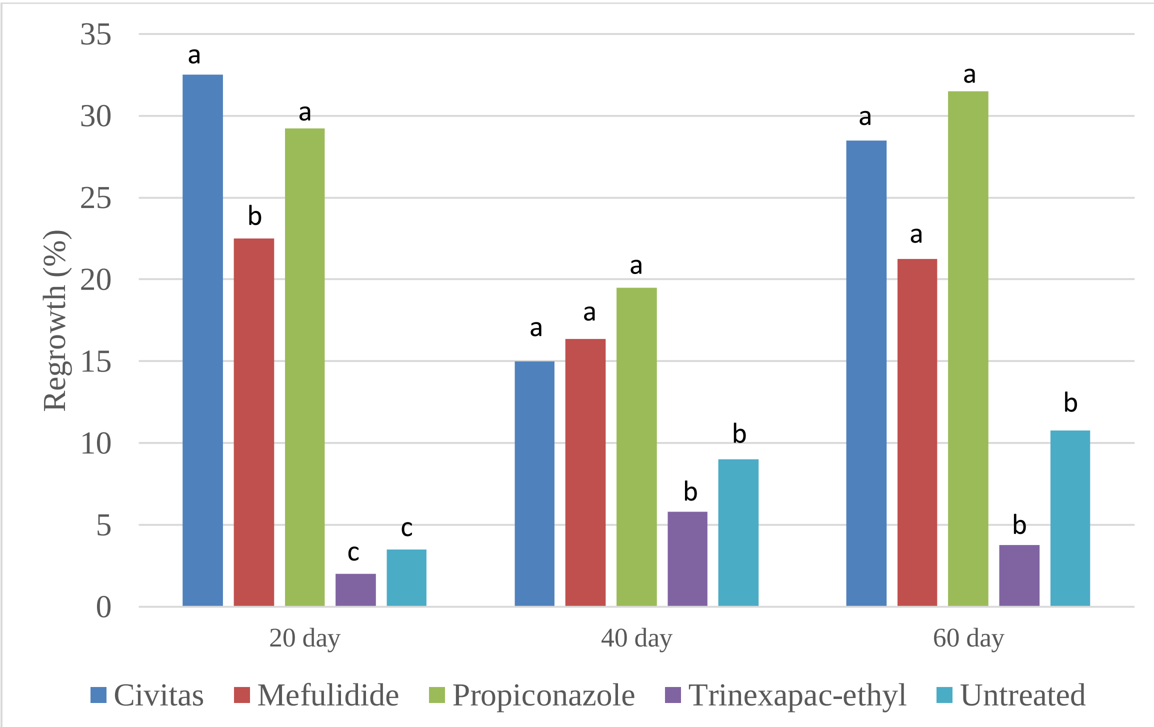


Table 1. List of free fatty acids found in annual bluegrass crown tissue exposed to different chemical treatments after 20 days of ice cover. The fatty acid designation ratios are (C, number of carbon atoms)/(D, number of double bonds). Different letters indicate statistically significant differences within each column ($P \leq 0.05$).

	Fatty Acids							
	Molar percentage (mol %)							
	saturated		**unsaturated**				**Trace**	
	16:0 Palmitic acid	**18:0 Stearic acid**	**16:1 Palmitoleic acid**	**18:1 Oleic acid**	**18:2 Linoleic acid**	**18:3 Linolenic acid**	**24:0 Lignoceric acid**	**26:0 Cerotic acid**
Civitas	30.5 bc	29.1 b	6.6 ab	6.7a	13.5 b	12.9 ab	0.08	0.06
Propiconazole	26.9 c	26.2 b	4.7 c	5.3a	21.6 a	15.3 a	N/A	N/A
Mefluidide	29.3 c	26.2 b	6.3 ab	7.1a	19.0 a	11.7 ab	N/A	N/A
Trinexapac-ethyl	33.4 ab	35.4 a	7.2 a	5.8a	9.0 bc	9.3 b	N/A	N/A
Untreated	35.0 a	37.0 a	5.5 bc	5.6a	8.0 c	8.1 b	N/A	N/A
LSD	3.83	1.33	4.73	2.22	4.83	5.73		

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

Zipeng Tian, Karen V. Ambrose, and Faith C. Belanger

Dollar spot is one of the most problematic diseases for many golf courses, particularly on creeping bentgrass, often requiring repeated applications of fungicides. In addition to creeping bentgrass, dollar spot can also be a problem on strong creeping red fescue. However, when strong creeping red fescue is infected with the symbiotic fungal endophyte *Epichloë festucae*, the plants exhibit resistance to dollar spot (Clarke et al., 2006). How infection by the endophytic fungus confers disease resistance to the host red fescue is not known. Resistance to fungal pathogens is not an established effect of endophyte infection of other grass species, and may therefore be unique to the fine fescues.

We recently carried out a large scale transcriptome study comparing endophyte-free and endophyte-infected red fescue plants, with the goal of identifying plant or fungal genes that may be involved in the observed disease resistance (Ambrose and Belanger, 2012). Analysis of the plant genes whose transcript levels were affected by the presence of the fungal endophyte did not reveal any strong candidates for genes directly related to enhanced disease resistance. However, one of the fungal abundant secreted proteins is of particular interest regarding the disease resistance observed in endophyte infected fine fescues. This protein is similar to characterized antifungal proteins from *Penicillium* and *Aspergillus* (Marx, 2004). We have therefore begun referring to the *E. festucae* protein as an antifungal protein. As a secreted protein, the *E. festucae* antifungal protein could come into direct contact with invading pathogens. Surprisingly, the gene for this antifungal protein is not present in most *Epichloë* species. The limited presence of the gene among the *Epichloë* species and its high level of expression in *E. festucae* suggest it may be involved in the disease resistance seen in *E. festucae* infected red fescue.

Understanding the mechanism behind the endophyte-mediated disease resistance in the fine fescues may lead to new approaches for dollar spot management in other grass species, such as creeping bentgrass. The objective of this project is therefore to characterize the endophyte antifungal protein and determine if it does play a role in the disease resistance.

We used protein sequencing to confirm the presence of the antifungal protein as a component of the secreted proteins extracted from endophyte-infected plants. The secreted proteins were extracted from the leaves of endophyte-free and endophyte-infected plants and compared on a SDS-polyacrylamide gel. One protein band was more prominent in the endophyte-infected samples and protein sequence analysis of the band indicated the antifungal protein was the major component in the band (Figure 1, E- and E+ lanes). We have partially purified the antifungal protein from the secreted proteins (Figure 1, lane 2). The partially purified protein did have antifungal activity against the dollar spot fungus in a plate assay (Figure 2). We are currently working on expressing the protein in yeast in order to produce larger quantities of the protein for additional tests of antifungal activity. In summary, the data we have obtained so far are promising regarding the possibility that the *E. festucae* antifungal protein may be a component of the disease resistance seen in endophyte-infected strong creeping red fescue.

References

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

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

Marx, F. (2004) Small, basic antifungal proteins secreted from filamentous ascomycetes: a comparative study regarding expression, structure, function and potential application. Applied Microbiology and Biotechnology 65:133-142

Bullet Points

1. The fungal endophyte *Epichloë festucae* secretes an abundant protein into the plant apoplast (the space between the plant cells) that is similar to proteins from *Penicillium* and *Aspergillus* that have antifungal activity.

2. We have partially purified the *E. festucae* protein from the secreted proteins.

3. The partially purified *E. festucae* protein had antifungal activity against the dollar spot fungus in a plate assay. It may therefore be a component of the well-established endophyte-mediated disease resistance seen in strong creeping red fescue.

Figure Legends

Fig. 1. SDS-polyacrylamide gel of secreted proteins from endophyte-free (E-) and endophyte-infected (E+) strong creeping red fescue leaves and column fractions from the purification of the antifungal protein (lanes 1, 2, and 3). The asterisks indicate the protein bands containing the antifungal protein. The antifungal protein was most concentrated in column fraction 2.

Fig. 2. Plate assay of activity of the partially purified antifungal protein against the dollar spot fungus. A small piece of the dollar spot fungus was placed in the center of an agar plate and the partially purified antifungal protein and a buffer control were spotted at opposite ends of the plate. The growth of the dollar spot fungus was inhibited by the antifungal protein (top, black arrow) but not by the buffer control (bottom, white arrow).

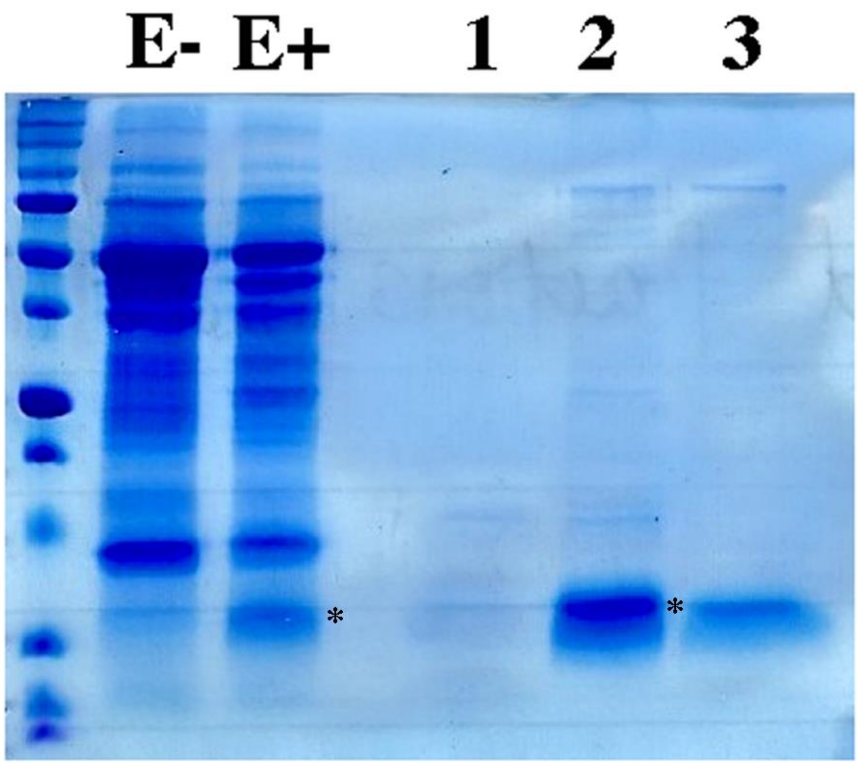


Figure 1. SDS-polyacrylamide gel of secreted proteins from endophyte-free (E-) and endophyte-infected (E+) strong creeping red fescue leaves and column fractions from the purification of the antifungal protein (lanes 1, 2, and 3). The asterisks indicate the protein bands containing the antifungal protein. The antifungal protein was most concentrated in column fraction 2.

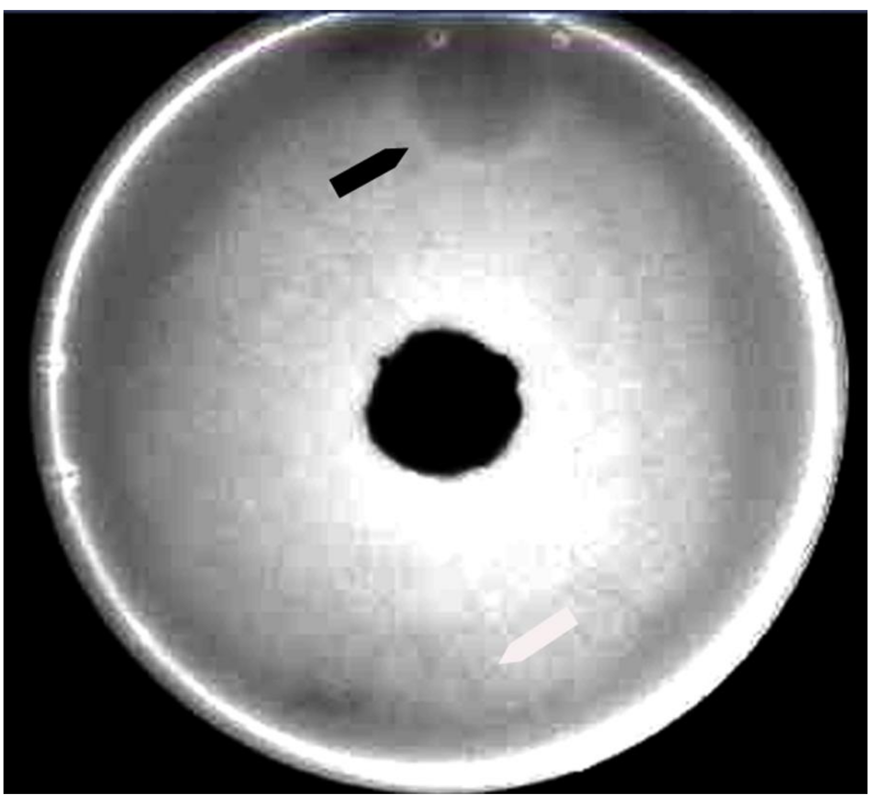


Figure 2. Plate assay of activity of the partially purified antifungal protein against the dollar spot fungus. A small piece of the dollar spot fungus was placed in the center of an agar plate and the partially purified antifungal protein and a buffer control were spotted at opposite ends of the plate. The growth of the dollar spot fungus was inhibited by the antifungal protein (top, black arrow) but not by the buffer control (bottom, white arrow).

Title: Bermudagrass Breeding and Genetics (2006-18-326)

Project Leader(s): Brian Schwartz

Affiliation: The University of Georgia

Objectives:

1. To evaluate the performance of new bermudagrass and zoysiagrass hybrids under actual golf course putting greens management.

Start Date: 1999

Project Duration: Ongoing

Total Funding: $160,000

We began the first phase of this research plan in 2012 as a way for me to develop relationships with golf course superintendents who had collaborated with the Tifton program in the past. Everyone who volunteered to participate took on the burden of building or renovating old practice greens for me to test the hypotheses of whether or not new bermudagrass hybrids, i.e., ones that are not 'Tifgreen' mutants, or if needle-like zoysiagrasses could be managed successfully. What we have learned to-date is that just because a grass has deeper roots, a thin mat-layer, and outperforms Tifdwarf, MiniVerde, Champion, and TifEagle on the research station does not mean that they will find a place on the golf course. The take-home message from the first few years of these trials has helped shape my strategy for breeding new putting greens grasses. Simply, a plant with smaller, upright leaves does not necessarily correlate with a faster, better putting surface.

Summary Points:

1. Prior to 2015: Ken Mangum fumigated the research green at the Atlanta Athletic Club with Basamid prior to planting on June 5th, 2012. The bermudagrasses established very quickly, but the zoysiagrasses took over one year to fully grow-in. A picture of the green and a summary of the stimp readings are below.

Atlanta Athletic Club (12 Stimp Measurements)			
(2012 – 2014)		May 2nd, 2013	Overall Avg.
Bermuda	Champion	**11.4'**	**10.1'**
	08-T-18	**9.9'**	**8.4'**
Zoysia	Diamond	**-**	**8.3'**
	L1F	**8.9'**	**8.2'**
	10-TZ-74	**-**	**8.2'**
	FAES 1301	**7.8'**	**7.4'**
Paspalum	1743	**8.3'**	**7.9'**

2. <u>2015</u>: Trials were planted during 2015 at the Country Club of Columbus, The Landings, and the Atlanta Athletic Club. Also, Scott Griffith built a 1,500 ft^2 research green with drainage at the University of Georgia Golf Course with partial funding from the USGA grant given to the UGA Tifton Breeding Program prior to planting 10-TZ-74 zoysiagrass sod on July 29th, 2015. The sod rooted relatively quickly and has been topdressed regularly since planting so that stimp meter evaluation can begin during 2016 at putting greens HOC. Pictures of the green at planting and during the fall 2015 are below.

3. <u>Future Work</u>: We have plans to establish new tests at the Valdosta Country Club and the Atlanta Country Club during 2016.

Development of Seeded and Vegetatively Propagated Bermudagrass Varieties Improved in Turf Quality and Stress Tolerance

Yanqi Wu and Dennis L. Martin
Oklahoma State University

Objectives:

1. Assemble, evaluate and maintain *Cynodon* germplasm with potential for contributing to the genetic improvement of the species for turf.
2. Develop and use simple sequence repeat markers.
3. Improve bermudagrass germplasm for seed production potential, turf performance traits, and stress tolerance.
4. Develop, evaluate and release seed- and vegetatively-propagated turf bermudagrass varieties.

Start Date: 2013
Project Duration: three years
Total Funding: $90,000

Bermudagrass is a major warm-season turfgrass that has been widely used on golf courses, sports fields, home lawns, and other landscapes in the United States. The major goal of the Oklahoma State University turf bermudagrass breeding program is to develop high quality, seeded and clonal cultivars with improved resistance to abiotic and biotic stresses. Research progress of the OSU turf bermudagrass breeding project in 2015 is summarized as follows.

Seed yield is a major trait targeted for improvement in common bermudagrass breeding programs because of the increased interest in seed-propagated cultivars. Understanding the nature of genetic variation for seed yield and its components in bermudagrass would aid development of seed-propagated bermudagrass cultivars. As part of Dr. Chengcheng Tan's Ph.D. research program, a field-based experiment was performed to estimate the genetic component of variation and narrow-sense heritability for seed yield and its two major components, inflorescence prolificacy and seed set percentage in common bermudagrass. Twenty-five half-sib families and their respective clonal parents were evaluated at two Oklahoma locations, Perkins and Stillwater. Half-sib families were different for seed yield, inflorescence prolificacy and seed set percentage, indicating the expression of additive genes in controlling these traits. Narrow-sense heritability estimates for seed yield was 0.18 based on variance component analysis among half-sib families and ranged from 0.26 to 0.68 based on parent-offspring regressions, indicating complex genetics control seed yield. Heritability estimates were moderate (0.30-0.55) for inflorescence prolificacy and moderate to relatively high (0.41-0.78) for seed set percentage. These results indicate that sufficient magnitudes of additive genetic variation for seed set percentage and inflorescence prolificacy will permit a positive response to selection.

A nursery of 98 cold hardy plants has been evaluated for turf performance, seed yield and related traits since 2011 as part of Ph.D. graduate student Yuanwen Guo's thesis project. More than 1,800 progeny plants were developed from equally mixed seed collected from the 98 plants grown in a selection nursery. The progeny plants transplanted in a nursery were visually evaluated for establishment rate, leaf texture, color, spring green up, seed head prolificacy in

2015 (Figure 1). Selected plants in the nursery will be evaluated for seed set and turf quality traits in 2016 and 2017. In the early summer of 2015, parental plants of 12 new polycrosses (to produce synthetic seed) were transplanted into separate nurseries (Figure 2). The parents were selected from four breeding populations based on relatively high seed yield and acceptable turf quality in previous years. Seed yields of the new crosses will be evaluated in 2016 and 2017.

Thirty-five official and four local entries in the 2013 NTEP bermudagrass trial were evaluated for sod tensile strength, sod handling quality and divot recovery characteristics during 2014 and 2015. This work was conducted by M.S. candidate Lakshmy Gopinath at Stillwater, OK. Bermudagrass sod harvested at 24 months after planting (MAP) generally had greater mean sod tensile strength (STS) and handling quality (SHQ) compared to sod harvested at only 14 MAP. Our experimental entries OKC 1131 and OKC 1302 had high STS and excellent SHQ on all harvest dates. A first-ever regression equation was developed that related bermudagrass STS (a quantitative measure of sod strength) to sod handling quality. We believe this relationship allows for decision making concerning the minimum STS necessary for satisfactory SHQ. Analysis of divot recovery data is not complete at this time. We anticipate the ability to characterize all entries for their divot recovery rate under spring, summer and fall growing conditions.

Summary Points

- A common bermudagrass experiment indicated low narrow-sense heritabilities of seed yield, but moderate and relatively high heritabilities of seed head prolificacy and seed set percentage.
- A common bermudagrass selection nursery was evaluated for phenotypic traits related to turf quality and seed yield.
- Twelve polycross plantings were field established to evaluate seed yield and selected traits related to turf performance.
- Sod tensile strength, handling quality and divot recovery were evaluated on 35 official and 4 local entries in the 2013 NTEP bermudagrass trial at Stillwater, OK.

Figure Captions

Figure 1. A field nursery of more 1,800 plants evaluated in establishment rate, turf quality, and seed yield related traits.

Figure 2. Twelve new polycross established to produce synthetic seed.

Development of Shade-Tolerant Bermudagrass Cultivars for Fine Turf Use

Yanqi Wu, Kyungjoon Koh, and Greg Bell
Oklahoma State University

Start Date: 2014

Project Duration: three years

Total Funding: $60,000

Objectives:

1. *Cross bermudagrass selections screened for shade tolerance and fine turf qualities.*
2. *Establish progeny from seed and evaluate the progeny for shade tolerance, seed yield, and fine turf qualities.*
3. *Develop a shade-tolerant seeded bermudagrass cultivar(s).*

Bermudagrass (*Cynodon* spp.) is the most popular warm-season turfgrass used on golf courses in the US. However, most currently available bermudagrass cultivars don't have sufficient shade tolerance. Since 2007, with financial support from the USGA, 45 common bermudagrass [*C. dactylon* (L.) Pers.] germplasm accessions assembled at the Oklahoma State University turfgrass breeding program with seed-producing potential were tested and selected for shade tolerance. Using the best germplasm accessions, two synthetics, OKS 2011-1 and OKS 2011-4 were created. In the summer of 2013, the two new synthetics along with 'Celebration', 'Latitude 36', 'NorthBridge', 'Patriot', 'Princess 77', 'Riviera', 'TifGrand', and 'Yukon' were planted in 0.91 m x 1.52 m (3 ft. x 5 ft) plots with four replications on each of three sites, one severe shade site, one partial shade site, and one full sun site. The three sites are adjacent each other and located on the OSU Turf Research Center. Plots were mowed 3 times per week at 5 cm height and nitrogen was applied at 5 g/m^2 (1 lb. /1000 ft^2) monthly. Irrigation was applied at rates and frequencies necessary to prevent drought stress.

In 2015, 67% of photosynthetic photon flux (PPF) was reduced in shade plots as compared to the full sun site. It was 23% more shade than the previous two years due to the adjustment of the shade cloth more toward to the center of the shade block. Shade plots received full sun light between ~ 9:30 to 10 am. Increase in shade duration decreased turf quality to 36% in 2015 from 26 % in 2014 and NDVI 26% from 7.7%. Celebration and NorthBridge were the top ranked bermudagrasses in shade plots (Table 1). However, the best six cultivars and worst four cultivars in shade remained same as year 2014. OKS 2011-1 was not significantly different from Riviera and Yukon. Among seeded type bermudagrasses, OKS 2011-1 was visually ranked the same as Riviera, Yukon, and OKC 2011-4 in shade. Patriot and TifGrand were the most poorly performed cultivars both in shade and full sun. On April 30, 2015, 98 best plants from 2011-3 nursery plots in severe shade (Photo 1) were collected for further development. OKS 2011-1 and 2011-4 were among the top ranked cultivars for spring green up both in shade and full sun.

Table 1. The visual turf quality (TQ) means of bermudagrass collected on nine rating dates from 15 May to 16 Oct 2015.

Bermudagrass	Shade			Sun			Shade/sun
	TQ	**Visual Rank***	**NDVI****	**TQ**	**Visual Rank**	**NDVI**	**Decline*****
	1-9=best	---- LSD ----		1-9=best	---- LSD ----		---- % ----
Celebration	5.3	A	0.6275	6.9	DE	0.8000	-21.56
NorthBridge	5.1	AB	0.6325	7.6	A	0.8075	-21.67
Riviera	4.8	BC	0.5750	7.4	BC	0.8175	-29.66
Yukon	4.7	BCD	0.6050	7.5	AB	0.8075	-25.08
Latitude36	4.7	BCD	0.6125	7.5	AB	0.8225	-25.53
2011-1	4.5	CDE	0.6250	7.1	CD	0.8050	-22.36
Princess77	4.4	CDE	0.6525	6.7	F	0.8000	-18.44
2011-4	4.3	DE	0.5625	7.0	D	0.8050	-30.12
TifGrand	4.2	E	0.5350	6.5	F	0.8150	-34.36
Patriot	3.6	F	0.5325	6.7	F	0.7950	-33.02
LSD	0.4		0.0557	0.24		0.019	

*Based on Fisher's protected least significant difference (*P*=0.05); means followed by the same letter do not differ significantly. **Normalized difference vegetation index (near infrared reflectance - red reflectance) / (near infrared reflectance + red reflectance). ***NDVI in shade compared with NDVI in full sun reported in %; (shade - full sun)/full sun*100

Table 2. The spring greenup ratings on April 9, 2015.

Bermudagrass	Shade		Sun	
	Visual rating	**Visual Rank***	**Visual rating**	**Visual Rank**
	1-9=best	---- LSD ----	1-9=best	---- LSD ----
Riviera	6.0	A	7.0	A
2011-1	5.5	AB	6.8	AB
NorthBridge	5.5	AB	6.0	BC
2011-4	5.5	AB	7.0	A
Yukon	5.5	AB	7.0	A
Latitude36	4.8	BC	5.8	C
Celebration	4.3	CD	4.3	D
TifGrand	3.8	DE	3.0	EF
Princess77	3.3	E	2.3	F
Patriot	3.0	E	3.3	E
LSD	0.8		0.9	

*Based on Fisher's protected least significant difference (*P*=0.05); means followed by the same letter do not differ significantly

Summary Points

- The overall turf quality of bermudagrass entries in shade compared with that in full sun declined from 27% in 2014 to 36% in 2015.The NDVI decline also deepened from 7.7% in 2014 to 26% in 2015 after moving 75% black woven shade clothes to the center of the plots in 2015.
- Best 98 plants were selected in a segregation population from the 2011-3 nursery plots under severe shade.
- OKS 2011-1 bermudagrass was equally ranked to Yukon, Riviera, Princess77 and OKS 2011-4 and better than Patriot in shade.

Photo 1. Best survival plants selected in the 2011-3 bermudagrass population grown in severe shade.

Annual Report on USGA ID#2014-03-492

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

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

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

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

In 2015, we have been working on the segregating population, provided by co-PI Wu. This segregation population was made by crossing a cold-tolerant entry A12396 (pollen donor) with a cold-sensitive entry A12395 (seed parent). The entry A12396 is a breeding line selected from the Oklahoma State University (OSU) bermudagrass germplasm known for cold hardiness. The entry A12395 is a collection from Puerto Rico which is susceptible to low temperature stress. With such a cross, we generated a population with anticipated segregation for cold tolerance.

First, a replicated experiment was conducted to evaluate the parent plants for their tolerance to AOPP herbicide. Results showed that A12395, the cold-sensitive entry collected from Puerto Rico, exhibited significant susceptibility to the AOPP herbicide, compared to the cold-tolerant entry A12396 (Fig 1). After germinating the progenies, the first set of 30 progenies were subjected to herbicide application in a replicated experiment. Data showed a differential response to the herbicide as we hypothesized (Fig 2.). As of now, we have screened 60 of a total 120 germinated progenies from this population. The current plan is to continue screening, then select representative progenies that exhibit various levels of herbicide tolerance for a chilling stress experiment. The correlation of plants to the two stresses will then be evaluated, before planting the selected plants into the field in the spring of 2016.

The second experiment we conducted was to rule out the possibility that the herbicide tolerance could be due to differences in herbicide absorption and/or translocation. A ^{14}C-labeled fluazifop (Fusillade II) has been acquired from Syngenta, and a known cold-tolerant and a cold-susceptible bermudagrass have been selected to perform such an experiment (Fig 3). All experiments were carried out with 3 replications. The isotope-labeled experiment revealed that, between the cold-tolerant and cold-susceptible bermudagrass plants, there were no or minimal differences in AOPP herbicide absorption (Fig 4) and translocation (Fig 5). These results collectively suggest other mechanisms, such as metabolism, especially in the fatty acid biosynthesis pathway, might contribute to the observed differential responses, and possibly explains the observed correlation between bermudagrass plant's responses to cold and AOPP herbicide. Currently, lipid fatty acid profiling is ongoing, which could potentially shed light as to the possible mechanism.

The future plan for this study in 2016 is therefore, to conduct a field experiment regarding the segregation progenies, and continue the lipid fatty acid profiling experiments to search for a possible mechanism.

Summary:

- A segregation population, based on the cold tolerance, has been screened and shown anticipated responses to AOPP herbicide;
- An isotope-labeled experiment has ruled out the possibility that differential responses were due to herbicide absorption and/or transportation;
- Future experiments are ongoing to decipher the underlying mechanism, possibly related to lipid fatty acid biosynthesis.

Fig 1. Bermudagrass responses to AOPP herbicide Acclaim Extra® (a.i. fenoxaprop-ethyl), at 0, 11, 18, and 25 days after treatment application. The top four pictures are entry A12395, a cold-sensitive collection, and the bottom four pictures are entry A12396, a cold-tolerant selection. In each picture, the top four pots were plants that received herbicide application, and the pot at the bottom serves as a control without herbicide application.

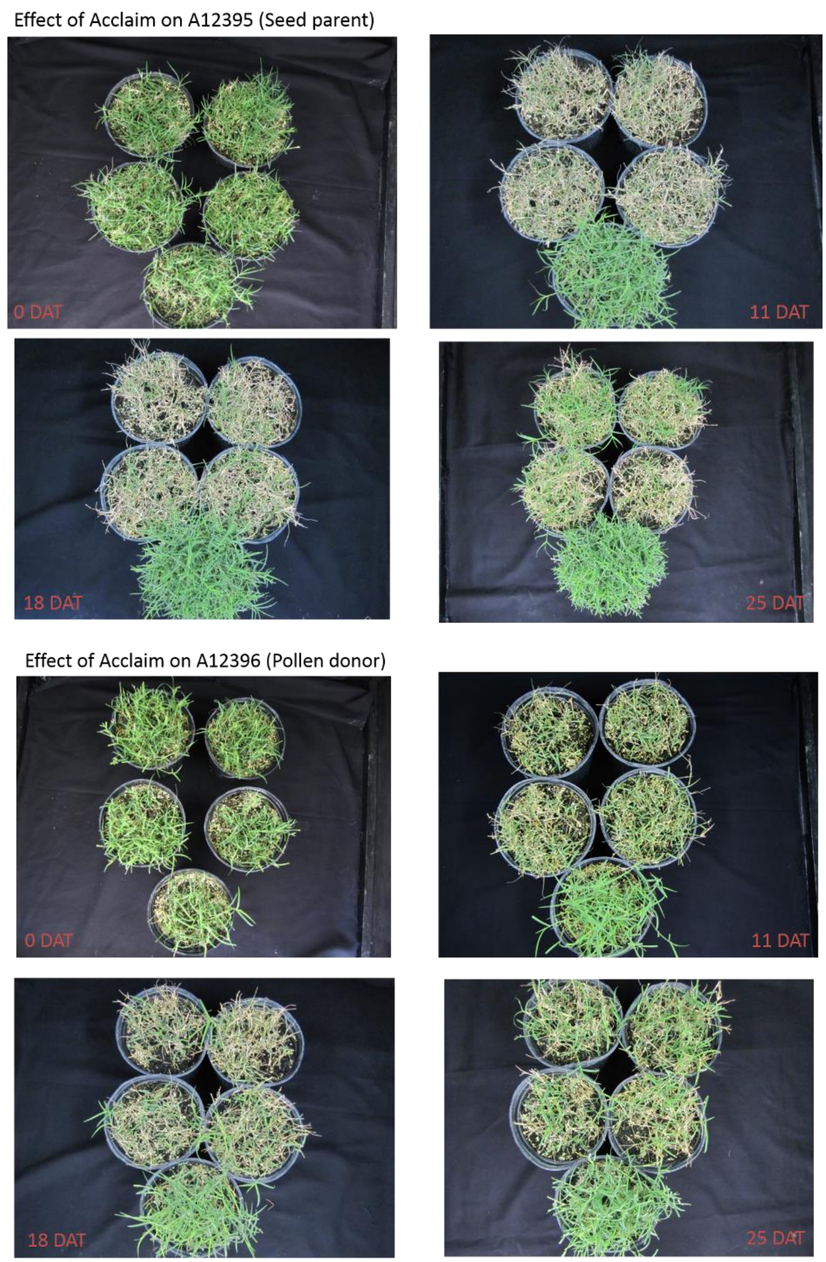


Fig 2. Representative images of progeny plants in response to Acclaim Extra® ((a.i. fenoxaprop-ethyl) application at 1 week after treatment.

Grasses resistance to Acclaim   Grasses susceptible to Acclaim

Fig 3. Bermudagrass plants prior to application of cold AOPP herbicide. Note the designated leaf that will be treated with isotope-labeled AOPP herbicide was carefully covered.

Fig 4. Isotope-labeled herbicide expressed as percent of applied (%) in leaf wash (LW), total absorbed and recovered from 'Celebration' and 'Riviera' bermudagrass (*C. dactylon*). Bars labeled with the same letter were not significantly different based on Fisher's Protected LSD at *P*<0.05.

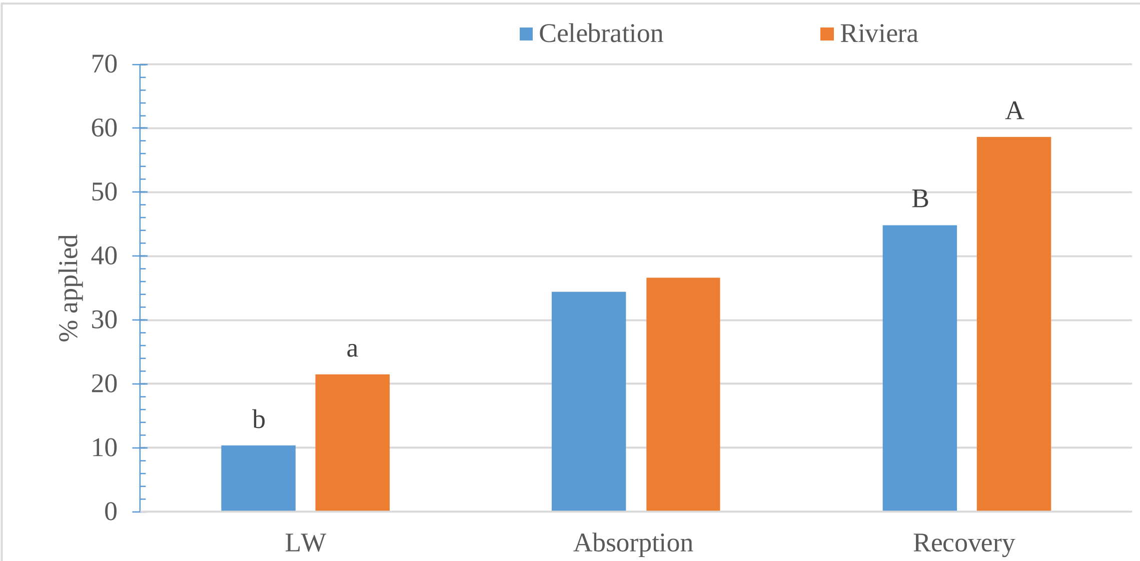
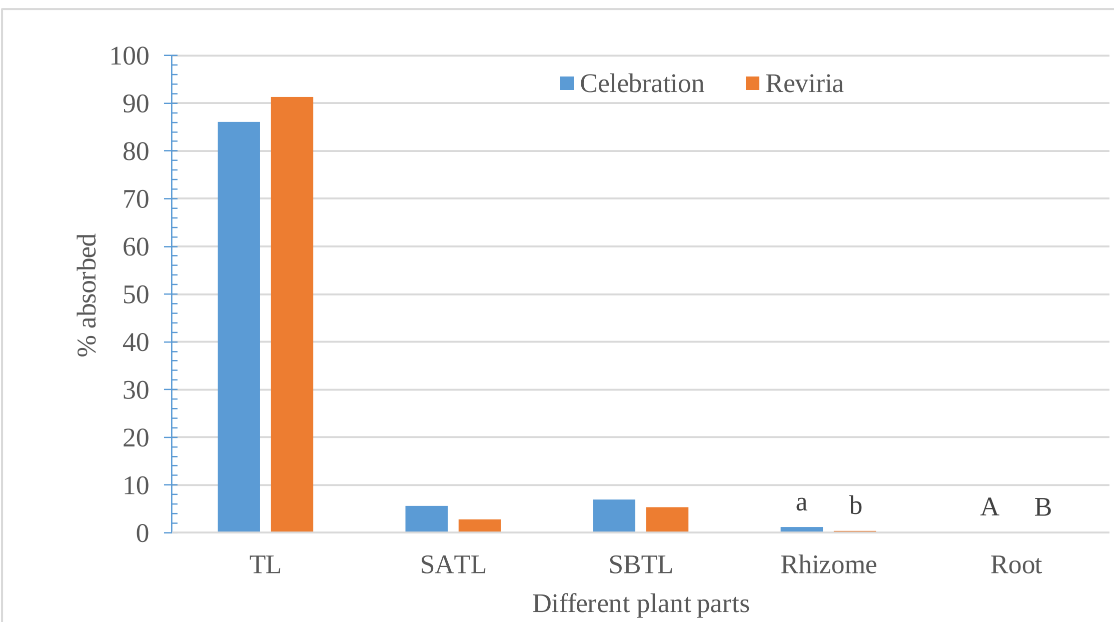


Fig 5. Isotope-labeled herbicide expressed as percent of applied (%) in treated leaf (TL), shoot above the treated leaf (SATL), shoot below the treated leaf (SBTL), rhizome and roots from 'Celebration' and 'Riviera' bermudagrass (*C. dactylon*). Bars labeled with the same letter were not significantly different based on Fisher's Protected LSD at *P*<0.05.



Year 4 Report
Cooperative Effort to Develop Fine-Textured and Cold Hardy Zoysiagrass Cultivars with Large Patch Tolerance for the Transition Zone – Texas A&M AgriLife-Research - Dallas Report

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

Objectives: The development of fine textured, cold hardy and large patch tolerant cultivars of zoysiagrass for the transition zone

Background: This project is an ongoing collaboration between Texas A&M AgriLife, Kansas State University (Jack Fry and Megan Kennelly) and Purdue University (Aaron Patton) funded by the USGA since 2012. As part of this project the A&M breeding team developed approximately 2,800 new hybrids in 2011/2012 by crossing selected parental lines exhibiting traits of interest. These hybrids were tested at three locations (Dallas, TX; Manhattan, KS and West Lafayette, IN) from 2012 to 2014 (2 yr. of winter recovery data). Based on the cold hardiness, texture ratings in comparison to 'Meyer' primarily, and initial testing for large patch tolerance at Dallas, we have selected the top 2% (60 hybrids) for advancement and further testing in the 2015 Zoysiagrass Cooperative Test currently underway at ten locations.

Start Date: January 2012
Project Duration: 6 years
Total Funding: $144,140

Summary Text –

Zoysiagrass is a warm season grass species that provides an excellent playing surface for the sport of golfing with the added benefits of low nutrient and pesticide requirements making it an ideal turfgrass species for use in the transition zone (Fry et al., 2008). 'Meyer' (*Z. japonica*) has been the cultivar of choice since its release in 1951 (Grau and Radko, 1951), in part because it has excellent freezing tolerance. However, Meyer is relatively slow to spread 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 AgriLife Research-Dallas and Kansas State University have worked together since 2004 to develop and evaluate zoysiagrasses with better turf quality than Meyer that are adapted to the transition zone. From this work, a number of advanced lines derived from paired crosses between *Z. matrella* and *Z. japonica*, have been identified with a level of hardiness equivalent to Meyer and 'Chisholm' (Okeyo et al., 2011), but with finer texture and better density than Meyer (e.g. – KSUZ 1201 entered in the 2013 NTEP; KSUZ 0802 recently released by Texas A&M AgriLife and KSU).

Large patch disease, caused by *Rhizoctonia solani* (AG 2-2 LP), continues to be the #1 pest problem on Meyer zoysiagrass fairways and tees in the transition zone (Kennelly et al, 2009). Most golf course superintendents treat with two applications of fungicide annually to limit damage from large patch. The best fungicides for suppressing this disease cost ~$350/acre. A course with 30 acres would then need to budget $21,000 annually to treat this disease alone. Incorporating large patch tolerance (LPT), along with cold hardiness and improved turf quality into new transition zone zoysiagrasses would reduce fungicide requirements and maintenance costs with the added bonus of increased sustainability.

We at Texas A&M AgriLife Research - Dallas have partnered with Drs. Jack Fry, Megan Kennelly from KSU, and Aaron Patton from Purdue University. These scientists have extensive experience with the test and evaluation of turfgrasses adapted to the transition zone for cold hardiness and disease susceptibility.

Phase III Testing (2015 to 2018): PI's at Purdue and KSU shipped their 20 selections to the Dallas Center in late August and early September of 2014 for propagation. Along with the 20 lines selected at Dallas, there were a total of 60 experimental entries. Plant materials were propagated to produce ten 18 cell trays for each line or 600 trays total for all entries across all locations. In 2015 replicated field trials were planted with the 60 advanced lines plus 5 standards/parental lines at seven diverse locations in the transition zone in addition to Manhattan, KS, West Lafayette, IN and Dallas, TX (Figure 1), making for a total of 10 test site locations (Table 1). The replicated field trial will span a three year period (2015 to 2018). There will be 65 x 3 reps = 195 plots (approx. 5' x 5' per plot) at each location. In addition advanced materials will be evaluated in disease nurseries at KSU, U. Arkansas and Purdue by inoculating with *Rhizoctonia solani* (AG 2-2 LP) isolates reared in the lab. Other testing will include using standard laboratory bioassays that will allow for measured comparative levels of LPT (KSU) and cold tolerance (KSU and Purdue) under controlled conditions.

Summary Points

- Phase I and II (2012 - 2014): Pairwise crosses were made between large patch tolerant germplasm and cold hardy zoysiagrasses adapted to the transition zone with the production of 2,858 progeny. Phase II: Spaced plant nurseries were planted late in 2012 and 2013 at three locations with a two year total of: 967 progeny at Manhattan, KS, 971 progeny at West Lafayette, IN, and 920 progeny at Dallas, TX in 2012. The nurseries were allowed to grow-in during 2013 and 2014. Selection of the top 20 lines from each location was made late in the growing season in 2014. Advanced lines were shipped to Dallas, TX for propagation.

- Phase III (2015 - 2018): Experimental lines and checks were propagated and plant materials distributed to 10 test locations. Plant materials were planted in replicated field trials (3 reps) with 5' x 5' plots. Data will be collected for a 3 year period (2015 to 2018). Cold hardiness, large patch tolerance and turf quality will be traits most critically scrutinized and prized.

Table 1. 2015 Zoysiagrass Cooperative Trial locations and cooperators.

Figure 1. Cold Hardy / Large Patch Tolerant Replicated Field Trial planted on 07/30/15 in Dallas, TX. Picture taken on 11/4/15.

References:

Fry, J.D., and P.H. Dernoeden. 1987. Growth of zoysiagrass from vegetative plugs in response to fertilizers. J. Am. Soc. Hortic. Sci. 112:286–289.

Fry, J., M. Kennelly, and R. St. John. 2008. Zoysiagrass: economic and environmental sense in the transition zone. Golf Course Management. May. p. 127-132.

Grau, F.V., and A.M. Radko. 1951. Meyer (Z-52) Zoysia. USGA J. Turf Manag. 4:30-31.

Kennelly, M., J. Fry, R. St. John, and D. Bremer. 2009. Cultural practices, environment, and pathogen biology: studies for improved management of large patch of zoysiagrass. In J.L. Nus (ed.) 2008 USGA Turfgrass and Environmental Research Summary. p. 20.

Okeyo, D., J. Fry, D. Bremer, C. Rajashekar, M. Kennelly, A. Chandra, D. Genovesi, and M. Engelke. 2011. Freezing tolerance and seasonal color of experimental zoysiagrasses. Crop Sci. 51:1-6

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.

Table 1. 2015 Zoysiagrass Cooperative Trial locations and cooperators.

10 Test Locations	Cooperator	Affiliation
Blacksburg, VA	Erik Ervin	Virginia Tech.
Chicago, IL	Ed Nangle	Chicago District Golf Association
Columbia, MO	Xi Xiong	U. Missouri
Dallas, TX	Dennis Genovesi and Ambika Chandra	Texas A&M AgriLife Research
Fayetteville, AR	Mike Richardson	U. Arkansas
Knoxville, TN	John Sorochan	U. Tennessee
Manhattan, KS	Jack Fry and Megan Kennelly	Kansas State
Raleigh, NC	Grady Miller	NC State
Stillwater, OK	Justin Moss	OK State
West Lafayette, IN	Aaron Patton	Purdue
Ancillary Locations for Large Patch		
Fayetteville, AR	Mike Richardson	U. Arkansas
Manhattan, KS	Megan Kennelly	Kansas State
West Lafayette, IN	Aaron Patton	Purdue

Figure 1. Cold Hardy / Large Patch Tolerant Replicated Field Trial planted on 07/30/15 in Dallas, TX. Picture taken on 11/04/15.

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

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

Objectives:

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

Start Date: 2014 (continued from 2010)
Project Duration: 3 years
Total Funding: $ 89,317

Summary Text –

Zoysiagrass (*Zoysia* spp.) is a warm season, perennial grass used on sports fields and home lawns that is increasing in popularity due the need for low inputs such as fertilizer, water and less frequent mowing. Most cultivars are vegetatively propagated by sprigging or solid sodding. Except for expensive solid sodding, other methods such as sprigging require a minimum of two years to establish and provide 90% cover (Patton et al, 2006). An alternative, relatively inexpensive, way is to propagate zoysiagrass is by seed. The cost for establishing one acre of fairway with a vegetative type zoysiagrass using sprigs is $3,000, strip sodding is $5,000 and solid sodding is $16,000 while the cost of establishment using seed is around $900 (Patton et al, 2006). Unfortunately the number of seeded varieties is limited with 'Zenith' being the most popular. This research projected is focused on the development of new and improved cultivars.

Optimizing seed yield and ease of harvest are important value added traits needed in the development of new seeded type zoysias. Diesburg (2000) reports that seed yields with zoysiagrass have been limited ranging from 100 to 600 pounds per acre as compared to yields for cool season grasses ranging from 700 to 1,600 pounds per acre. Stacking genes that maximize seed yield in the species while maintaining good turf quality is our target and is of utmost importance to the commercial success of newly released varieties**.** Our goal is to develop a multi-clone synthetic variety which exhibits a texture that is finer than Zenith and seed yields that meet the production goals needed to make it profitable to produce. One of our breeding objectives is to minimize inbreeding depression by selecting parental clones with a broad genetic base (different pedigrees) but with approximately the same flowering time in order to enable cross pollination and to create commercially viable synthetic populations.

Since the initiation of the project in 2010, our breeding strategy has been the utilization of the classical plant breeding method known as phenotypic recurrent selection. Recurrent selection is a strategy that has proven to be useful with corn breeding at Iowa State in the development of the Stiff Stalk Synthetic (Lamkey, 1992). The method focuses on population improvement by increasing the frequency of quantitative genes that influence seed yield in the breeding populations. The approach involves alternating between Spaced Plant Nurseries (SPN) and isolation crossing blocks. Selections are made from spaced plant nurseries for individuals with improved seed yield combined with fine leaf texture. Selected lines are entered into isolation crossing blocks for further recombination. This strategy should allow for the gradual increase over multiple generations of desirable alleles in the population.

In 2015 we began our third cycle of recurrent selection. Four isolation blocks were planted in 2013 and grouped based on seed head color and flowering date with (1) nine of the 32 classified as red seedhead /early flowering , (2) seven as red seedhead / late flowering, (3) nine green seed heads / early flowering and (4) seven lines with green seed heads / late flowering. Seed from these blocks were collected in mid-summer of 2014, cleaned during the winter and processed in early spring of 2015. Seed was scarified with 30% NaOH for 35 min. (Yeam, et. al. 1985). Scarified seed was germinated in potting mix in small rectangular pots first under mist then at ambient air. Once germinated, individual seedlings were moved to 50 cell trays where families of 60 were allowed to grow in. The 50 strongest seedlings from each family were planted in the field 7/23/15 to establish a Spaced Plant Nursery of 1,750 progeny with Zenith and Compadre as checks (Figure 1).

In addition, seed that had been harvested from three synthetics in the summer of 2014 (1) early flowering / red seed head, (2) late flowering / red head and (3) late flowering / green seed head were cleaned and scarified as before. The early flowering/red seedhead synthetic was not very productive and produced only 17.5g /54 sq. ft. The yield from the late flowering / red seed head synthetic (DALZ 1512) was much better and yielded 171g /54 sq. ft. (estimated 303.4 lbs./acre). The late flowering / green seed head synthetic (DALZ 1513) yielded 163 g /54 sq. ft. (estimated 289.3 lbs./acre). Seed from these three synthetics were used to plant a replicated field trial (RFT) 7/14/15 at the Research Center – Dallas at a rate of 2 lbs./1000 sq. ft. (Figure 2). In addition a second RFT was planted by Johnston Seeds 6/10/15 in Enid, OK. Seed from DALZ 1512 and DALZ 1513 were also transferred to Patten Seeds for evaluation.

Summary Points

1. The third cycle of recurrent selection was begun with the germination of seed harvested in 2014 from 4 isolation blocks planted in 2013. A spaced plant nursery consisting of 1,750 progeny were planted on 7/23/15. Advanced lines with finer leaf texture combined with high seed head density and good height of seed head exertion will be identified in the spring of 2017.
2. Along side the recurrent selection breeding strategy, three sets of 3 parent synthetics were identified for evaluation of a potential commercial product. Seed harvested in 2014 was treated and planted in replicated field trials on 7/14/15.

References:

Diesburg, K. L. 2000. Expanded germplasm collections set the stage for increased zoysiagrass breeding for turf use. Diversity 16(1):49-50.

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

Lamkey, K. R. 1992. Fifty years of recurrent selection in the Iowa stiff stalk synthetic maize population. Maydica 37(1): 19-28.

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.

Figure 1. Third cycle of recurrent selection spaced plant nursery planted 7/23/15 with 1,750 progeny.

Figure 2. Plot coverage 112 days after sowing/planting. A. DALZ 1512, B. DALZ 1513, C. Zenith seeded check and D. Zorro vegetative check.

Figure 1. Third cycle of recurrent selection. A spaced plant nursery planted on 7/23/15 with 1,750 progeny.

Figure 2. Plot coverage 112 days after sowing/planting. A. DALZ 1512, B. DALZ 1513, C. Zenith seeded check and D. Zorro vegetative check.

Project Title: Utilizing Molecular Technologies to Develop Zoysiagrass Cultivars with Improved Cold Tolerance
USGA ID#: 2015-03-518
Investigators: S.R. Milla-Lewis, Aaron Patton, and Brian Schwartz

Objectives: The overall objective of this project is to improve the efficiency of selecting for cold tolerance in zoysiagrass breeding by identifying genomic regions controlling this trait and associated molecular markers that can be used for selection. Phase I (year 1) of the project focused on evaluation of a mapping population for field winter survival at Laurel Springs, NC, and West Lafayette, IN. The second objective of Phase I is to genotype the population with DNA markers in order to generate a map of the zoysiagrass genome.

Progress Update and Results: A mapping population of 175 individuals derived from the cross of cold-tolerant 'Meyer' and cold-susceptible 'Victoria' has been developed. In June 2014, three replications of each single individual and nine controls including the two parents were planted in a randomized complete block design (RCBD) in 3 x 3 ft plots at the Upper Mountain Research Station in Laurel Springs, NC, and the William H. Daniel Turfgrass Research and Diagnostic Center in West Lafayette, IN. Additionally, the population was planted at the University of Georgia Coastal Experiment Station in Tifton, GA for quality evaluations. Digital imaging was used to evaluate establishment and winter injury (Figure 1). The progenies exhibited great variability for color, texture, and aggressiveness (Figure 2). Winter injury and survival was analyzed for winter 2014-2015. Under the more severe winters of West Lafayette, IN, the population had a 21% survival rate (Figure 3). At Laurel Springs, NC, greater variation was observed in response to winter injury, with 59% survival. Thirty-three genotypes including Meyer and Zenith suffered no winter injury in Laurel Springs (Table 1) while seven including Meyer, Zenith, and Chinese Common suffered no winter injury in West Layafette. No significant winter injury was observed in Tifton, GA. A wide range of trait expression within a population is integral to the identification of DNA markers, so the variability in winter survival seen in these progenies is promising for the identification of markers associated with cold tolerance in zoysiagrass. Marker data is being collected on the population and used to generate a linkage map of the zoysiagrass genome. Two hundred simple sequence repeat (SSR) primers have been screened across the parents, Meyer and Victoria. Of those, 125 were found to be polymorphic and are being amplified across the progeny (Figure 4). Additionally, library construction for the genotype by sequencing (GBS) protocol has been initiated in order to generate single nucleotide polymorphism (SNP) markers to increase map density.

Progress update and results:

- A mapping population of 175 individuals has been developed crossing cold-tolerant cultivar 'Meyer' and cold susceptible cultivar 'Victoria'.
- The mapping population was established in June 2014 in Laurel Springs, NC, West Lafayette, IN and Tifton, GA in 3'x3' plots in three replications in randomized complete block design (RCBD). Additionally, the population was replanted at these three locations in June 2015 for secondary evaluations during the 2015-2016 winter season.
- The mapping population was evaluated for winter injury and survival using digital image analysis in 2015. Survival rate of the population was 21% at West Lafayette, IN and 59% at Laurel Springs, NC. A total of 33 lines suffered no winter injury in Laurel Springs, NC. Seven lines suffered no winter injury in West Lafayette, IN. Only three genotypes, including Meyer, had no winter injury at both locations.
- Out of 200 markers screened, 125 have been found to be polymorphic between the parents and are being amplified in the progeny in order to generate a linkage map.

Table 1: Zoysiagrass lines that suffered no winter injury during the winter of 2014-2015 at the Upper Mountain Research Station (Laurel Springs, NC) and the William H. Daniel Turfgrass Research and Diagnostic Center (West Lafayette, IN). Lines that suffered no injury at either location are highlighted in red.

Laurel Springs, NC					West Lafayette, IN
11-TZ-4720	11-TZ-4753	11-TZ-4784	11-TZ-4826	11-TZ-4884	11-TZ-4720
11-TZ-4724	11-TZ-4757	11-TZ-4789	11-TZ-4836	11-TZ-4877	11-TZ-4755
11-TZ-4726	11-TZ-4758	11-TZ-4794	11-TZ-4837	11-TZ-4890	11-TZ-4778
11-TZ-4727	11-TZ-4768	11-TZ-4799	11-TZ-4840	Meyer	11-TZ-4842
11-TZ-4738	11-TZ-4779	11-TZ-4800	11-TZ-4843	Zenith	11-TZ-4877
11-TZ-4740	11-TZ-4781	11-TZ-4815	11-TZ-4851		Meyer
11-TZ-4745	11-TZ-4782	11-TZ-4819	11-TZ-4854		Chinese common

Figure 1: Digital image analysis is used to estimate percent cover by quantifying green pixels.

Figure 2: The mapping population showed variation in color, texture, turf quality, aggressiveness, and winter injury in the winter of 2014-2015.

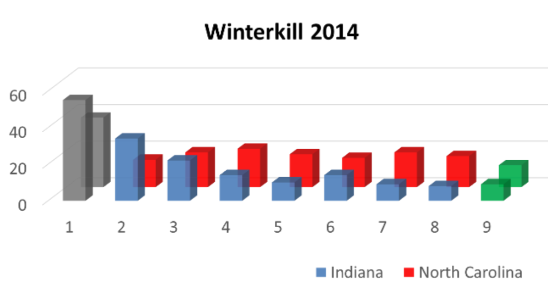


Figure 3: Distribution of winterkill for 175 progeny, Meyer, and Victoria at Laurel Springs, NC and West Lafayette, IN in 2014. Winterkill is a measure of winter injury on a scale of 1 (completely dead) to 9 (no winterkill). Bars in grey and green indicate where Victoria and Meyer, respectively, fell.

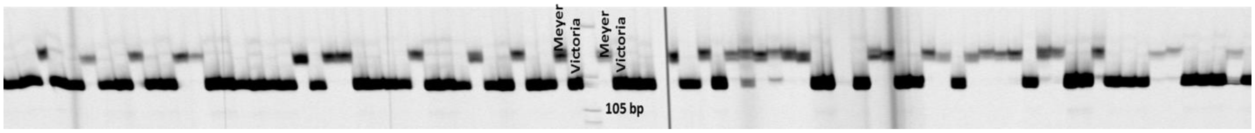


Figure 4: Polyacrylamide gel showing amplified products generated with SSR primer b02d15 across the Meyer x Victoria mapping population.

Buffalograss Breeding and Genetics

Keenan Amundsen

USGA ID#: 2003-36-278

1. Late spring applications of propiconazole effectively control false smut in seed production fields
2. Identified false smut and buffalograss decline resistant germplasm
3. Aerial robotics can quickly and easily document timing of winter dormancy

Buffalograss is often regarded as a model low-input turfgrass species, requiring less management inputs to maintain an acceptable quality level compared to most other commonly used turf species. Pesticide applications are not typically recommended for buffalograss unless stand loss is imminent, thus host resistance to pests is a primary objective of the buffalograss breeding program.

Buffalograss false smut, caused by *Porocercospora seminalis*, is primarily a cosmetic disease in managed turf but negatively impacts seed quality and production. The pathogen grows in place of a developing caryopsis reducing the number of viable caryopses per bur. Following greenhouse screens, and two years of field studies, the female experimental lines NE-BFG-11-3625, NE-BFG-5-3010, NE-BFG-7-3453-35, NE-BFG-7-3462-69 and NE-BFG-7-3464-5 were identified as having exceptional false smut resistance. Management studies were also conducted to evaluate application timing of three different fungicides for false smut control. Propiconazole (Banner Maxx), boscalid (Emerald), and pyraclostrobin (Insignia) were applied at high label rates in the first and third weeks of either May or June. At the end of the growing season, seed was harvested and 125 seeds were randomly selected and separated based on occurrence of disease. Banner Maxx applied in June provided 100% control of the disease giving needed tools for controlling buffalograss false smut in seed production fields (Figure 1).

Buffalograss decline has also been observed sporadically in managed buffalograss turf. Buffalograss affected by buffalograss decline do not break winter dormancy in the spring. Presumably these plants are compromised before the onset of winter dormancy and succumb to winter injury. Damage is similar to patch diseases in other species, but the causal pathogen has yet to be identified. In 2014, an older germplasm nursery exhibiting significant buffalograss decline symptoms was rated for visual quality. Variability for resistance to buffalograss decline was documented (Figure 2). The resistant line NE-BFG-2974 was identified suggesting host resistance is present in the germplasm collection (Figure 3). During the summer of 2015, a more exhaustive evaluation was performed and NE-BFG-03-098 was highly resistant to buffalograss decline and an additional 21 accessions were moderately resistant. In the absence of knowing the cause of buffalograss decline, host resistance will provide a means for mitigating the disease impact in future cultivars. Crossing blocks were established in 2015 to increase false smut, leaf spot, and buffalograss decline resistance in breeding stocks.

In addition to pest resistance, the buffalograss breeding program is focused on improving visual and functional quality, seed yield, canopy density, sod strength, and length of growing season. As an example, aerial robotics were used to document timing of spring green up and onset of winter dormancy in the fall (Figure 4). Data is being compared to visual quality ratings and weather data to develop a model predicting timing of dormancy which will then be used to quantify variation in growing season length. Selections were also made from approximately 6,000 segregating progeny for establishment rate, gender expression, stolon internode length, and canopy density. Together these data along with information on host resistance are expanding our knowledge and germplasm collections of buffalograss, providing valuable resources for cultivar development and improved management practices.

Figure 1. Number of false smut infected burs per 125 seed sample following fungicide applications. Error bars represent standard deviation among three replications.

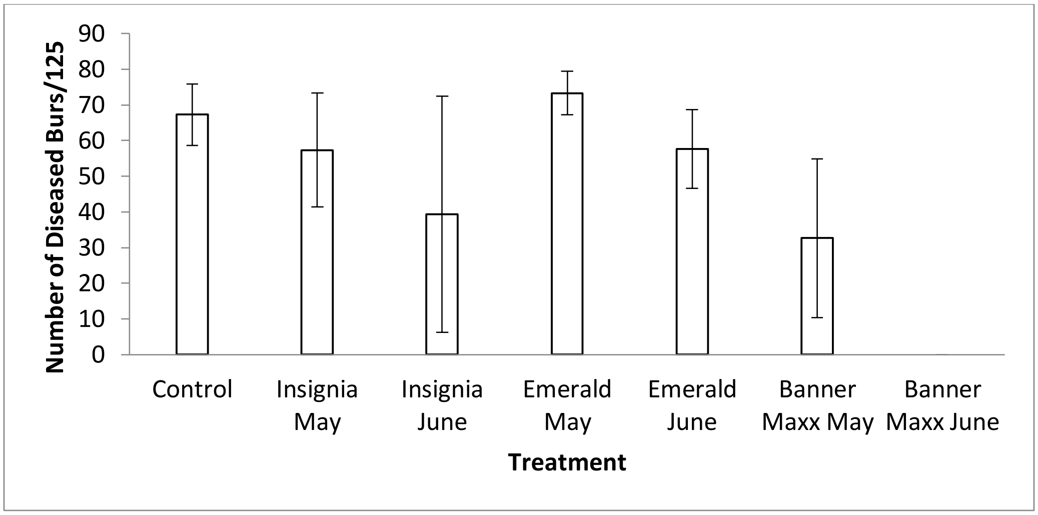


Figure 2. Experimental lines exhibiting buffalograss decline symptoms.

Figure 3. Mean visual quality ratings for host resistance to buffalograss decline.

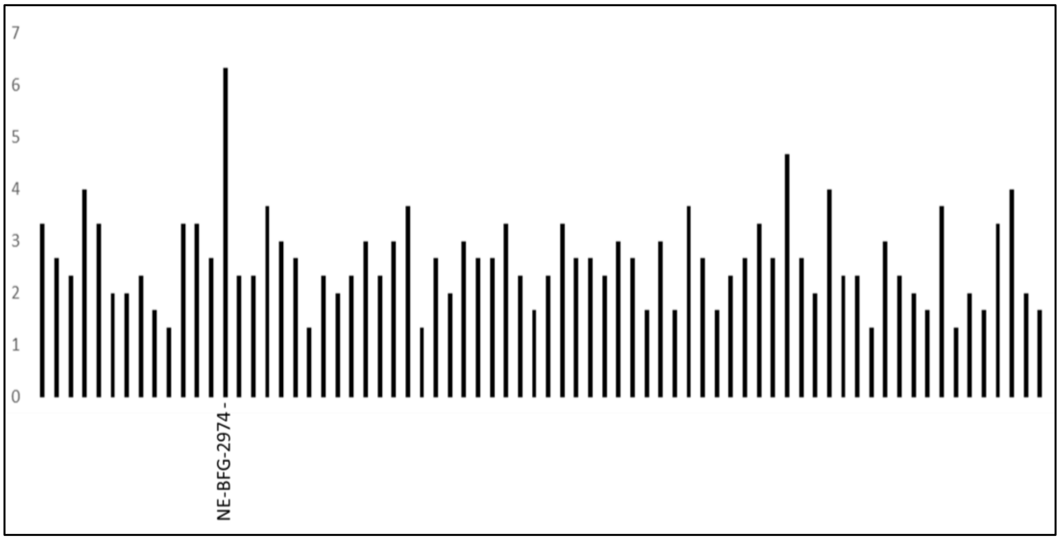


Figure 4. Variability of spring green up of experimental buffalograss accessions.

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: nine years
Total Funding: $90,000

Prairie junegrass (*Koeleria macrantha*) has shown the potential to be successfully used as a turfgrass in lower-input environments. The species is widely distributed throughout much of the western United States and can also be found throughout much of Europe and Asia. The species has several attributes that would make it a useful low-input turfgrass including drought tolerance, survival of low and high temperature extremes, and reduced vertical growth rate. We have evaluated material from our collection and material from the USDA National Plant Germplasm Resources Network (NPGS) and used those evaluations to assemble breeding nurseries.

Currently, there are a small number of cultivars that have been developed from germplasm collected in western and northern Europe; however, these cultivars are difficult to obtain and the seed quality is often not adequate. Germplasm from North America has greater seed production potential and resistance to important diseases, but does not possess acceptable turf quality. Most of this turf quality decline is due to shredded leaves from mowing and an early onset of summer dormancy during stress periods. Poor mowing quality is a challenging problem in this species, and one approach to improvement in this area may come from studying silica bodies.

Grasses have specialized silica cells that produce bodies that are distinguishable as silica bodies. Silica bodies can have many important physiological roles in plants such as decreased herbivory and stress tolerances such as decreased fungal colonization and salinity tolerance. These bodies could also be responsible for some of the differences we have observed in mowing quality between North American and European genotypes (Fig. 1). We have developed a method that combines dry-ashing, fluorescence microscopy and image processing for the high throughput quantification of silica bodies in *Koeleria macrantha* leaf tissues.

We examined 14 accessions and cultivars of prairie junegrass and found significant differences between accessions (Fig 2). We observed some accessions that have a significant difference in spatial silica body deposition as well as silica body number and the leaf area occupied by the silica bodies. These differences may be resulting in turf performance differences, but we have not yet conducted the experiments necessary to confirm this. Our method should be useful for quantification in other grass species as well as we have observed this technique useful in over 20 different species ranging from sedges and cereal grasses to cool-season and warm-season turfgrasses (Fig. 3). This method could be useful for plant breeders selecting grasses with better mowing quality and increased stress tolerance.

Summary Points:

- We have developed a new method for dry ashing and high-throughput image processing of silica bodies in turfgrasses
- We found significant differences in silica body number between accessions of prairie junegrass as well as significant differences in spatial deposition and the leaf blade area occupied by silica bodies
- Preliminary results suggest that higher silica body count is correlated with decreased mowing quality.
- Silica body imaging may lead to rapid screening of native grasses that can perform well under mowing.

Figure captions:

Figure 1. This image shows the silica body arrangement in leaves from *Koeleria macrantha* genotypes originating from Minnesota (bottom images) and Ireland (top images). The accession from Ireland has very good turf quality under low-input turfgrass management.

Figure 2. We found significant differences between prairie junegrass accessions and cultivars (Barkoel and Barleria) for mean number of silica bodies.

Figure 3. Images of silica bodies from other grass species. From left to right: teff (*Eragrostis tef*), Chewings fescue, blue hard fescue, perennial ryegrass, sheep fescue, and tall fescue.

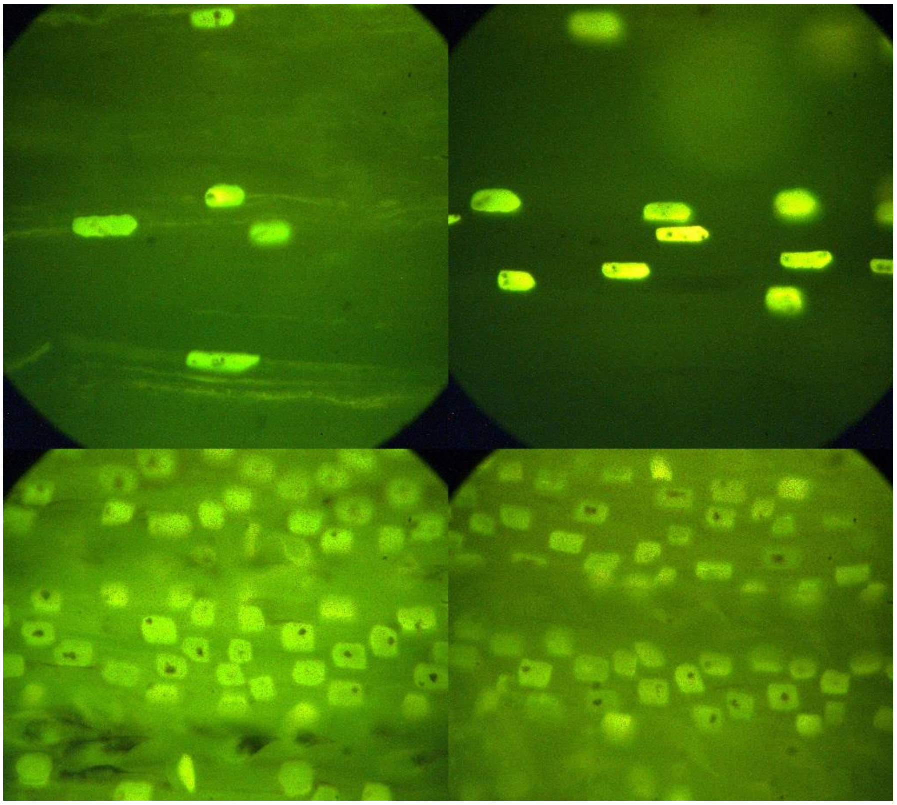


Figure 1. This image shows the silica body arrangement in leaves from Koeleria macrantha genotypes originating from Minnesota (bottom images) and Ireland (top images). The accession from Ireland has very good turf quality under low-input turfgrass management.

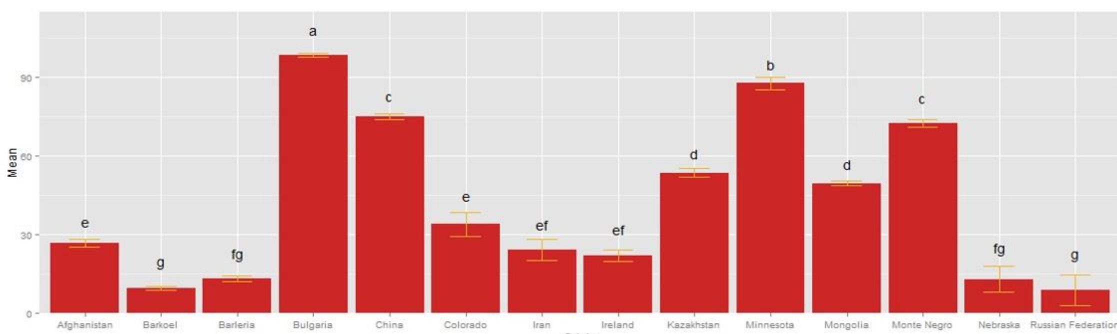


Figure 2. We found significant differences between prairie junegrass accessions and cultivars (Barkoel and Barleria) for mean number of silica bodies.

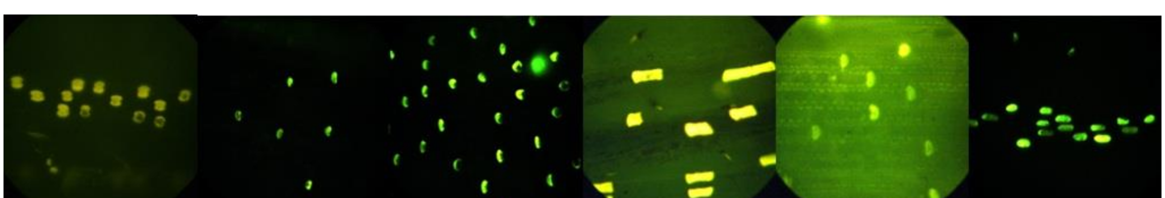


Figure 3. Images of silica bodies from other grass species. From left to right: teff (Eragrostis tef), Chewings fescue, blue hard fescue, perennial ryegrass, sheep fescue, and tall fescue.

APPENDIX C

Arizona Department of Agriculture
Specialty Crop Block Grant Program (SCBGP)
FFY 2015 Quarterly Report, Current to Sept 2015 :(Q1,Q2, Q3and Q4 current).
Grant Award Agreement #SCBGP-FB14-13

Project Title

Low Maintenance Grasses for Reduced Irrigation. D.M. Kopec et.al. University of Arizona.

Activities Performed

- ☐ Briefly describe the work accomplished during the reporting period. What specific tasks from the **Work Plan** of the approved project proposal were accomplished? Whenever possible, describe the work accomplished in both quantitative and qualitative terms, including any significant results, accomplishments, conclusions and recommendations resulting from the work completed during the reporting period. Be sure to include any favorable or unusual developments.

- ☐ Clearly describe the progress made towards achieving the **Expected Measurable Outcomes** identified in the approved project proposal. Include any baseline data developed through the project and any results from the implementation of the project's performance measures. Provide any survey results or research data developed during the period.

- ☐ If the project has the potential to benefit non-specialty crop commodities, describe the activities that were conducted to ensure that grant funds were used to solely enhance the competitiveness of specialty crops.

- ☐ If a target of a project has already been achieved, project staff is encouraged to amend the outcome measure in the performance report. This permits the project staff to "stretch" the goals in order to go beyond what they are already doing.

   a. First Quarter (Oct. 2014 – Dec. 2014) Activities:

Work Plan: Spring Year 1: Establish all grass species in linear irrigation gradient. Field preparation, establishment, and irrigation line source maintenance

In an effort to enhance the grass species early for enhanced root growth, the seven grass entries were initially planted in the last week of Sept of 2014. The field was previously sprayed with glyphosate to remove any existing vegetation, followed by light rototilling for seed bed preparation. All plots were marked with survey whiskers for permanent maintenance and identification. For each of the seven grass entries, seed was mixed in a small cement mixture with topdressing sand. Sand was then transferred to a drop spreader. From there the drop spreader applied the sand/seed mixture across the plots. There fixed volume of sand allowed for 5 full passes across the length of the plot. Immediately after that, each single plot was then lightly raked with an inverted bow rake, and then rolled with an 875 lb. 36 inch diameter Brouer roller.

Irrigation was applied for germination and emergence, using all perimeter heads and select gradient heads only, to provide uniform irrigation using a standard square-spacing design. The test was irrigated with 4 to 5 short irrigation cycles per day, with manual starts based on field surface moisture observations.

Grasses began to emerge within 7 to 8 days. The three Cynodon entries emerged first, along with Galleta grass. Grasses progressed for emergence. Two days of consecutive rain then occurred on October 8^{th} and 9^{th}, 2014.

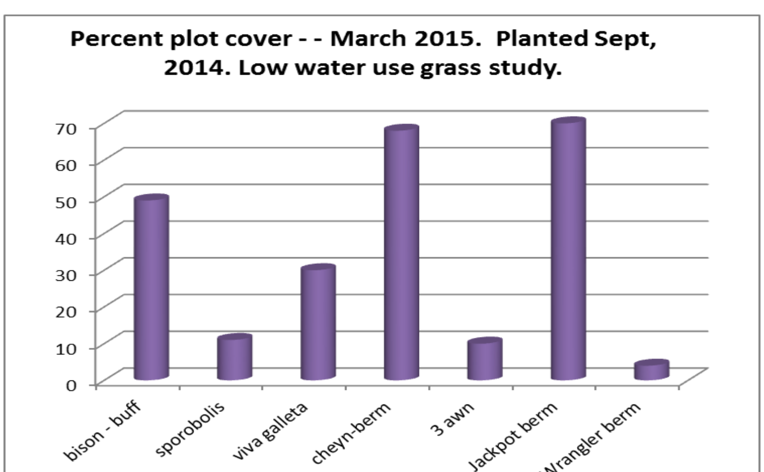
b. Second Quarter (Jan. 2015 – Mar. 2015) Activities:

Grasses emerged at different rates, and at different amounts. Surprisingly, young seedlings that survived the flooded condition in October 2014 increased in leaf width, tiller capacity, stolon capacity (where applicable) with the early return of warmer (somewhat spring like) daytime temperatures which began in late February and early March. Winter weeds were either removed physically or with a herbicide on 3 occasions this quarter, while the warm season grasses were winter dormant.

Data collected for percent ground cover showed that among the seven warm season grasses included, mean plot cover ranged from roughly 5% (Wrangler bermudagrass, to 70 percent for Jackpot bermudagrass. The other native grasses did not survive the previous flood in October.

A surprise here is that one of the bermudagrass entries (Wrangler) had very little ground cover (5%), while the other two bermudagrasses (Jackpot and Cheyenne had 65-70% ground cover. This will be investigated by conducting a lab germination to check on seed viability before this entry is reseeded. Also a positive surprise was that the Bison buffalograss had more grass cover than expected (from both seedling flood survival and late winter stolon growth). Viva galleta grass averaged 30 percent cover, and will be interseeded again, as will Sand dropseed (sporobolis), which has 10-15% cover.

The figure below shows the current main plot grass coverage as of the end of March 2015.

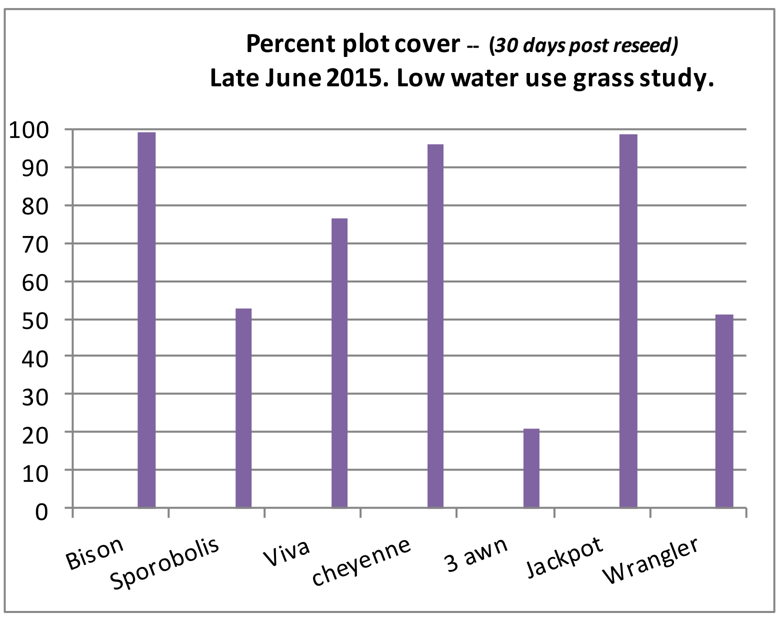


Grasses will be inter-seeded accordingly to increase density as soon as the night temperatures allow for a stable increase in soil temperatures (required for germination). This spring, soil will be prepped (prior to re-seeding) based on amount of existing vegetation and surface soil condition. These include the options of vertical mowing the soil surface, hydro-seeding, or slit seeding.

c. Third Quarter (Apr. 2015– June 2015) Activities:

- By mid-spring of 2015, grass entries had increased in ground cover, as three of the following entries had 90% or more cover within 4 weeks after green up. These three entries which would NOT need to be reseed included "Jackpot ", "Cheyenne II" and Bison buffalograss. "Wrangler" had 25-30% cover and was thus reseeded. The reaming three entries of Sand drop seed, Viva galletagrass and purple 3 awn all had less than satisfactory cover and also required reseeding as well.

  The figure below represents the percent ground cover of 7 low maintenance grasses at the third week of July, 2015, 30 days after hydroseeding 'Viva Galletagrass', 'Wrangler bermudagrass', 'Sand dropseed', and 'Purple 3 awn'.



All plots were mowed to 3 inches (7.6cm) during the second and third quarter to promote uniform coverage. Feral plants of bermudagrass were removed on several occasions by direct spay applications of glyphosate.

On June 4th, the four entries which had 50% or less ground cover were hydro-seeded at no charge by Desert Seeders Inc, with direct assistance from the P.I. The irrigation system was set for emergence of these grasses. Each day, plots were also hand watered as needed by observation to assure a wet surface moisture condition for the new seeds. The trial was under constant daily attention from June 4th afterwards, for daily irrigation needs. On June 15, it was noticed that the emerged seedlings of purple3 awn quickly to 2 inches, and then stopped. This was followed by die back from the leaf tips. Immediately plants were sampled for any seedling diseases, which proved not to be present. Immediately after that event, soil samples were taken for analysis. Samples were taken at the top1 inch (were the seedling crowns and initial roots are located) and for the entire 6 inch root zone. Soils test showed extremely high salts at the top inch level (2500 ppm TDS) along with a high sodium soil content (ESP of 23%). The salinity level proved too high for seedling germination and emergence for the newly hydro-sprigged entries.

The entire root zone profile (0-6 inches) of the plots which failed, is suitable for seedling emergence (500 ppm TDS) and a low sodium soil content (ESP = 6%). Since soil penetration at depth was easily accomplished across all plots, under irrigation was **not** the cause of salt build up at the soil surface. Instead, cumulative surface evaporation is most likely the cause of salt (and sodium) accumulation at the soil surface.

At this time, two action items are planned to establish 7 grasses in the trial.
First and foremost, the soil will be tilled to a depth of 8 inches to dilute the soil and sodium salinity levels that reside in the top inch. Flowers of sulfur will be added to that entire profile to reduce the overall soil ESP down to ‘0’, to eliminate any sodium hazard.

Secondly, four low maintenance grasses will be seeded (matching the two species which did not have problems at the initial fall seeding or the later spring hydro-seeding. These include low maintenance Cynodon cultivars and the low maintenance Buffalograsses.

Viva Galletagrass (which had the most cover of the grasses that needed to be reseed) may also be included, which is under deliberation.

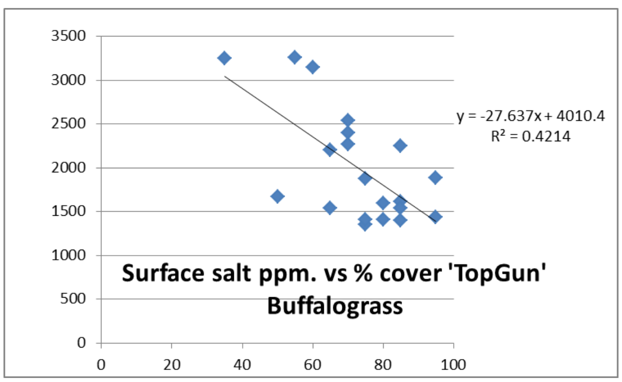
d. Fourth Quarter (July 2015 – Sept. 2015) Activities:

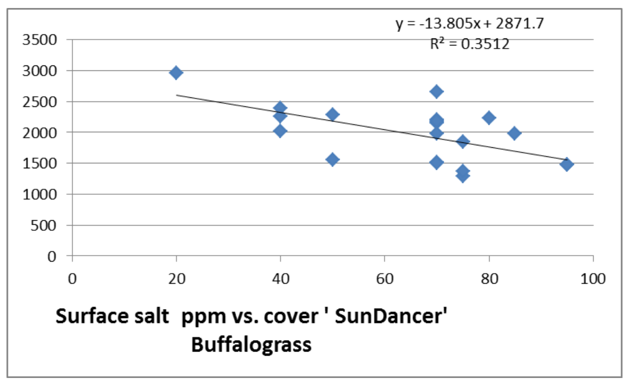
The fourth quarter included renovation/replacement of the treatment entries which did not re-establish well due to the salinity and sodicty as noted in Q3 above. These entries were replaced/renovated in all 4 of the field replicates. Viva Galleta and sand dropseed were removed with a herbicide in early July since these entries also did not tolerate the mechanics of mowing traffic. Purple three- awn was also removed due to uneven stand density across the plots. On all plots of these 3 entries, gypsum was applied on the renovated surface at the rate of 50 lbs. per 250 feet. Plots were then irrigated by hand twice daily to dissolve the gypsum. The entry replacements were then re-seeded were as follows; Sand dropseed was replaced by “TopGun” Buffalograss, Viva Galleta was replaced with “SunDancer” buffalograss, and purple three- awn was replaced with “Nu-Mex Sahara,” a large rhizome producing turf-type bermudagrass. Thus the test entries therefore stand as four (4) commercially available bermudagrass cultivars, and three (3) commercially available buffalograsses.

All seeding was done on August 3rd, 2015. Soil crusting occurred on the new buffalograss plots (which had slower emergence than Nu-Mex bermudagrass). On August 15th, these plots were soil drilled to depth of 16 inches with a 3/4inch masonry bit on a six in spacing to assist surface drainage which was related to surface crusting.

On August 19th, the thin areas within the recently planted buffalograss entries were reseeded by hand, and then top-dressed with ¼ inch of washed sand. Plots were irrigated by standard irrigation (heads) and by hand throughout the day when required. Only one field replicate of the Nu-Mex Sahara required partial re-seeding.

As some initial establishment differences were observable both within plots and between entries among the new buffalograss entries, surface salinity measurements were taken every 10 feet within the plots of SunDancer and TopGun. Salinity levels were determined using a 1:1 dilution of soil/distilled water, which were then correlated to percent grass cover. While the correlations are only moderate, TopGun bufflograss is slightly more salt tolerant than SunDancer in initial establishment as far as seedling salinity tolerance is concerned. SunDancer would provide 50% initial cover at 2100 ppm TDS, while TopGun would provide 50% initial ground cover at 2700 ppm TDS.





E. Fifth Quarter (Oct 2015 – Dec 2015) Activities:

After the replacement of 'Viva' Galletagrass, Purple 3 awn , and Sand drop (Sporobolus) seed during the summer, soil samples taken warranted the applications of gypsum at that time to reduce soil salinity and sodium levels (see 4th quarter report).

From June to December 2015 (5th quarter) the test received irrigation plus rainfall of 8.81 inches. To investigate the levels after the rains during the 5th quarter, soil samples were taken on eight plots which had the grass replaced (due too poor grass performance from high salinity and soil sodium (ESP) levels). These eight plots received gypsum in mid- June 2015. For comparison, eight other plots which did not have high salinity or sodicity (and thus did not require re-establishment or gyspum) were also selected for soil sampling in December 2015. Therefore,16 plots were sampled in December 2015.

Note (reported earlier) that salinity and sodicity were extreme at the soil surface, which diminished emergence and seedling survival of some of the original native grass stand early on in June 2015. The high levels of salt and soil sodium also resulted in slower emergence of the two buffalograss cultivars used for replacement in late August 2015 (reported earlier). In the previously noted cases, salinity and ESP in the surface soil (0-1 inch) was up to five times higher than that of the root zone profile at the same sampling location.

In December 2015, Within each of the sixteen plots, soils were sampled at the soil surface (0-1”), and for the root zone of 0-6 inches, each at distances of 20 and 40 feet from the Line source.

In “irrigation treatment mode”, the 40 foot distance would receive less water than the 20 foot distance. With less water applied at 40 feet, one would expect higher salinity and perhaps higher ESP because less leaching would occur with less than an optimal ET replacement, as opposed to the 20 foot distance, which receives a higher applied irrigation rate.

Lab results show that in all cases (for both gypsum amended vs. non gypsum amended plots) the surface salinity levels have decreased significantly compared to previous values. The salinity levels are now extremely low (0.54 to 1.4 dS/m = 350 ppm to 900 ppm) and fully suitable for unrestricted growth for both buffalograss and bermudagrass. (See Table 1 below).

Table 1. Soil Salinity (EC) and Exchangeable Sodium Percentage (ESP) of gypsum and non gypsum treated LIGA strip plots, December
Results show gyspsum treated plots now have similar soil salinity and ESP to plots which did not exhibit previous turf loss, and thus, did not require gyspsum.

		20 feet From Line Source				40 feet from Line source			
		Soil Depth				Soil Depth			
PLOT	Gypsum applied	(0-1 inch)	(0-6 inch)	(0-1 inch)	(0-6 inch)	(0-1 inch)	(0-6 inch)	(0-1 inch)	(0-6 inch)
		EC -salt		ESP- sodium		EC-salt		ESP-sodium	
3	YES	0.91	0.74	3.9	4	1.4	1.4	6.8	8.3
4	no	0.6	0.59	5.1	5.3	0.82	1.3	5.3	9.3
5	YES	0.67	0.68	2.6	4	0.84	1.2	2.7	5.9
6	no	0.59	0.52	4.7	4.7	0.72	1	4.5	7.2
8	YES	0.96	1.1	4.2	6.6	0.93	1.2	2.7	3.6
10	no	0.66	0.6	4.7	5.5	0.67	1.3	4.3	6.7
11	YES	0.68	0.6	2.4	3.3	0.75	0.88	1.8	5.1
12	no	0.59	0.48	3.9	4.1	0.69	0.73	3.8	6.7
15	no	0.61	0.52	4.2	4.5	0.61	0.6	4.3	5
16	YES	1	0.85	4	4.9	1.5	0.87	6.6	5.1
18	YES	1.2	1	3.4	4.7	1	0.91	3.8	5
20	no	0.54	0.47	4.7	4.8	0.57	0.64	5.3	6.7
22	YES	0.93	1	4.4	8.4	0.96	0.89	5.2	6.1
24	YES	1.6	1	8.9	5.9	0.91	0.72	4.3	4.7
25	no	0.58	0.57	4.9	5.6	0.59	0.86	4.8	8.5
27	no	0.64	0.58	5.2	5.6	1.1	0.73	4.6	5.9

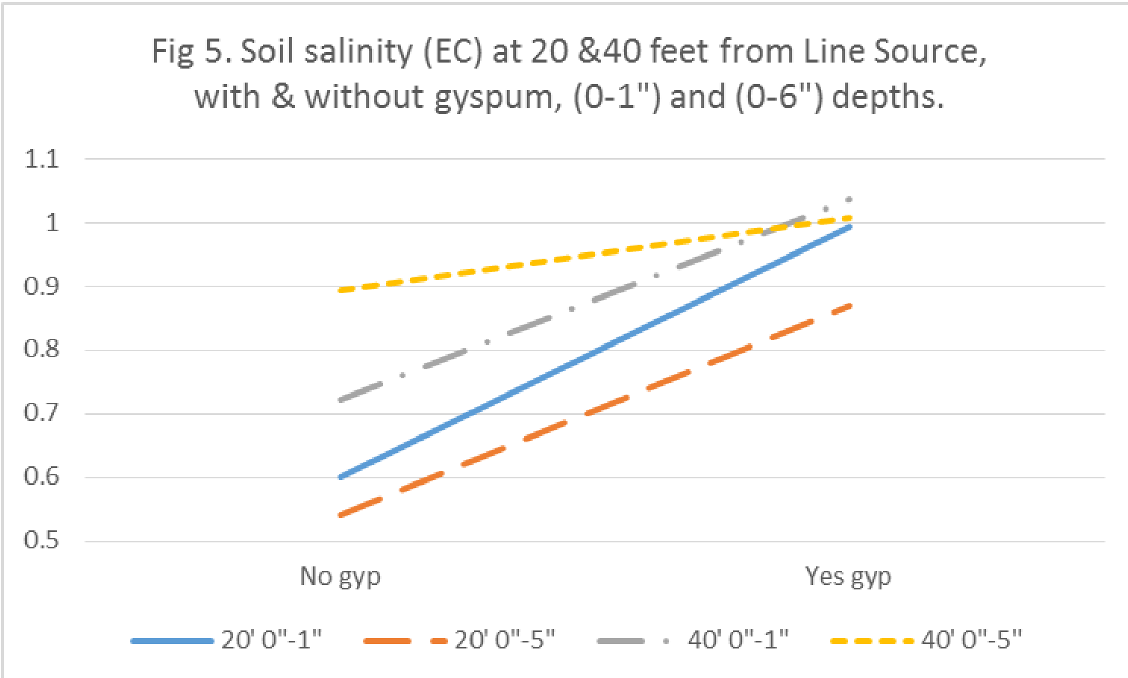
[1] Soil salinity measured as dS/m, 1:1 soil/water, Motzz Laboratories. 1 dS/m = 640 ppm TDS.

[2] Exchangeable sodium percentage (ESP). Percent of total soil cations which are sodium.

[3] Gypsum applied 3000 lbs. acre mid June 2015, to plots which had turf failure from high salinity and sodicity in spring 2015. . Additional an equal number of plots soil tested (n=8) which did not exhibit turfgrass failure = no gypsum applied.

Rainfall in inches: June (0.32), July (0.69), Aug (2.17), Sept (2.48), Oct (2.30), Nov (0.28), Dec (0.57). Total 7 months = 8.81 inches.

Likewise, salinity for the surface and root zone soil profile is also very low, (0.47 to 1.1 ds/m) (See Table 5 below).

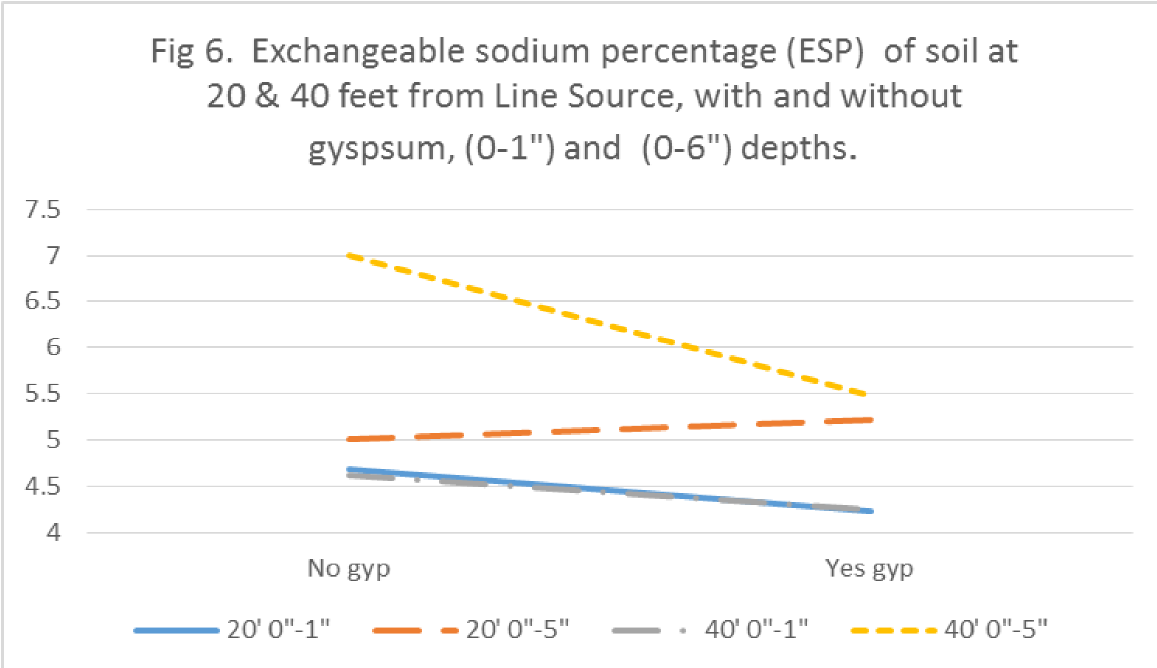


Of the samples collected in the December soil harvest, 51 of the 64 (79%) of the samples had salinity levels of less than 1.0 ds/m. Reclaimed waste water used for landscape and large turf areas from Tucson Water (used at the test site as well) averages 1.32 to 1.5 ds/m (same as 830- 960 ppm) or more. The soil salinity is now actually less than that of the reclaimed waste water, which demonstrates the benefits of natural rainfall in leaching soil salts.

Thus, the current soil conditions show a successful reclamation of surface soil salinity and sodicity. The applied gypsum has reduced the surface soil ESP to acceptable levels. Leaching has greatly reduced to salinity from the surface as well. Salinity for the 0-6 inch root zone is now very low as well.

As reported previously, plots which failed after the early July 2015 hydro-seeding were found to have surface salinity levels of 4.2 (moderate salinity), and extremely high ESP values of 25%. Comparing soil samples taken at the end of August, to those collected in December 2015 showed a reduction in ESP levels. For example, plot 22 (sand dropped seed, replaced with 'Topgun' Buffalograss) had an ESP of 26.7% in August, and an ESP of only 4.4% at the end of December 2015. Likewise, plot 16 (Viva Galleta, replanted to 'Sun Dancer' buffalograss) went from an ESP of 18.3% to 6.6%. Plot 3 (Viva Galleta, replanted to 'Sun Dancer') went from 15.4% to 6.8% ESP. The applied gypsum thus had sufficiently dissolved and successfully exchanged the soil sodium adequately

For the final December soil responses, soil ESP averaged 5.3% without gypsum, and 4.8% when gypsum was applied (when averaged across both soil sampling depths and location distance from the line source) (See FIG. 6 below).



Applied gypsum did not affect ESP levels at the 20 foot location for the overall root zone (0-6 inches), as the ESP was 5.0% and 5.2% for the non- treated and gypsum treated plots, respectively. At the 40 foot distance, the surface (0-1 inches) and root zone (0-6) soils had the same ESP values (4.4- 4.5%) whether gypsum was applied or not. More importantly, the gypsum had reduced the ESP on the plots that failed originally in the summer.

In review, all plots at all locations (distance from the source), at either soil depth, now have extremely low salt levels, of 1.0 ds/m, or less. Gypsum plus leaching (which was greatly assisted by rainfall of 8.81inches during the last seven months) has reclaimed the soil surface to manageable levels in terms of salinity and soil sodium (in plots that formerly had grass failure). Now the species at hand (bermudagrass and buffalograss) can be tested for response to differential amounts of applied water, avoiding the immediate confounding effects of soil salinity and sodium affected soils.

Problems and Delays

- ☐ Describe any unexpected delays, impediments, and challenges that have been confronted in order to complete the goals for the project such as changes or delays to the approved **Work Plan** activities and **Expected Measurable Outcomes**. Explain why these changes took place.

- ☐ Describe the corrective actions that were taken in order to address these delays, impediments, and challenges and to prevent their recurrence.

- ☐ If challenges occurred, review measurable outcomes to determine if targets are still realistic and attainable. An objective that is too stringent should be scaled back and identified in the performance report. Keep in mind that targets may slip due to all kinds of factors, such as employee turn-over and bad weather.

a. First Quarter (Oct. 2014 – Dec. 2014) Activities:

During the establishment phase, the two rain days of October 8th and 9th dropped 1.50 inches of rain. Even with the irrigation system off, this rain "sat" on the plots for 3 days after October 9th. After the surface drained several days later, visual assessment of the plots showed that emerged seedlings had become necrotic due to the standing water condition. The lack of oxygen for these young plants (many with just the cotyledon showing) killed the plant. This occurred more soon the native species of Buffalograss, Three-awn, Viva Galletagrass, and Sand Drop seed. The three Cynodon entries were the least effected, which subsequently proved to have a high level of emergence by the end of October.

Starting in the spring of 2015, the 4 native grasses will be replanted in full. Based on weather and the condition of the surviving bermudagrass, the native grasses may be irrigated by hand if necessary (hose/quick coupler) to avoid potential overwatering of the Cynodon plots.

Based on the immediate above note, it is hoped that establishment will be satisfactory to begin in the LIGA irrigation treatments by either early June (preferred) or late June (second choice), based on the new establishment growth of the 4 native grasses.

b. Second Quarter (Jan. 2015 – Mar. 2015) Activities:

Based on the noted existing groundcover percentages, entries will be re-seeded or interseeded once adequate soil temperatures are achieved. Existing seed inventory is adequate with the exception of purple -3- awn, which will be re-acquired. A laboratory seed germination will be conducted for Wrangler bermudagrass, which unexpectedly currently has a low groundcover status. Perhaps this line of bermudagrass was effected more so by the flood the previous October, than that of the other two bermudagrass entries.

c. Third Quarter (Apr. 2015– June 2015) Activities:

See Section above: 'Activities performed, Third quarter':
That section includes the description of the spring 2015 re-seeding of the four grass entries which suffered stand loss from the flood of October 2014, followed by the subsequent loss of seedlings after the June 4th 2015 reseeding. Loss in 2015 occurred from high salinity and high soil sodium content present in the top 1 inch soil layer. That section includes a description of the two step renovation process that will take place immediately this July to include soil amendments/deep soil cultivation, and the establishment of 4 new grass entries.

d. Fourth Quarter (July 2015 – Sept. 2015) Activities:

See section above: "Activities performed, Fourth Quarter':
That section describes the removal of grasses which either did not tolerate mechanical mowing, had unsatisfactory plot uniformity in terms of plot cover from salinity/sodicity, or both. Plots

have been treated with gypsum, leached, and replanted with one commercially available seeded bermudagrass, and two commercially available seeded buffalograsses.

e. Fifth Quarter (Oct 2015 – Dec 2015) Activities.

The previous section above addressed the activities taken to secure a test site which now (1) has 100% grass cover (2) is void of any confounding issues of soil salinity at both the surface and root zone profile, and (3) is void of any dispersed/unstable soil conditions caused by a high soil sodium content (high soil ESP). Both the physiological osmotic stress (salinity) and poor physical soil conditions (from sodicity) are no longer a problem. Therefore, turf responses to different irrigation levels will now be a plant based response. The methods and results performed to achieve this are included in the previous section.

Future Project Plans

☐ Briefly describe the work to be accomplished in the next reporting period. What specific tasks from the **Work Plan** of the approved project proposal will be accomplished? Make sure to include those activities that will be required to track and collect the data necessary to report on the **Expected Measurable Outcomes** from the approved project proposal.

☐ If the timeline of the approved project **Work Plan** has changed or is anticipated to change during the next reporting period, please provide an updated timeline for the remainder of the project.

☐ Describe any additional changes that are anticipated in the project in the future.

- When it is necessary to modify the **Project Purpose**, substantially change the **Expected Measurable Outcomes** and/or the proposed **Work Plan** deliverables of an award, you must submit a formal scope amendment request to the ADA. This must be submitted as a separate document.
- When it is necessary to make cumulative budget changes of 20% or more of the project's total budget, you must submit a formal budget change request to the ADA. This must be submitted as a separate document.

a. First Quarter (Oct. 2014 – Dec. 2014) Activities:

Time line has not changed per contract, only the effort to establish the plots at the end of the previous summer has resulted in partial success to date. Corrective actions within the normal planned activity period are noted in previous section.

•

b. Second Quarter (Jan. 2015 – Mar. 2015) Activities:

As noted above, all entries will be reseeded or interseeded to establish at least 95% cover or more.

Once re-established and capable of being mowed, the linear irrigation plots (perpendicular within and too the grass main plots) will be determined by measuring successive water delivery patterns from when the main linear irrigation line is in sole operation. This allows for identifying critical plot width and location (as a % of line source water replacement).

The success of replanting and emergence will determine exactly when the Irrigation treatments are first implemented. Ideally, this would take place by June 1, which would allow for a full months of grass observation and measurements, before the (unpredictable) monsoon.

c. Third Quarter (Apr. 2015– June 2015) Activities:

Activities:

The grass failure of four of the grass entries mandates that starting in early July 2015, that the soil condition of high salinity and sodicity at the soil surface be remediated by deep rototilling, which will dilute the immediate surface salinity and sodium levels to acceptable levels (similar to the entire root zone profile of 0-6 inches). This involves the activities of (1) removing any remaining exiting vegetation with glyphosate, (2) roto-tilling to a depth of 6 inches, (3) including elemental sulfur for the entire 6 inch root zone to reduce the ESP level to nil ‘0’ and (4) establishing the additional 4 low maintenance grasses.

Work Plan - Updated time line:

Soil remediation and another establishment will delay the employment of the Irrigation treatment phase, due to the grass establishment. When new plots have reached 95% or more groundcover, with an established root zone of 4-6 inches, the Linear Irrigation treatments will begin. The current loss of data time is now one month. It is hoped that by mid-August, that full data collection will begin. Data will be taken into the fall before cooler night temperatures cause a pronounced cessation of growth.

d. Fourth Quarter (July 2015 – Sept. 2015) Activities:
For Oct. Nov, December 2015, soil samples will be taken for ESP and salinity. Based on results, gypsum will be applied if ESP values require it, and leaching will take place if soil salinity requires it. This winter is predicted to be an El Nino season, which will greatly assist in leaching (if required). Bermudagrass stolon contaminants continue to be removed mechanically from any bufflalograss plot entries.

e. Fifth Quarter (Oct 2015 – Dec 2015). Activities:

During the 6th quarter (January, February, March), the test site will be managed for (1) eradication of any bermudagrass contaminants (2) maintenance of plot integrity (3) a proper mowing frequency to promote maximum shoot density and (4) weed control, as necessary.

During the 6th quarter, the linear irrigation plots will be delineated and defined as the percent of ET replacement value from the line source to the outer plot edge. This will be accomplished by placing catch cans in successive equidistant locations across the entire plot. The irrigation (collection) values are then plotted as a function of distance from line source. These absolute values are then divided by the application rate at the line source itself, to provide the percentage of replacement water realized as function of distance from the line source. This is essentially the calibration of the LIGA system itself. Calibration is required to delineate and establish the irrigation treatments across the plots in gradient fashion, and also to define the levels of applied irrigation themselves. From there, plant responses will be recorded once only the main line source is in operation.

Funding Expended To Date

- ☐ Provide the actual dollar amount or percentage of grant funds expended on the project from the beginning of the project to the end of the reporting period covered by this report, regardless of whether expenses have been reimbursed by the ADA.

- ☐ If less than 1/2 of the project funds were expended in the first half of the total project period, please verify if you anticipate expending the remaining funds on approved project activities and budgeted expenditures by the end date of the grant. Please also describe your plans to ensure that the funds are expended in a timely manner.

- ☐ The progress to date should coincide with the level of funds expended. If problems or delays have occurred, these should be described in the **Problems and Delays** section along with any corrective actions taken.

- ☐ If your original grant proposal included matching funds, provide information regarding the level of matching funds expended to date.
- ☐ In the event that a project generated income because of planned activities, report the amount of this additional funding and describe how it has been or will be reinvested into the project to solely enhance the competitiveness of specialty crops.

a. First Quarter (Oct. 2014 – Dec. 2014) Activities:
Expenditures: Expenditures were not posted in the first quarter (Oct, Nov, Dec 201) by the UA system, but appear as part of the accumulated total for the second quarter (Jan,Feb, Mar, 2015).

Indirect Cost share (matching funds) for first quarter (Oct, Nov, Dec 2015) = $0

b. Second Quarter (Jan. 2015 – Mar. 2015) Activities:

Expenditures Second quarter (Jan, Feb, Mar, 2015) = ($11,139)($4,711)($4,590), respectively.
Expenditures for technical salary, Jeff Gilbert. Note January ($11,139) includes charges from first quarter accounting period.

Indirect cost share (matching funds) : Second quarter :Q2 (1/1/15 – 3/31/15) =$13,026.50. Note this value includes the cost share not posted from first (previous) quarter.

c. Third Quarter (Apr. 2015– June 2015) Activities:

Expenditures this quarter:
April (3,443), May (1,213), June (not reported yet).
Cumulative expenditures to date.
($11,139)($4,711)($4,590), ($3443) = $23, 883
Expenditures for Jeff Gilbert, Technician.

Indirect Cost (cost share) this quarter:
Mar, Apr, $6,542.75. June not yet reported.
Cumulative indirect cost share to date.
$13,026.50. + $6,542.75 = $19569.25

d. Fourth Quarter (July 2015 – Sept. 2015) Activities:
Expenditures for this (4^{th}) quarter:
Salary, J. Gilbert Technician for fourth quarter = $3031
(July, Aug, Sept 2015 = $743, $1144, $1144 = $3031).
Cumulative expenditures to date: J. Gilbert.
($11,139)($4,711)($4,590), ($3443) (Q4 $3031)

Expenses for student labor fourth quarter. July, Aug, Sept, 2015.
($749, $1019, $629 =$ 2397) Cumulative student labor = $2397.

Non-salary expenses for fourth quarter, plot maintenance/irrigation repair. $607.04

Indirect Cost (cost share July, Aug, Sept 2015) this quarter was $3556.
$13,026.50. + $6,542.75 + $3556

e. Fifth Quarter (Oct 2015 – Dec. 2015) Activities:
Expenditures for this (5^{th}) quarter.
Salary, J. Gilbert. Technician for fourth quarter =
(Oct, Nov, Dec = (2,546 ,1,974,1,974) =$ 6494

Cumulative salary to date.
J Gilbert.= ($11,139)($4,711)($4,590), ($3443) (Q4 $3031) ($6494) = ($33,408)

Expenses for student labor (Oct, Nov, Dec 2015 = $1421)
Cumulative student labor to date, student.
($2397) + ($1421) = $3818

Non-salary expenses for fifth quarter = none (0).

Indirect Cost- Cost share (Oct, $358.30, Nov $358.30, Dec 358.30) = $1074.90

2015 Annual Report on USGA Grant

Grant Title: Evaluation, Selection and Production of Turf-Type Bahiagrass

Principal Investigators: Kevin Kenworthy, Ken Quesenberry, Bryan Unruh, Ann Blount, Fredy Altpeter, and Esteban Rios

Grant Objectives:
1) Continue to evaluate the bahiagrass genotypes at three locations in Florida for their phenotypic value [turfgrass performance].
2) Evaluate the mutagenic genotypes for their mode of reproduction and seed production characteristics.
3) Evaluate the potential to establish bahiagrass by sprigs.

Research Progress (500 word summary):

Phenotypic Value Evaluations – In addition to the 10 superior lines identified in 2014 and propagated as described for further testing, in summer 2015 we identified 10 additional lines based on maintenance of color and lack of wilting during a drought event. These lines will be propagated in fall-winter 2015-16 and an additional larger plot evaluation experiment will be planted. The original UF experimental turf-type bahiagrass experiment has now been terminated.

Selection & Testing of Superior Lines – The ten superior lines identified in 2014 were vegetatively propagated along with the two parental lines and planted at two locations: Experiment 1 PSREU, Citra FL, planted September 2014 (10 x 10 ft. plot), and Experiment 2 Jay, FL planted April 2015 (10 x 10 ft. plots). Data collected on these plots includes rate of grow-in and cover, turf quality, and other phenotypic value attributes (Table 1a, 1b). We are currently developing plans to harvest sod from the PSREU site and use it for a field sprigging experiment on a sod grower cooperator farm in summer 2016 (this will be the third location projected in our proposal) as well as to evaluate sod lifting quality and sod installation success of the lifted sod.

The same 10 lines were planted Experiment 2 in 4 x 4 ft. plots in a shade house under 60% shade cloth at PSREU, Citra, FL. These shade plots have been evaluated for rate of cover and turf quality (Table 2).

In addition to these plots, 36 ramets of each of the selected lines were shipped to Albany, OR, under a materials transfer agreement to obtain seed production data on these lines under a long day, low humidity growing environment in the Willamette Valley seed production area of Oregon. Data on flowering and seed production of these lines is presented in Table 3.

Evaluation of M2 Progeny – Between 20 and 44 M2 progeny from 7 of the 10 selected lines plus the Argentine and Wilmington parents were transplanted to the field at PSREU on 3 September 2014 to evaluate uniformity/ segregation (apomictic reproduction vs any possible sexual progeny) under field conditions in 2015. No off-type plants were observed in any progeny indicating a high level of apomictic reproduction in these selections.

Digging and Planting Sprigs – A repeat of the preliminary greenhouse sprigging experiment described in our 2014 report was conducted in 2015. Sod pieces were dug from the original field experiment, chopped apart into 1 to 2 inch stolon pieces and planted in flats in USGA-spec sand. Results from 2015 varied from the first experiment with some of the better lines in 2014 being among those with lowest emergence in 2015 (Table 4). We are hopeful that attempts at sprigging in the field will resolve these genotype x year interactions found in the greenhouse experiment.

Summary Points

1. A group of 10 superior selections of turf type bahiagrass was identified, vegetatively propagated and planted in larger plots to fully characterize these genotypes for turf potential. A second group of 10 lines were identified in late spring 2015 based on improved drought stress response.
2. The 10 initial genotypes have been evaluated for their ability to regenerate from stolon sprig pieces in two greenhouse experiments. Results from two studies have not been consistent. Follow-up field “sprigging” experiments are planned for 2016.
3. The 10 initial genotypes were planted in Oregon and preliminary flowering data was obtained in summer/fall 2015 with more complete results expected in 2016.
4. The field experiment of larger plots of the 10 initial selections was featured as a tour stop at the 2015 North Florida Turfgrass Field Day (October 7) and were viewed by approximately 175 attendees with signage indicating USGA grant support of this research.
5. The performance of the 10 lines under 60% shade after one year is not acceptable. Only two or three of the lines show any potential for minimal cover under 60% shade.

Table 1a. Percentage Cover, Turf Quality, and Turf Color of Selected Turf Type Bahiagrass Lines Grown in Full Sun at PSREU, Near Gainesville, FL

	24-Mar-15		25-Jun-15	25-Aug-15		22-Sep-15	14-Oct-15	1-Dec-15
Entry	% cover	Spring Color	% cover	% cover	Turf Quality	Turf Quality	Turf Quality	Turf Quality
M27	65	5.5	80	85	5.5	5.5	5.0	6.5
3 Fpen 8	70	7.0	90	93	6.0	6.0	6.0	8.0
M36	40	5.0	45	55	5.0	5.0	4.0	4.5
W Con 1	45	8.0	70	85	6.5	5.5	5.5	5.5
3 Fpen 7	55	3.5	75	85	6.0	6.5	6.5	7.0
WXR02	45	7.5	75	88	7.0	7.0	6.0	7.0
WEMS 18	55	7.5	70	78	6.0	6.0	5.0	5.5
Fldw5-1	55	4.0	65	80	6.0	6.0	6.0	6.5
M98Alt	65	6.0	80	88	5.5	5.5	6.0	7.0
Argentine	40	6.0	60	73	5.0	4.5	4.5	5.0
WEMS12	35	7.5	50	73	6.5	6.0	5.0	5.0
MidRoad3	50	9.0	70	88	6.5	6.0	5.5	7.0

Table 1b. Percentage Cover and Turf Color of Selected Turf Type Bahiagrass Lines Grown in Full Sun at WFREC, Jay FL							
Entry	Cover 25 Aug 15	Cover 30 Sep 15	Cover 30 Oct 15		Color 25 Aug 15	Color 30 Sep 15	Color 30 Oct 15
M98 ALT	85	95	100		6.5	6.5	5.5
Argentine	75	85	95		6.0	7.0	6.5
3FPEN7	75	90	100		7.5	8.0	7.5
3FPEN8	85	95	100		8.0	8.0	7.5
FLDW5-1	80	90	90		6.5	6.5	6.5
M36	80	85	90		8.0	8.0	7.0
WEMS12	65	80	85		9.0	9.0	8.5
MR3	65	75	80		8.0	8.0	8.5
WEMS18	75	85	80		8.5	8.0	8.0
M27	90	95	95		7.0	7.0	6.5
WXR02	70	90	95		8.5	8.0	7.5
WCON1	80	90	95		8.5	8.5	8.0

Table 2. Percentage Cover and Turf Color of Selected Turf Type Bahiagrasses Grown Under 60% Shade at PSREU near Gainesville, FL					
Entry	Cover 24 Mar 15	Cover 25 Jun 15	Cover 10 Oct 15	Cover 1 Dec 15	Color 24 Mar 15
3FPen7	20	40	70	65	8.5
3FPen8	40	60	35	30	8.5
Fldw5-1	15	25	30	25	8.5
M27	45	55	30	45	9.0
M36	30	55	30	40	5.0
M98Alt	40	60	60	60	9.0
WEMS12	30	30	10	5	9.0
WEMS18	25	35	15	25	8.5
WXR02	30	40	30	40	9.0
MR3	25	45	15	20	9.0
Argentine	30	45	40	35	6.0
WCon1	30	50	20	25	9.0

Table 3. Flowering of Selected Turf Type Bahiagrasses in Oregon, Summer 2015	
Entry	% Flowering
M27	90
3FPen8	100
M36	40
WCon1	87
3FPen7	97
WXR02	90
WEMS18	87
Fldw5-1	97
M98Alt	7
Argentine	0
WEMS12	10
MR3	90

Table 4. Number of shoots produced from stolon sprig pieces of selected turf type bahiagrasses in two GH experiments		
Entry	No. shoots Exp 1	No. shoots Exp 2
FLDW5-1	15.8	3.3
3FPen8	15.3	2.0
M27	15.0	3.0
M36	13.5	5.5
WCon1	12.	5.8
M98Alt	9.8	2.8
Argentine	9.8	1.8
MR3	9.3	3.8
3FPen7	9.0	8.8
WXR02	8.8	5.3
WEMS18	5.3	10.0
WEMS12	3.3	5.3

Development of Large Patch Resistant and Cold Hardy Zoysiagrass Cultivars for the Transition Zone

2015 Update

Investigators: Jack Fry, Megan Kennelly, and Mingying Xiang

Objective: Phase III (year 3-6) of the evaluation process is focused on field testing in the form of replicated spaced plant nurseries comprised of the newly generated progeny population. The objective of Phase III field test is the selection of experimental lines that have comparable/superior cold tolerance to Meyer, fine texture, and large patch tolerance.

Update on Progress:

This was the first year of field evaluation for 60 zoysiagrass experimental lines after they were selected from 985 zoysiagrass progeny which were developed at Texas A&M AgriLife Research in Dallas, Texas by crossing 22 cold-hardy zoysiagrasses with TAES 5645. These progeny have also demonstrated some resistance to large patch in growth chamber studies.

In September 2014, twenty top-performing progeny were selected from the Manhattan location and sent back to Texas A&M AgriLife Research, Dallas for vegetative (clonal) propagation. Twenty additional selections were identified at each of the other two evaluation sites (West Lafayette, IN and Dallas, TX) and propagated in Dallas. In June 2015, all 60 progeny, plus controls (Meyer, El Toro, Chisholm, Zorro, Zeon), were shipped from Dallas, TX and planted in 6 by 6 ft. plots. The plots are maintained under golf course fairway/tee conditions in Manhattan. These progeny have also been planted in West Lafayette, IN; Dallas, TX; Blacksburg, VA; Chicago, IL; Columbia, MO; Fayetteville, AR; Knoxville, TN; Raleigh, NC; and Stillwater, OK. Growth vigor was rated on a 1-9 scale with 9 equaling maximum vigor. In 2016, after plots are fully established, one-half of each plot will be inoculated with the large patch fungus; a similar inoculation will be done in West Lafayette, IN, and Fayetteville AR. The other aforementioned sites will evaluate zoysiagrass progeny for quality characteristics and large patch resistance based upon natural infestations.

Summary highlights:

- Over 900 unique zoysiagrass progeny from Texas A&M AgriLife Research-Dallas, each arising from a cross between a large-patch resistant parent and cold-hardy parent, were planted as single plugs in Manhattan, KS in 2012 and 2013.
- Grasses were evaluated for winter survival, color, texture, and quality in 2013 and 2014.
- In September 2014, 20 of the highest rated progeny were selected and sent to Texas A&M AgriLife Research, Dallas for propagation; 20 progeny were also selected in Indiana and Texas and propagated in Dallas.
- In 2015, the compiled 60 progeny were expanded into larger plots with three replications, maintained under golf course fairway conditions.
- In 2016, after the plots are full established, each plot will be inoculated with the fungus causing *Rhizoctonia* large patch to evaluate potential for resistance. Data will be collected on turf quality, fall/winter color retention, spring green-up, percentage winter injury, leaf texture, genetic color, and pest problems.

Fig. 1. Zoysiagrass plugs were planted on 22 July 2015 in Manhattan, KS.

Fig. 2. Part of the zoysiagrass study area at the Rocky Ford Turfgrass Research Center on Nov. 3 2015 in Manhattan KS, two weeks after the first frost.

Establishment of a Standard Screening Method for Drought Tolerance in Creeping Bentgrass

Principal Investigator(s): Dr. Qi (Chee) Zhang
University: North Dakota State University

The goal of this project is to determine the reliability of selecting drought-tolerant creeping bentgrass in a polyethylene glycol (PEG) - hydroponic culture based on root characteristics. It includes two specific objectives:

(1) Evaluating drought tolerance of 25 creeping bentgrass cultivars under putting green and fairway conditions in field plots;

(2) Quantifying the differences in rooting depth and root to shoot ratio of 23 creeping bentgrass cultivars in a PEG-hydroponic system.

Creeping bentgrass is the dominant turfgrass species for golf course putting greens and fairways. Frequent irrigation, however, is required to remain its playability and aesthetical qualities under intense use. Limited water resources and rapid suburban expansion have led to restricted irrigation in many communities. Deficient irrigation (i.e. drought) causes reduced turfgrass quality, and plant death when the stress is severe. Use of drought tolerant plants can help reduce water use and minimize stress damage. Large progress has been made to breed drought-tolerant plants, including creeping bentgrass, generating a large number of new plant materials. Accurate phenotyping (i.e. screening) is critical for a successful breeding program. An ideal phenotyping technique includes use of reliable (heritable) selection criteria and a simple, rapid, and cost effective screening process. Various traits contributing to drought tolerance have been identified in plants, including two important morphological characteristics, deep rooting and high root to shoot ratio. These morphological characteristics are not only reliable but also easier and less costly to measure than physiological and molecular indices; however, sampling roots from field plugs or potted plants (most commonly with soil-based rooting mixtures) is labor intensive. Polyethylene ethylene - hydroponic culture has been successfully used in selecting drought-tolerant field crops; however, its potential application as a screen technique in turfgrass breeding has not been determined.

Field evaluation

Two creeping bentgrass field trials were established at the Turfgrass Research Center, Fargo, ND in fall, 2008. The field trials have been maintained under golf putting green (soil-based pushup-type) or fairway conditions since spring, 2009. Both trials included 25 commercially available creeping bentgrass cultivars (Tables 1 and 2). The experimental setup was randomized complete block design with three replicates. In 2015, Irrigation was applied during spring green-up, but withheld since July 7 to stimulate drought conditions. Canopy reflectance was measured in the 340 - 1023 nm range using a spectrometer (Model: JAZ-COMBO-2; OceanOptics, Inc., Dunedin, FL). Data were collected every 7 – 14 days during cloud-free days during midday (10:45 a.m. - 12:00 p.m). The spectrometer was help at 3.1 ft. above the canopy. Three water indices, water index (WI) = R_{970} / R_{900}, normalized water index (NWI) = $(R_{970} – R_{880}) / (R_{970} + R_{880})$, and floating-position water band index (fWBI) = $R_{900} / \min(R_{930–980})$ were estimated, in which R and the subscript numbers indicate the light reflectance at the specific wavelength (nm). Soil moisture content was recorded with a time-domain reflectometry (Model: Trime-FM; IMKO Micromodultechnik GmbH, Germany) in four randomly selected locations within each trial, after the canopy reflectance was measured. Turfgrass visual quality was recorded with a 1 – 9 scale, where 1 = dead grass, 6 = acceptable quality for putting green or fairway, and 9 = optimal quality. Air temperature and rainfall were recorded daily by a weather station located 200 ft away from the research trials.

Frequent rainfall occurred in 2015 (Fig. 1). The longest duration without precipitation was 12-day, lasting from Aug. 24 to Sept. 4. Monthly accumulated rainfall for July, Aug., and Sept. was 2.80, 2.14, and 1.6 inch, respectively. Soil water content decreased from 35.1% in early July to 15.4% in late Sept. in the putting green trail and from 43.7% to 21.2% in the fairway trail (Fig. 2). No significant differences were detected between the cultivars in any water index during the growing season of 2015 (Tables 1 and 2). It is probably due to a combination of frequent precipitation, high water holding capacity of clay soil at the research site, and cool climate of the upper Northern region. No visual drought symptoms were observed on any evaluation date in either trial.

Laboratory experiments

Twenty-three creeping bentgrass cultivars, including 19 cultivars from the field trials (Table 1) and 'Focus', 'Cobra 2', 'V8', and 'Pinup' creeping bentgrass, will be exposed to a PEG-hydroponic system to determine rooting characteristics during the germination and seedling growth stage (Experiment 1) and the vegetative growth stage (Experiment 2) . The grasses were germinated under the control (i.e. non-stress, 0 MPa) and PEG at -0.4, -0.8, and -1.2 MPa in a preliminary study (data not shown). All grasses showed adequate germination (> 90%) under the non-stress condition and at -0.4 MPa. Seedling dry weight ranged from 13.9 to 62.9 mg and 40.9 to 104.5 mg at 0 and -0.4 MPa, respectively. Germination rate decreased to less than 18% at -0.8 MPa with little seedling biomass to be collected. Grasses at -0.4 and -0.8 MPa appeared in darker green color than the control plants (visual observation). No grasses germinated as the drought level increased to -1.2 MPa.

Based on the preliminary results, two PEG levels, -0.3 and -0.6 MPa, have been selected to be used in to determine rooting depth and root to shoot ratio during germination and seedling growth (Experiment 1) and vegetative growth (Experiment 2). Data will be collected on seedling biomass (shoot and root) and the longest root length in Experiment 1 and visual quality, tissue biomass (shoot and root), and the longest root length in Experiment 2. Experiment 1 is currently ongoing.

Table 1. Water index (WI), normalized water index (NWI), and floating-position water band index (fWBI) of 25 creeping bentgrass cultivars managed under golf putting green condition on three representative dates in 2015.

	July 14			Aug. 12			Sept. 1		
Cultivar	WI¶	NWI¶	fWBI¶	WI	NWI	fWBI	WI	NWI	fWBI
L-93	1.020	-0.006	1.543	1.078	-0.035	1.290	1.099	-0.051	1.836
T-1	1.022	-0.008	1.580	1.035	-0.016	1.161	1.094	-0.049	1.773
Alpha	1.011	-0.002	1.515	1.045	-0.019	1.130	1.086	-0.046	1.790
Putter	1.010	-0.001	1.551	1.045	-0.021	1.151	1.083	-0.043	1.662
South shore	1.014	-0.003	1.529	1.053	-0.025	1.189	1.077	-0.040	1.756
Kingpin	1.023	-0.007	1.578	1.050	-0.020	1.197	1.103	-0.051	1.792
Crenshaw†	1.013	-0.002	1.529	1.039	-0.0169	1.180	1.083	-0.043	1.771
Imperial†	1.017	-0.005	1.627	1.043	-0.0199	1.171	1.083	-0.043	1.795
Century†	1.014	-0.003	1.500	1.039	-0.0150	1.151	1.087	-0.045	1.781
Penncross	1.010	-0.001	1.573	1.033	-0.0133	1.143	1.072	-0.037	1.731
Penn A-4	1.003	0.001	1.626	1.038	-0.0151	1.153	1.089	-0.045	1.822
Crystal bluelinks	1.017	-0.004	1.546	1.060	-0.0278	1.228	1.090	-0.047	1.814
Alister†	1.015	-0.004	1.479	1.046	-0.0195	1.134	1.080	-0.040	1.689
Pennlinks II	1.004	0.002	1.487	1.040	-0.0184	1.180	1.082	-0.042	1.660
Penn A-1	1.006	0.002	1.580	1.041	-0.0178	1.159	1.092	-0.047	1.780
Penn G-6†	1.008	-0.001	1.534	1.039	-0.0158	1.121	1.071	-0.037	1.702
007	1.005	0.002	1.494	1.042	-0.0169	1.148	F1.086	-0.045	1.800
MacKenzie	1.022	-0.007	1.532	1.050	-0.0226	1.156	1.095	-0.049	1.834
Tyee	1.006	0.001	1.606	1.038	-0.0137	1.120	1.095	-0.049	1.952
SR 1150	1.010	-0.002	1.552	1.050	-0.0204	1.134	1.103	-0.052	1.812
Memorial†	1.016	-0.004	1.481	1.045	-0.0194	1.161	1.109	-0.055	1.774
Independence	1.029	-0.010	1.590	1.065	-0.0294	1.204	1.093	-0.047	1.744
Declaration	1.013	-0.003	1.600	1.036	-0.0155	1.139	1.082	-0.041	1.764
LS - 44†	1.012	-0.002	1.554	1.043	-0.0189	1.161	1.092	-0.048	1.787
Bengal	1.023	-0.008	1.571	1.050	-0.0225	1.158	1.095	-0.048	1.794
	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns means not significantly different at $P \leq 0.05$ level.
†Creeping bentgrass cultivar not included in the laboratory experiments as it is no longer commercially produced.
¶water index (WI) = R_{970} / R_{900}, normalized water index (NWI) = $(R_{970} - R_{880}) / (R_{970} + R_{880})$, and floating-position water band index (fWBI) = R_{900} / [min($R_{930-980}$)], in which R and the subscript numbers indicate the light reflectance at the specific wavelength (nm).

Table 2. Water index (WI), normalized water index (NWI), and floating-position water band index (fWBI) of 25 creeping bentgrass cultivars managed under golf fairway condition on three representative dates in 2015.

Cultivar	July 14			Aug. 12			Sept. 1		
	WI	NWI	fWBI	WI	NWI	fWBI	WI	NWI	fWBI
L-93	1.022	0.000	1.146	1.037	-0.012	1.177	0.924	0.052	0.994
T-1	1.027	-0.005	1.119	1.045	-0.018	1.196	0.932	0.045	1.026
Alpha	1.048	-0.030	1.555	1.063	-0.027	1.198	0.967	0.025	1.136
Putter	1.026	-0.003	1.163	1.042	-0.015	1.193	0.920	0.053	1.012
South shore	1.026	-0.006	1.157	1.045	-0.016	1.186	0.925	0.049	0.994
Kingpin	1.030	-0.013	1.186	1.046	-0.017	1.190	0.958	0.030	1.060
Crenshaw[†]	1.026	-0.003	1.160	1.043	-0.016	1.185	0.912	0.057	0.980
Imperial[†]	1.034	-0.009	1.119	1.056	-0.022	1.205	0.926	0.050	1.010
Century[†]	1.044	-0.012	1.142	1.058	-0.023	1.209	0.921	0.051	1.020
Penncross	1.031	-0.006	1.147	1.047	-0.018	1.208	0.917	0.054	0.989
Penn A-4	1.033	-0.008	1.160	1.046	-0.017	1.192	0.920	0.051	0.986
Crystal bluelinks	1.023	-0.002	1.156	1.044	-0.016	1.193	0.920	0.052	0.981
Alister[†]	1.029	-0.005	1.152	1.057	-0.023	1.194	0.926	0.050	0.996
Pennlinks II	1.022	-0.003	1.160	1.040	-0.014	1.190	0.917	0.053	1.013
Penn A-1	1.042	-0.013	1.160	1.050	-0.019	1.181	0.924	0.050	1.017
Penn G-6[†]	1.018	-0.013	1.149	1.045	-0.017	1.222	0.960	0.031	1.109
007	1.051	-0.018	1.180	1.055	-0.022	1.192	0.928	0.047	0.999
MacKenzie	1.023	-0.001	1.110	1.042	-0.015	1.183	0.926	0.049	0.991
Tyee	1.036	-0.010	1.176	1.046	-0.017	1.207	0.958	0.030	1.112
SR 1150	1.038	-0.012	1.187	1.054	-0.021	1.188	0.925	0.051	1.002
Memorial[†]	1.025	-0.003	1.162	1.039	-0.013	1.183	0.923	0.050	1.008
Independence	1.041	-0.012	1.132	1.059	-0.024	1.209	0.929	0.048	1.005
Declaration	1.049	-0.017	1.199	1.037	-0.012	1.191	0.913	0.057	0.988
LS - 44[†]	1.026	-0.021	1.224	1.045	-0.017	1.194	0.987	0.013	1.172
Bengal	1.036	-0.009	1.148	1.043	-0.015	1.189	0.929	0.053	1.013
	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns means not significantly different at $P \leq 0.05$ level.
[†]Creeping bentgrass cultivar not included in the laboratory experiments as it is no longer commercially produced.
[¶]water index (WI) = R_{970} / R_{900}, normalized water index (NWI) = $(R_{970} - R_{880}) / (R_{970} + R_{880})$, and floating-position water band index (fWBI) = $R_{900} / [\min(R_{930-980})]$, in which R and the subscript numbers indicate the light reflectance at the specific wavelength (nm).

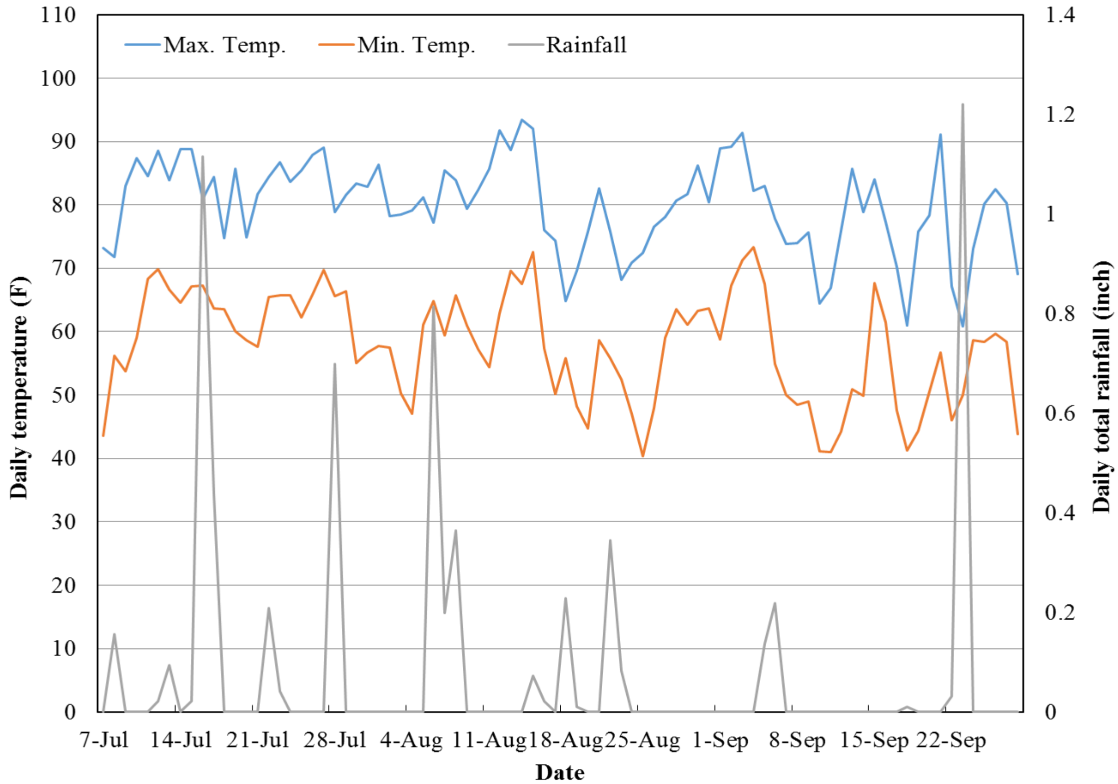


Fig. 1. Daily maximum and minimum temperature and rainfall from July 7 to Sept. 29, 2015 at the Turfgrass Research Center, Fargo, ND.

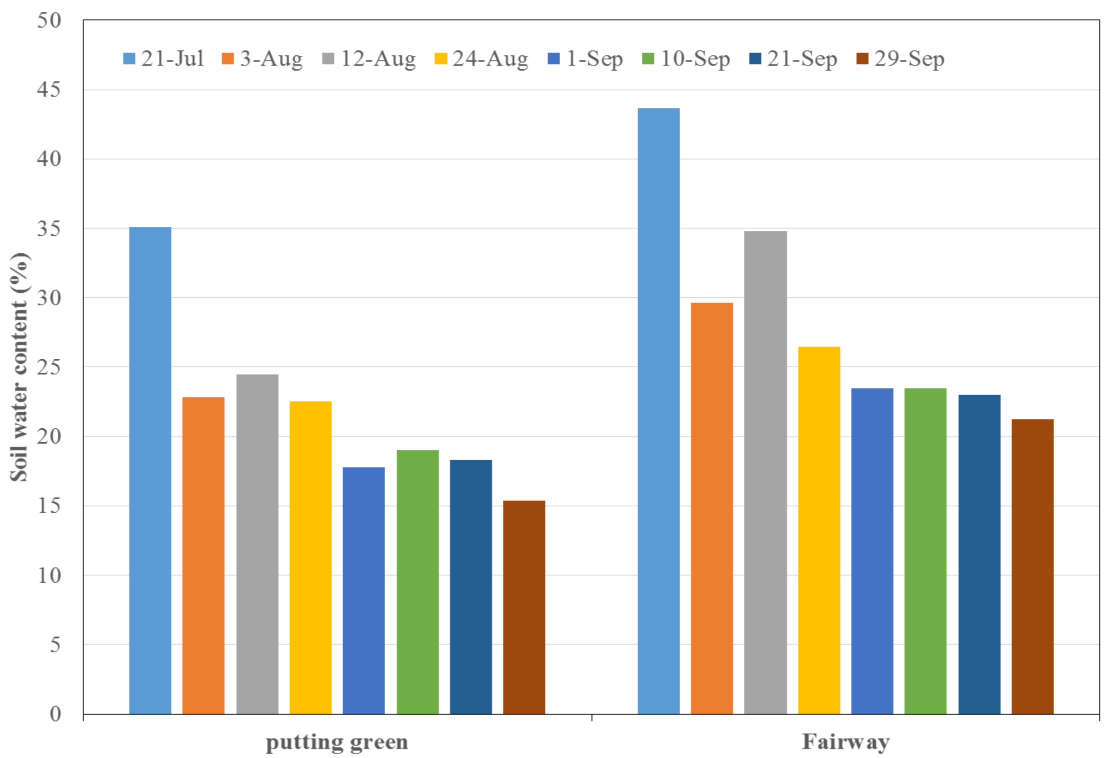


Fig. 2. Soil water content of creeping bentgrass putting green and fairway at Fargo, ND in 2015.

Progress Report: November 29, 2015

Project Title: Evaluation of Putting Green Bermudagrass for Shade Tolerance and Evaluation of Fairway Bermudagrasses for Water Use Rates

Principal Investigators: Justin Q. Moss

University: Oklahoma State University
Address: Dr. Justin Q. Moss
358 Ag Hall
Stillwater, OK 74078-6028

Telephone: 405-744-5729
e-mail: justin.moss@okstate.edu

Start Date: 2014
Number of Years: 3
Total Funding: $60,000

Project #1: Evaluation of Putting Green Bermudagrass for Shade Tolerance

Objectives:

- *Evaluate experimental and commercialized putting green bermudagrasses against Diamond zoysiagrass under full sun and shaded conditions.*

Research Progress:
- Plots were planted from sprigs on a sand based putting green in July 2013 and fully established in 2014.

Preliminary Results:
- TifEagle, 264, MiniVerde, and Champion performed best in 2014 while Diamond, MiniVerde, TifEagle, and Champion were the best cultivars in 2015.
- 16-13-8 and 1-75-2 were consistently ranked lowest in 2014 and 2015.
- Diamond Zoysiagrass exceptionally performed well in 2015 compared to all bermudagrass cultivars.

A research site was planted using greenhouse-grown grass sprigs on June 7, 2013. A row of fully mature *Platanus occidentalis* runs parallel to the east side of the study area and provides natural, tree shade in the morning and early afternoon, depending on season. The site was blocked to provide six replications of each cultivar. Photosynthetically active radiation was collected throughout the study period. The plots were covered with a geo-textile to protect against low temperature injury.

The standard entries, ‘Champion’, ‘Mini Verde’, ‘TifEagle’ Bermudagrass, and ‘Diamond’ zoysiagrass and experimental entries, were planted on 5 x 5 ft. plots. Plots were mowed 6 times per week at a 0.155 height and nitrogen was applied at 49 kg/ha monthly. Irrigation was applied at rates and frequencies necessary to maintain acceptable green turf. Trinexapac–ethyl was applied as a standard treatment to all plots during the growing season.

Turfgrass visual quality was assessed monthly based on 1-9 scale. In addition, Normalized difference vegetative index (NDVI) was collected monthly using a GreenSeeker NDVI hand-held sensor to assess shade stress through changes in turfgrass color and cover.

In 2014, TifEagle had higher turf quality than other entries with the exceptions of MS264 and MiniVerde (Table 1). The standard entries had higher turf quality and NDVI compared to all OSU experimental entries in 2014. The OSU entries and Diamond zoysiagrass showed unacceptable turf quality in 2014. In 2015, all bermudagrass entries had lower turf quality compared to Diamond zoysiagrass. In both years, OSU1-75-2 was the lowest performer in terms of turf quality and NDVI.

Table 1. The whole season turf visual quality and normalized difference vegetation index (NDVI) response of bermudagrass entries maintained as a putting green in the shade in Stillwater, OK in 2014 and 2015.

2014			2015		
Cultivar	TQ	NDVI	Cultivar	TQ	NDVI
TifEagle	6.6a*	0.739a	Diamond	6.0a	0.663a
MS264	6.1ab	0.708a	Miniverde	5.5b	0.649a
MiniVerde	6.1ab	0.737a	TifEagle	5.4bc	0.657a
Champion	6.0b	0.743a	Champion	5.0cd	0.636a
OSU13-78-5	4.8c	0.656b	MS264	5.0cd	0.644a
Diamond	4.8c	0.596cd	OSU13-78-5	4.8d	0.635a
OSU16-13-8	4.3cd	0.617bc	OSU16-13-8	3.9e	0.582b
OSU1-75-2	3.9d	0.563d	OSU1-75-2	3.4f	0.538c

* Treatments within column with same letters are not significantly different at p=0.05.

Project #2: Evaluation of Fairway Bermudagrasses for Water Use Rates

Objectives: *Evaluate, measure, and explain any differences in water use rates among several industry standard bermudagrass cultivars vs OSU experimental bermudagrasses.*

Research Progress:

- Lysimeters were maintained in the greenhouse from December to April each year to prevent winter injury.

Preliminary Results:

- ET rates in 2014 ranged from 4.93 mm d^{-1} to 6.19 mm d^{-1} and ranged from 3.88 mm d^{-1} to 6.03 mm d^{-1} in 2015.

- DT-1 was a higher water using entry in 2014 and 2015 with ET of 6.19 mm d^{-1} and 6.03 mm d^{-1}, respectively, but was not different than standard entries Celebration or Tifway.
- OKC 1131 and OKC 1163 were lower water using entries in both 2014 and 2015.

The research site was a former 2002-2006 NTEP (National Turfgrass Evaluation Program) bermudagrass trial with 2.4 x 2.4 m plots. Six genotypes out of ten were new which were not included in the original NTEP trial. These were 'Latitude 36', 'NorthBridge', DT-1, OKC 1302, OKC 1131, and OKC 1163.

The lysimeters were constructed using polyvinyl chloride (PVC) tube, 15.2 cm inside diameter and 35.6 cm long with a root zone depth of 30.48 cm and an extra 5.1 cm of length below the root zone to accommodate a drain valve on the bottom (Photo 1). A threaded ball valve was installed onto the bottom inside of each lysimeter. The inner side of the lysimeter was filled with a geo-textile porous sheet to prevent any loss of the rooting medium. The rooting medium is a calcined clay product.

Field ET rate was collected from May to September in 2014 and August to September in 2015 (Photo 3).

NorthBridge, OKC 1131, and OKC 1163 were the lower water use entries in both 2014 and 2015 whereas Celebration, Tifway, DT-1 were higher water use entries (Table 2).

Table 2. Mean daily evapotranspiration (ET) rates (mm d^{-1}) of ten bermudagrass entries under non-limiting soil moisture conditions in 2014 and 2015.

2014		2015	
Entries	ET*	Entries	ET
DT-1	6.19a**	DT-1	6.03a
Celebration	6.08ab	Tifway	5.36ab
OKC 1302	6.07ab	Celebration	5.19ab
Tifway	6.00b	Premier	5.15ab
Premier	5.71c	Latitude36	5.10b
Latitude 36	5.70c	TGS_U3	4.99bc
TGS_U3	5.51d	OKC1302	4.59bcd
OKC 1131	5.18e	NorthBridge	4.19cd
NorthBridge	5.17e	OKC1163	4.01d
OKC 1163	4.93f	OKC1131	3.88e

* Water use in mm d^{-1}. Values are the mean of 14 ET rates and 6 ET rates in 2014 and 2015, respectively.
** Treatments within column with same letters are not significantly different at p=0.05.

Photo 1. A row of fully mature *Platanus occidentalis* on the east side of the study area.

Photo 2. A lysimeter in a field plot.

Photo 3. ET rate collection from field plots.

Evaluating sand-capping depth and subsoil influence on fairway performance, irrigation requirements and drought resistance

B. Wherley, K. McInnes, W. Dyer, C. Reynolds, and J. Thomas- Texas A&M University

Sand-capping of golf course areas has gained popularity in recent years, especially on golf course fairways. Fairways represent one of the largest areas of irrigated turf on golf courses, and management of these areas can become especially difficult where fine textured native soils become degraded due to high sodium levels in irrigation water leading to loss of soil structure and permeability. Common problems arising in these scenarios include excessive fairway wetness, slow drainage, poor aeration, and severe compaction of highly trafficked areas; all of which result in poor quality turf. While no USGA recommendations currently exist for specific depths or particle size distribution of capping sands, less than optimal depths of sand are often used to reduce the cost of renovation. The ideal placement depth ultimately depends on physical properties of the sand, environmental conditions, and providing a balance of water- to air-filled porosity for optimal growing conditions. Preliminary testing of the capping sand used in this project indicated equal air to water filled porosity was achieved at 22 cm water tension (Fig. 1).

The objectives of this research are to 1) evaluate 'Tifway' bermudagrass (*Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis* Burtt-Davy) fairway performance and rooting characteristics as influenced by four initial capping depths (0= topdressed only, 5 cm, 10 cm, and 20 cm) atop two subsoils (clay loam and sandy loam), 2) determine how sand-capping by subsoil combinations influence root zone soil moisture and irrigation frequency requirements, and 3) monitor development of subsoil sodicity (SAR) and electrical conductivity and as a function of sand-capping by subsoil by irrigation treatments.

Plots were sprigged late summer 2014. Plots with shallower capping depths achieved full cover more rapidly than plots with deeper capping, however all plots reached full establishment by May 2015 (Fig. 2). Irrigation-frequency treatments of 1 and 2 events weekly were imposed beginning June 2015, with all plots receiving irrigation amounts of 60% of reference evapotranspiration. Despite a very dry 2015 summer, no significant differences in quality or percent green cover occurred between the 1 and 2 day per week irrigation frequency, regardless of sand-capping depth. A significant effect of capping depth on percent green cover occurred within plots having sandy loam subsoil, but not within plots with clay loam subsoils (Fig. 3). Sodium adsorption ratio (SAR) of fairway subsoils (upper 10 cm) increased sharply within the initial 12 months of the study, due to high Na concentration (~270 ppm) of irrigation water, but the rate of increase was delayed by sand-capping (Fig. 4). Assessment of thatch development and rooting profiles (root biomass and root length density) within the sand cap by subsoil treatments is currently underway. Preliminary observations indicate root development into subsoils has not been impeded, regardless of capping depth. Data on temporal dynamics of water movement within and through sand-cap treatments following summer irrigation/rain events have also been collected and are being analyzed. In the final year of the study, a 60-day drought will be imposed on all plots, with recovery under irrigation evaluated.

Summary Points

- While construction of a 20-cm deep sand cap would provide equal air to water filled porosity with this sand if it were placed above a capillary barrier such as in a green, this study will evaluate the impacts of capping depths on substrates that wick water.
- Bermudagrass sprig establishment time was increased as capping depth increased during the establishment period, however, all plots reached full establishment by May 2015 after being sprigged in late summer 2014.
- Despite a very dry 2015 summer, no significant differences in turf quality or percent green cover due to irrigation frequencies of 1 and 2 times per week (at 60% of reference evapotranspiration) were observed, regardless of sand capping depth.
- SAR is rapidly approaching sodic (SAR ≥ 13) conditions in both sandy loam and clay subsoils, however, this increase has been delayed by sand-capping.
- This study may lend insight into how recommendations for the physical properties of capping sands may differ from those currently used for USGA putting greens.

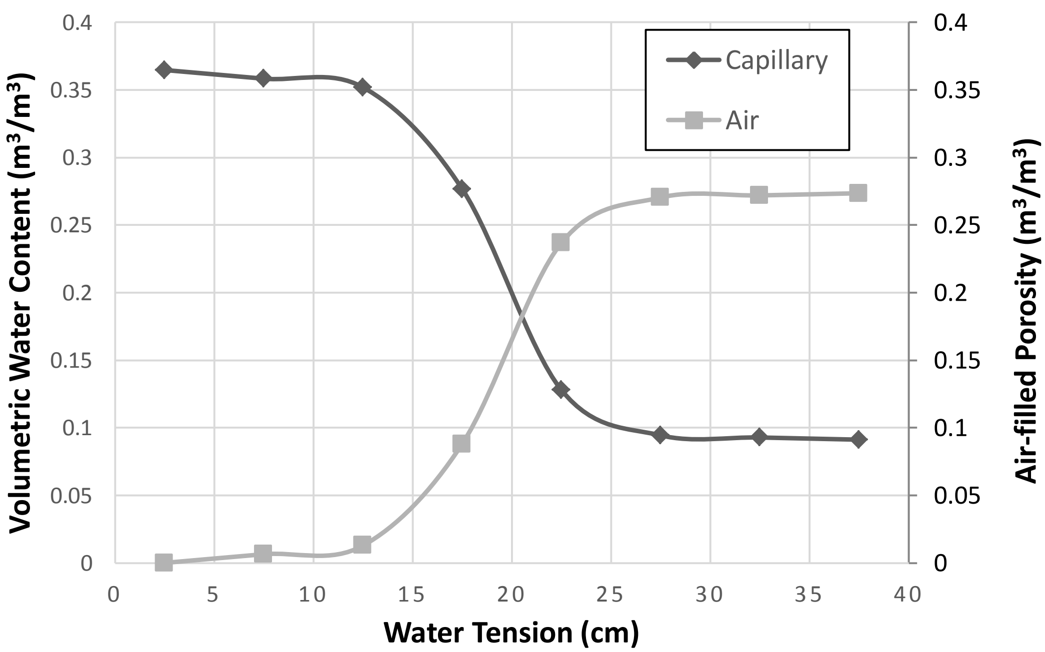


Figure 1. Volumetric water content and air/water filled porosity of the capping sand as a function of water tension (cm).

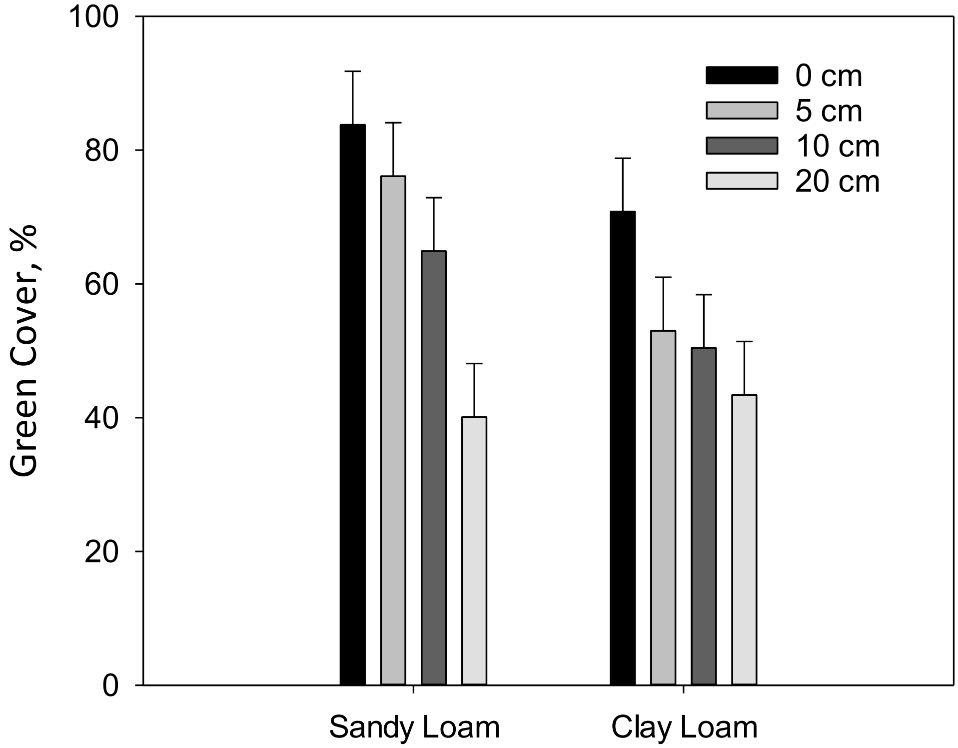


Figure 2. Green cover of fairway plots 8 weeks following sprig establishment as influenced by sand-capping depth on sandy loam or clay loam subsoils (November 2014). All plots reached full coverage by May 2015.

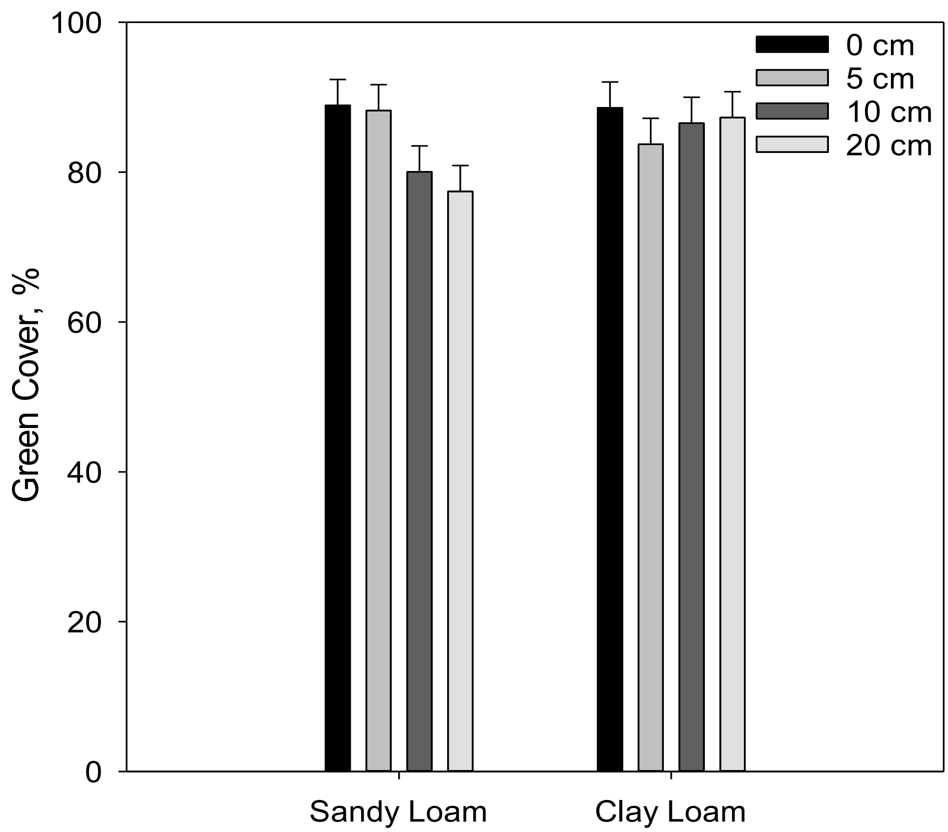


Figure 3. Mean percent green cover of sand-capping treatment plots on clay and sandy loam subsoils over the 2015 season. Means are pooled across irrigation treatments. Error bars denote LSD (0.05).

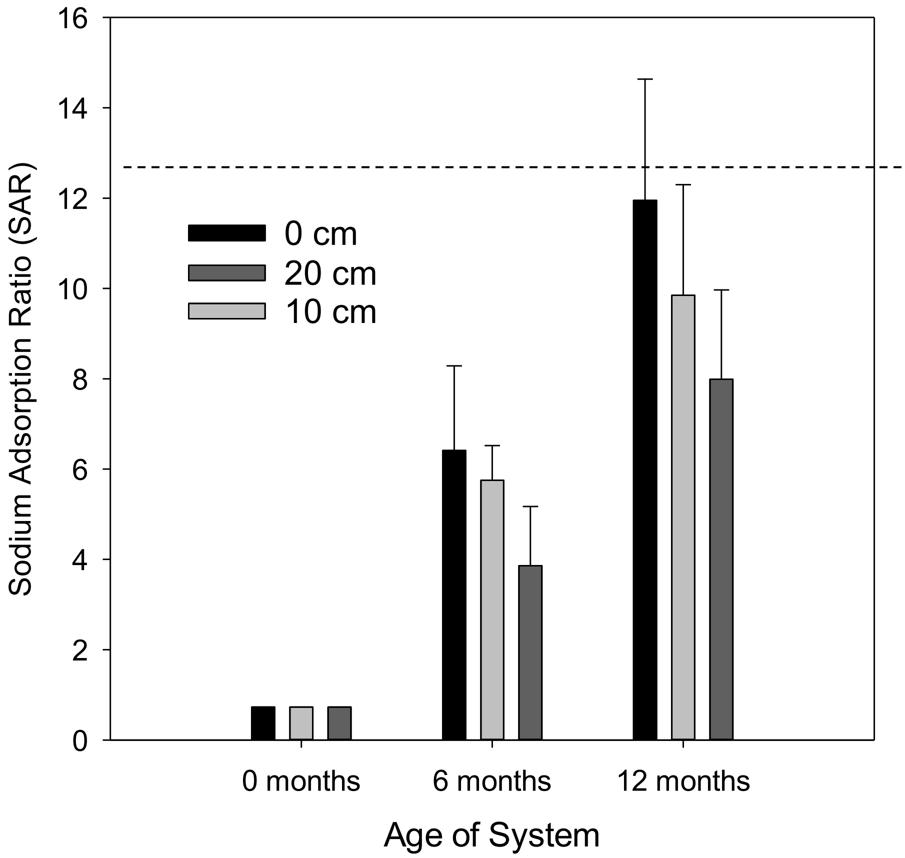


Figure 4. Increase over time in sodium adsorption ratio (SAR) of the sandy loam subsoil beneath the 0, 10, and 20 cm capping depths (0, 6 and 12 months into the study). Dotted line represents SAR level indicative of sodic soil. Error bars denote standard error.

Figure 5. Image of the sand-capping research fairway study at Texas A&M University Turf Field Laboratory taken during July 2015, just after topdressing of the 0 cm plots.

Figure 6. Construction of sand-capping treatments during summer of 2014.

Title: Comparison of soil properties and mineral composition of turfgrass shoots prior to and after 10 years of irrigation with effluent water

Investigator: Yaling Qian

Affiliation: Colorado State University

Objectives:

1) To determine chemical property changes of soil at 5 different depths prior to and 10 years after irrigation with effluent water.
2) To determine turfgrass mineral composition prior to and 10 years of irrigation with effluent water.
3) To determine soil ESP changes along soil profile (to 1 m deep) on fairways with gypsum treatment when compared to no gypsum treatment as the control.

Start Date: 2014

Project Duration: 2 years

Total Funding: $31150

Project Summary:

To determine the impacts of effluent water irrigation on turfgrasses and soils, it is difficult to conduct long-term field monitoring due to budget limitations. One opportunity for this project is that in 2004, PI collected soil and turfgrass baseline information for several landscape facilities (including 3 golf courses) prior to their use of effluent water for irrigation. All the sampling sites were marked physically. The original soil samples were archived for measurement comparison. Baseline data are available.

In 2009 and 2015, five years and eleven years after the initiation of recycled water for irrigation, soil samples were collected (to 1 m deep at 20 cm increments) again from the original sites to determine if any changes had occurred. Concurrently, Kentucky bluegrass clippings were collected for mineral analysis. In addition, soil exchangeable sodium percentage (ESP) and other parameters along the soil profile (1 m deep at 20 cm increments) on four locations that have been subjected to annual gypsum applications (aerify 1-2 times a year and apply gypsum at 50 lb/1000 sq ft/year) were sampled to compare to locations that did not receive gypsum application.

Results:

Soil analyses prior to and 10 years after effluent water irrigation indicated that soil sodium content, sodium exchangeable percentage, and soil pH increased after effluent water irrigation. One of the three golf courses had a significant increase in soil salinity (as gauged by soil electrical conductivity) in 2015 when compared to the benchmark baseline. The increase in soil salinity was not significant at other two golf courses. All three golf courses had increased soil pH. 2015 data indicated that the degree of soil pH increase was greater at deeper than at shallow soil depths (Fig. 1). In general, soil sodicity [as gauged by exchangeable sodium percentage (ESP)] was higher in 2009 and 2015 when compared to 2004.

Eleven years of effluent water irrigation has increased clipping sodium content by more than 4 times. Boron and chloride content increased, whereas tissue zinc content was reduced (Table 1). Despite the significant mineral content changes, turfgrasses generally exhibited good quality. However, there was a linear relationship between turf quality and sodium content in the clippings. We observed salinity stress on some localized sites with fine soil texture and poor drainage under effluent water irrigation.

For gypsum treated fairways, the increase in ESP from 2004 to 2009 at 0-20 cm and 20-40 cm depths were not statistically significant under effluent water irrigation (Figure 2 A). The increase became significant from 40 to 100 cm. The changes along the soil profile reflect sodium leaching that effectively prevented a significant increase in soil ESP at the shallow soil depths (0-40 cm). For control sites (effluent water irrigation with no gypsum treatment on site), the increases in ESP from 2004 to 2009 were significant at 0-60 cm depths, with ESP at the 0-20 and 20-40 cm depths being approximately tripled (Figure 2 B). The relatively high levels of sodium concentration relative to calcium and magnesium in effluent water resulted increased soil ESP, especially at the shallow soil depths (Figure 2 B). Although the gypsum treatment continued from 2009 to 2015, the wastewater treatment plant has also added calcium products to effluent water before the water leaves the treatment plant. As such, soil analysis exhibited reduced ESP at the surface depth for both treatments. Results from this study indicated that management (aggressive aerification and gypsum application)/or calcium product addition into effluent water helped to displace sodium and reduce ESP at the surface depth, although soil ESP increased significantly at deeper soil depths.

Summary Points:

- ✓ Turfgrass sites that have been irrigated with effluent water for 11 years exhibited an increased soil pH, soil ESP, and soil sodium content;
- ✓ Ten years of effluent water irrigation has increased Kentucky bluegrass clipping sodium content by more than 4 times. Boron and chloride content increased , whereas tissue zinc content was reduced.
- ✓ Despite the significant mineral content changes, turfgrasses generally exhibited acceptable quality. We observed salinity stress on some localized sites with fine soil texture and poor drainage under effluent water irrigation.
- ✓ Soil aerification and gypsum addition effectively prevented a dramatic increase in soil ESP at the shallow soil depths, although soil ESP increased significantly at deeper soil depths.
- ✓ The degree of soil pH increase under effluent water irrigaton was greater at deeper than at shallow soil depths

Table 1. Mean grass clipping ion concentrations of Kentucky bluegrass prior to and 11 years of irrigation with effluent water.

Parameters (mg kg^{-1})	Prior to effluent water irrigation	After 10 years of effluent water irrigation
B	9.0**	17.7
Ca	3754	3425
Fe	296	387
K	19048	22642
Mg	1874	2725
Na	328***	1427
P	4915	5080
Zn	45.1	34.7
Cl	5207*	7545
K/Na	64***	17
Turf quality	8.2	7.6

*, **, *** Significant difference at $P \leq$ 0.05, 0.005, and < 0.001, respectively.

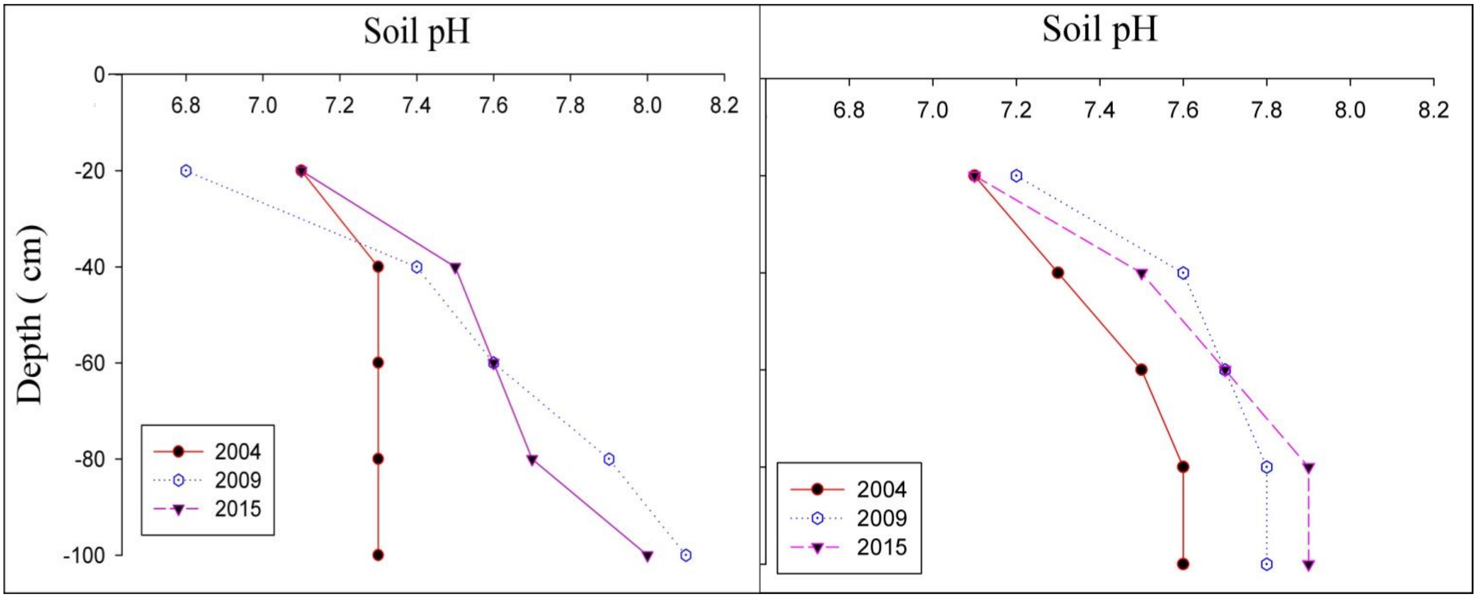
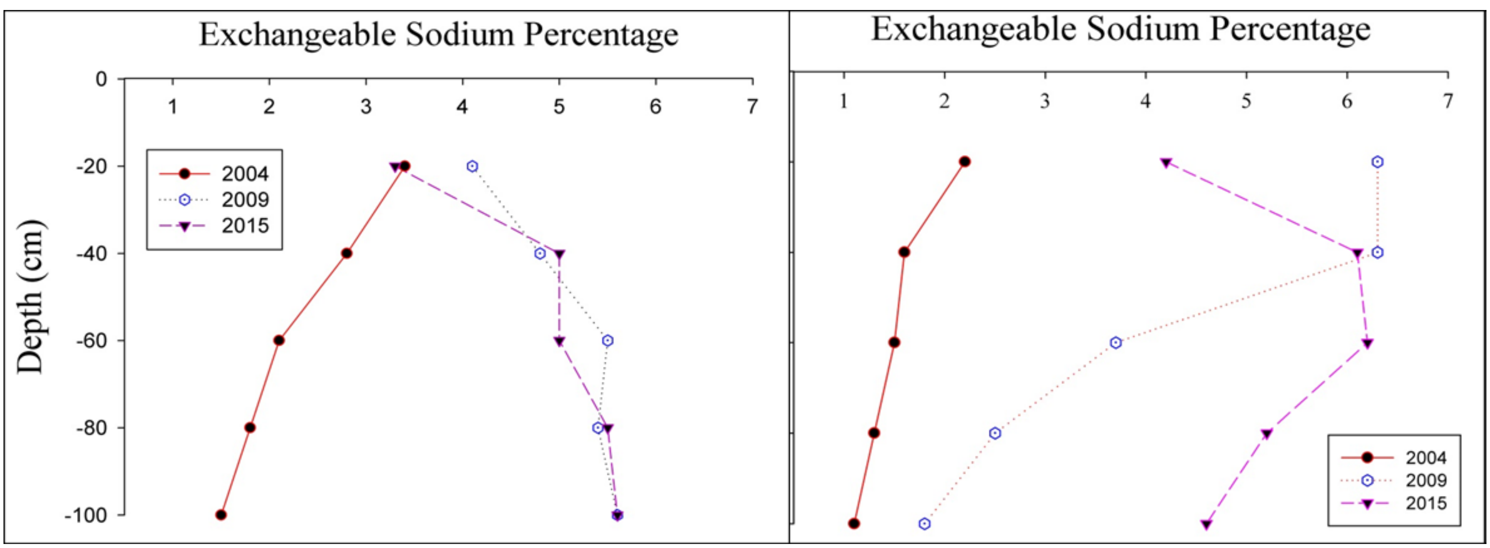


Figure 1: Soil pH at five soil depths at the initiation (2004), 5 years and 11 years after effluent water irrigation (2009 and 2015) on two golf courses. Each data point is the mean of 4 replications.



Fairways with Gypsum Additions **Fairways without Gypsum Additions**

Figure 2: Exchangeable sodium percentage at five soil depths at the initiation (2004) , 5 years and 11 years after effluent water irrigation (2009 and 2015). Each data point is the mean of 4 replications.

Reclamation of Saline-Sodic Fairway Soils

Progress Report: USGA ID#: 2014-07-496
Submitted to the United States Golf Association

Paul Brown and James Walworth
University of Arizona

4 December 2015

The objective of this study is to develop remediation strategies for saline-sodic fairway soils. The study is being conducted on 24, 12'x12' plots of established bermudagrass located at the University of Arizona's Karsten Turf Research Facility in Tucson, Arizona. Sodium chloride was applied to study plots during the summer of 2014 to develop saline-sodic soil conditions (ECe>4; ESP>15). Plans to initiate treatments during the late summer of 2014 were postponed when heavy rains and flooding compromised the salinity and sodium levels of plot soils. Plot soils were resampled during the spring of 2015 and additional amounts of sodium chloride were applied to increase sodium and salinity to targeted levels.

Study treatments were initiated in July of 2015 and were designed to assess the effectiveness of soil chemical amendments (gypsum, sulfur), irrigation rate (deficit and leaching) and soil tillage (hollow tine vs. no tillage) on soil salinity (ECe) and sodium levels (ESP). Tillage treatments were applied to a depth of 3" using a walk-behind aerator outfitted with 0.5" hollow tines (Fig. 1). Gypsum and sulfur treatments were applied using a hand spreader (Fig. 2) at rates of 5.8 and 1.2 tons/acre, respectively. Irrigation treatments were initiated after application of soil amendments and consisted of daily irrigations at rates equal to 70% (slight deficit) and 100% (leaching) of standardized reference evapotranspiration (ETos) as estimated from a weather station located within 100' of the study site. Irrigation events were reduced or eliminated during periods of rainfall to maintain water applications near targeted levels. All plots and subplots were subjected to a series of bi-weekly measurements to assess visual turf quality, turf growth rate (from clippings), soil moisture and soil compaction. Data from biweekly measurements obtained this past summer are being analyzed at present.

The study was overseeded with perennial ryegrass in October of 2015. Irrigation treatments were suspended for the two-week establishment period, but care was taken to minimize overwatering in an effort to maintain the non-leaching (deficit) irrigation treatment. The bi-weekly measurements of visual quality, turf growth rate, soil moisture and soil compaction were reinstated in November and will continue until next spring when a second aerification operation will be imposed on subplots supporting the tillage treatment.

Soils will be resampled in mid-December and analyzed for ECe and ESP to provide an initial assessment of the effectiveness of the various treatment combinations. This initial post-treatment assessment may provide the lone chance to effectively assess study irrigation treatments. Current forecasts for the coming winter call for above normal precipitation due to the presence of a strong El Niño event in the tropical Pacific Ocean. Abundant winter precipitation could lead to high levels of leaching in both irrigation treatments and minimize or eliminate the impact of the irrigation treatments going forward in time.

Project Bullets

1. The study was initiated in July 2015 after a delay of nearly one year caused by heavy rains and flooding during the summer of 2014. Sodium chloride was applied to soils supporting established bermudagrass turf to create saline-sodic soil conditions (ECe>4.0 and ESP>15%).

2. Treatments were implemented to evaluate the effectiveness of recommended remediation procedures for saline-sodic soils and included applications of soil chemical amendments (gypsum, sulfur and control), two levels of irrigation (deficit and leaching) and soil tillage (hollow time and control).

3. Measurements of turf quality, turf growth rate, soil moisture and soil compaction are obtained every two weeks on all plots and subplots.

4. Soils will be sampled in December of 2015 to provide a preliminary assessment of the effectiveness of the remediation treatments.

Figure 1. Student worker, Adam Killebrew, applies NaCl to the plots

Figure 2. Tillage treatments consisted of one pass with walk-behind aerator outfitted with hollow times. Soil cores were raked off and removed from the plots.

.

Figure 3. Applications of gypsum and sulfur were made using a hand spreader.

Figure 4. Irrigation treatments consist of a deficit and surplus (leaching) regime. Catch cans are used to monitor the precipitation rates of the plot irrigation systems.

Annual report on USGA ID#: 2014-09-498

Is It True That Certain Wetting Agents Remove Organic Coatings from Water-Repellent Sand Particles?

Xi Xiong[1], Stephen H. Anderson[2], Keith W. Goyne[2], and Robert J. Kremer[2]

University of Missouri, [1]Division of Plant Sciences and [2]Department of Soil, Environmental and Atmospheric Sciences.

Objectives: To evaluate various wetting agents for effects of removing organic coatings from hydrophobic sand surface.

Soil water repellency, responsible for localized dry spot (LDS), is caused by formation of organic coatings, which builds up on sand surface over time during the decomposition of organic matters. Some wetting agents in turf market acclaim functions of removing organic coatings, and this needs to be confirmed by research-based experiments.

In 2015, we continued the laboratory study, and initiated a two-year field-based experiment. Laboratory experiments utilized naturally occurring hydrophobic sand collected from a USGA green with LDS. Sands were homogenized, and the hydrophobicity level was determined to be “moderate to high”, based on water droplet penetration test (WDPT) and molarity of ethanol droplet test (MED; 2.2 molars). Sands were then packed uniformly into a tube system described in the proposal, and selected wetting agents were applied once at the label suggested rates, followed by three sequential washes (Fig 1). Leachates from wetting agents applications and three washes were collected and analyzed for dissolved (DOC) and particulate organic carbon (POC).

Sand Mass (g)	Depth (cm)	Diameter (cm)	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)	Pore volume (ml)
254	7.8	5	1.66	2.68	38	58

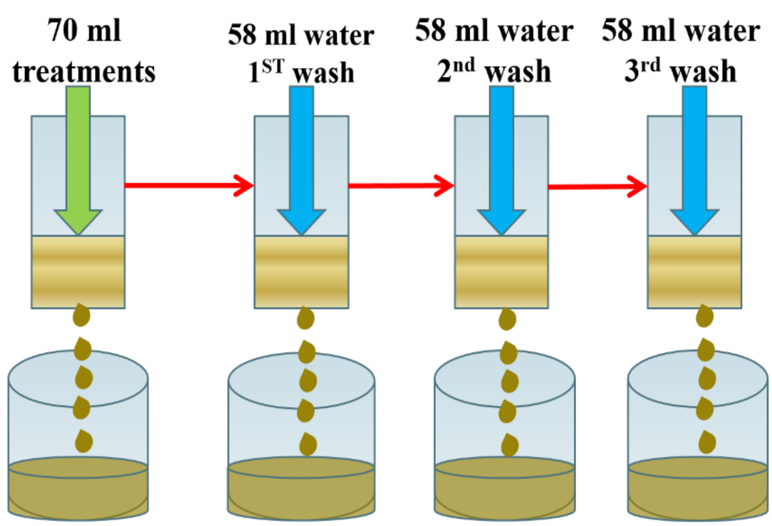


Fig 1. Sand tube properties and a sketch of wetting agent treatment application, followed by three wash events. After homogenization, the hydrophobic sands were packed uniformly to the same bulk density (1.66 g/cm^3), prior to wetting agent application at a higher volume than the pore volume (58ml). Three washing events at pore volume occurred 24h after wetting agent application. All leachates were collected for further analysis.

Three wetting agents in addition to water control were arranged in a CRD with 3 replications, and the entire experiment was repeated. Data were subjected to ANOVA using Proc mixed procedure in SAS 9.4. No treatment by experimental run interactions occurred, hence, data were pool from the two runs.

Leachates collected after wetting agent application revealed that Matador® and OARS® resulted in 94% water retention, compared to water–treated sand columns (Table 1). Columns treated with OARS® continued water retention after 1st wash, while Matador®-treated columns yielded 12% more leachates compared to control.

Table 1. Leachate volume (ml) after wetting agent (WA) application and each wash event.

Treatment	WA application	1st wash	2nd wash	3rd wash
	--	ml	--	
Matador	1 c3†	44 a2	55 a1	55 ab1
OARS	1 c3	16 d2	55 a1	56 a1
pHAcid	12 b4	41 b3	52 b2	55 b1
Water	17 a4	39 c3	49 c2	54 ab1

†Means followed by the same letters in each column are not significant different based on Fisher's protected LSD (*P*<0.05); Means followed by the same numbers in each row are not significant different based on Fisher's protected LSD (*P*<0.05).

After combining from all leachates, it showed that Matador® and OARS® removed significantly higher amount of organic carbon, especially as dissolved form (Fig 2). These results likely contributed to the reduced hydrophobicity of the treated sands, compared to control.

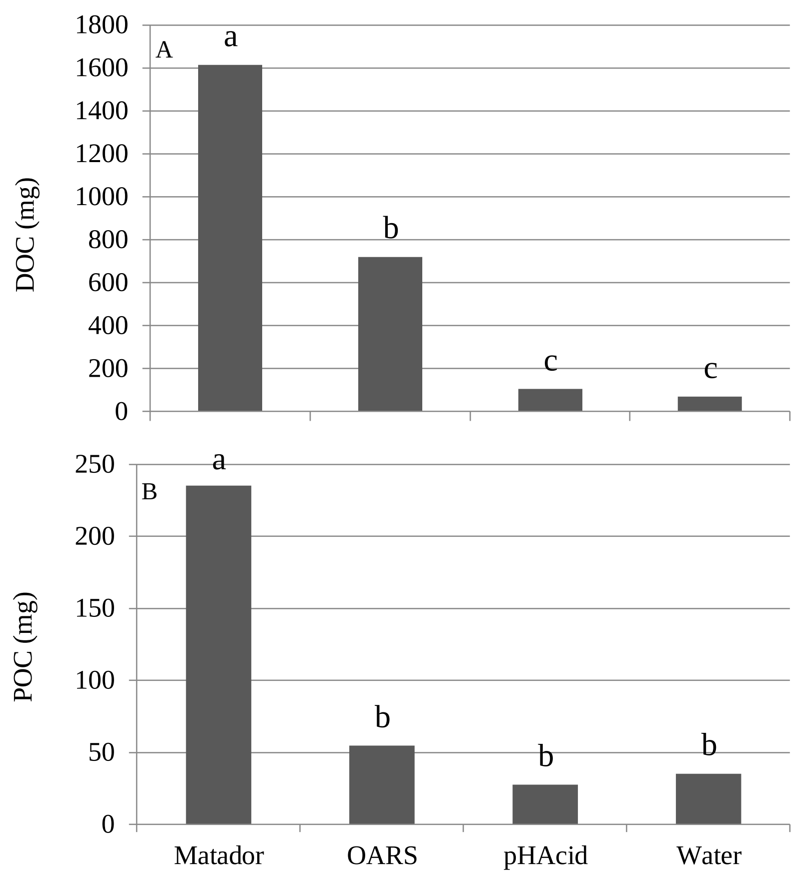


Fig 2. Total output of dissolved (DOC; A) and particulate (POC; B) organic carbon (mg) in all leachates combined after wetting agent application and three wash events. Bars labeled by the same letter were not significantly different based on Fisher's Protected LSD (*P*<0.05).

Field experiment, arranged as RCBD with 4 replications, involved monthly application (from May to September) of wetting agents described above, in addition to Hydro-Wet®, Tournament-Ready®, and Cascade Plus®. Hydrophobicity, measured as MED at 0-5 months after the initial treatment application (MAIT) showed that reduced hydrophobicity following applications of all wetting agents to various extents, with the only exception of pHAcid® (Table 2).

Table 2. Treatment effect on soil hydrophobicity, measured by molarity of ethanol droplet test (MED; molar) at 1 inch soil depth, from 0 to 5 months (May to October, respectively) after initial treatment application (MAIT).

Compound	0 MAIT	1 MAIT	2 MAIT	3 MAIT	4 MAIT	5 MAIT
	--------------------	------------------MED (molar)	-----------------			
Control	3.0 a3†	3.1 b23	3.3 a12	3.4 a1	3.1 a23	3.3 a12
pHAcid	2.9 a3	3.4 a1	3.2 a2	3.3 ab12	2.9 b3	3.1 ab23
Hydro-Wet	3.0 a1	3.1 b1	3.0 b1	3.1 bc1	2.6 c2	2.9 bc1
Tournament	3.0 a1	3.1 b1	3.1 a1	3.1 bc1	2.3 d3	2.7 cd2
OARS	3.0 a12	3.1 b1	2.8 b23	3.0 c12	2.3 d4	2.7 cd3
Matador	3.0 a1	3.1 b1	2.9 b12	2.7 c23	2.4 d4	2.6 d34
Cascade	2.9 a1	2.9 b1	2.9 b1	2.9 c1	2.3 d3	2.6 d2

†Means followed by the same letters in each column were not significantly different based on Fisher's protected LSD at $P<0.05$; Means followed by the same numbers in each row were not significantly different based on Fisher's protected LSD at $P<0.05$.

Summary

- Certain selected wetting agents were able to remove organic carbons from the sand-wetting agent system;
- Field experiment confirmed the effect of selected wetting agents, although the mechanism is yet to be determined.
- Research in 2016 will continue the field experiment, and focus on assessing sand particles by Scanning Electron Microscope.

Development of Golf Course Fairway Renovation Strategies to Transition to More Sustainable Cool-Season Turfgrasses

John C. Inguagiato, Jason J. Henderson, Kevin M. Miele
Department of Plant Science and Landscape Architecture, University of Connecticut

Fairway conversion to newly developed stress tolerant turfgrasses provide golf courses an opportunity to reduce inputs over their largest maintained acreages. However, a challenge for many superintendents is identifying the best practices to rapidly and effectively renovate fairways with minimizing disruption to play and annual bluegrass (ABG) infestation. A series of studies are being conducted to provide best management practices for fairway renovation that address these concerns.

Current glyphosate label recommendations specify waiting 7-d before initiating mechanical practices that may interfere with herbicide translocation. A study was conducted in 2014 and 2015 to determine how soon after glyphosate application seedbed preparation practices could be initiated to shorten the duration of fairway renovations without reducing herbicide efficacy. Glyphosate was applied to a mature creeping bentgrass (CBG) fairway turf 7-, 5-, 3-, 1-, or 0-days before seedbed preparation practices were initiated. Seedbed preparation treatments included vertical mowing (1 inch depth, 2 directions), core cultivation (0.5 inch tines, 1.5 x 2 inch spacing, 2 inch depth), vertical mowing + core cultivation, or none. Glyphosate provided complete CBG control regardless of application timing or seedbed preparation method. No CBG recovery was observed after 40 days. Results from this study demonstrate that aggressive seedbed preparation and seeding practices may commence within one day of glyphosate application with no reduction in herbicide efficacy. The outcome of this research is a potential savings of one week for courses closed due to fairway renovation.

A larger three factor study was initiated during early-September 2014 and 2015 on golf course fairways in Connecticut. This study was designed to assess optimal eradication strategies of existing turfgrass, seedbed preparation methods, and seeder types to establish CBG and minimize ABG contamination. The main plot was seedbed preparation (none, verticut, or core cultivation), sub-plot was seeder type (no seed, drop, spike, or slit seeder), and sub-sub plot was non-selective herbicide (glyphosate only vs glyphosate + dazomet). Creeping bentgrass (007, 13M, Barracuda blend) was seeded at 1 lb. 1000 ft^{-2} except in the no seed plots. All treatments were completed within 5 days of herbicide application.

Bentgrass cover was similar among the three seeder types wherever seed was applied during both years. Preparing the seedbed by core cultivating or verticutting increased bentgrass cover in 2014, but had no effect in 2015. Dazomet + glyphosate more than doubled (2.4-fold) bentgrass cover compared to glyphosate only, in all seeded plots during 2015 (Figure 1).

A seedbed preperation and seeder type interaction influenced ABG contamination in both years; although specific differences were variable between years. When no CBG seed was applied, verticutting increased ABG contamination 79-81% compared to core cultivation during both years (Table 1). Core cultivation and non-cultivated plots had similar ABG contamination when CBG seed was not applied during both years. Applying CBG seed, regardless of method, frequently reduced ABG contamination. Core cultivation followed by slit seeding or drop spreader were among the treatments which resulted in the least ABG contamination each year (Table 1). Dazomet + glyphosate reduced ABG contamination

70% compared to glyphosate only, regardless of seedbed preparation or seeder type in 2015, but had no effect on ABG in 2014.

Additional studies are planned comparing our optimized renovation strategies during summer, and fall timings as well as evaluation of post-renovation chemical control of ABG. Separately, we will seek to determine the minimum time play should be excluded from newly established CBG fairways to minimize disruption to play and turf damage. These studies should provide best management practices to rapidly and effectively transition existing fairways to new, more sustainable creeping bentgrass varieties.

Bullet Point Summary:

- Core cultivating or verticutting before seeding occasionally improved bentgrass establishment. However, verticutting before seeding increased ABG contamination.
- Seeder type (i.e., slit, spike, or drop) had little effect on efficacy of bentgrass establishment over the two years of this study.
- Applying bentgrass seed, frequently reduced ABG contamination regardless of method. However, core cultivating with slit or drop seeding were typically among the treatments with highest CBG and least ABG cover over both years.
- Dazomet greatly improved CBG cover and reduced ABG cover, however result was only observed in 2015.

Table 1. Percent annual bluegrass infestation affected by interaction of seedbed preparation and seeder type on golf course fairways in Wethersfield, CT and Baltic, CT during Autumn 2014 and 2015, respectively.

	Seedbed Preparation					
	20 Oct 2014 (6 weeks after seeding)			2 Nov 2015 (7 weeks after seeding)		
Seeder Type	None	Verticut	Core Cultivate	None	Verticut	Core Cultivate
	---------- % annual bluegrass ----------					
No Seed	19.9 a†B‡	62.2 aA	34.8 aB	58.9 aAB	75.3 aA	41.7 aB
Drop	29.8 aAB	48.4 abA	6.7 bB	46.7 abA	32.1 bA	30.3 aA
Spike	36.9 aA	18.5 cA	18.6 abA	29.3 bA	24.9 bA	32.1 aA
Slit	36.6 aA	26.2 bcAB	8.8 bB	43.1 abA	26.5 bA	25.0 aA

† Means within columns followed by the same lowercase letter are not significantly different based on Fisher's LSD test.

‡ Means within rows, and evaluation date, followed by the same uppercase letter are not significantly different based on Fisher's LSD test.

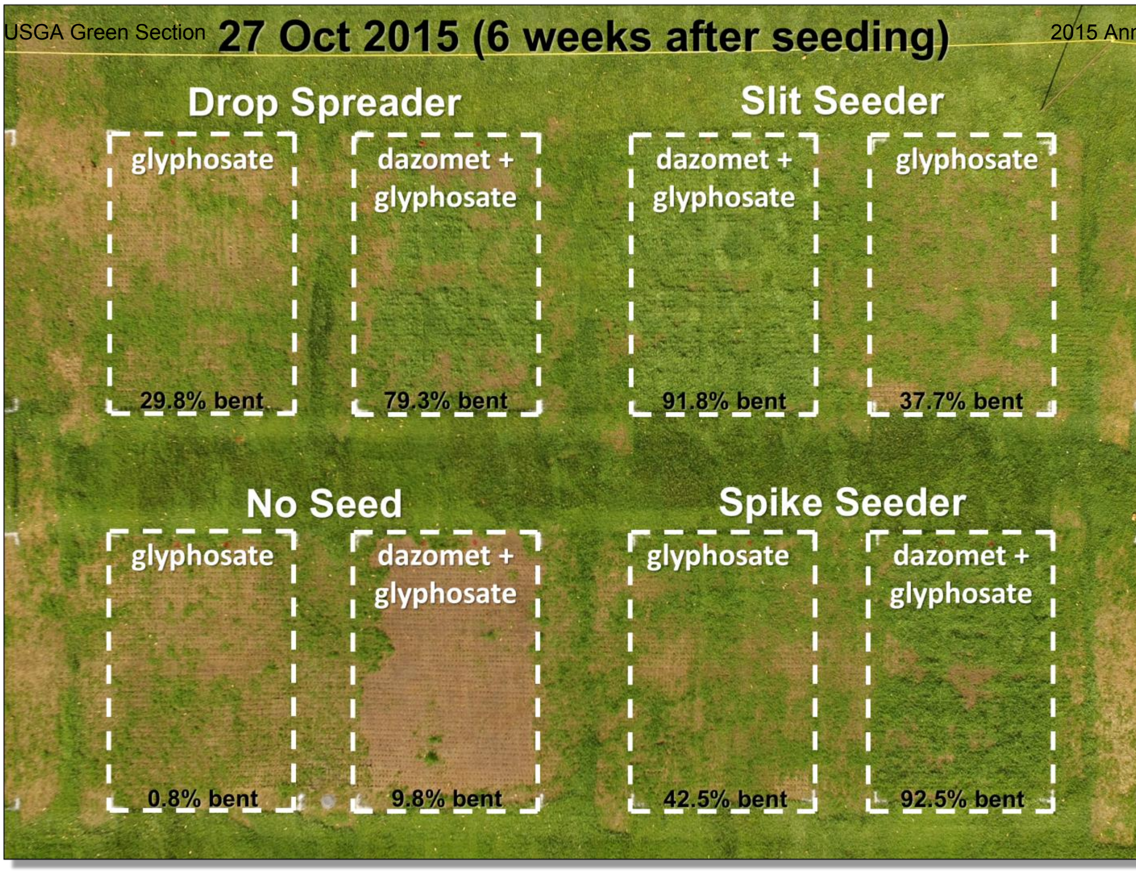


Figure 1. Percent creeping bentgrass establishment affected by interaction of seeder type and herbicide on a golf course fairway in Baltic, CT during Autumn 2015. Plots shown below were core cultivated

Figure 2. Verticutting the top inch of existing fairways prior to re-seeding increases annual bluegrass contamination.

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

Doug Soldat, Ph.D.

University of Wisconsin-Madison

There is no bigger challenge facing the golf industry than water use. We believe that one day, use of potable water for golf course (and landscape) irrigation will be considered indefensible, even in water-rich parts of the world. This means that alternative sources of potentially poor water quality will become the norm. Alternative sources of irrigation include primary, secondary or tertiary effluent and harvested water from surface runoff. These sources have considerable spatial and temporal variation in their chemical composition. A plethora of management guides can be found for using poor-quality water for turfgrass irrigation; however, very little research has been conducted as to how the specific water quality parameters affect golf course soils. We recently discovered flaws in the SAR and SARadj equations which lead to inaccurate assessments of sodic hazard and faulty recommendations. For this project, we will test a new equation that corrects the flaws of the previous equations using an experimental approach in the laboratory that allows us to observe exactly what happens to saturated hydraulic conductivity as sodium and salinity levels change during evapo-concentration. The results of this research are expected to demonstrate a more accurate way of estimating sodic hazard and will improve our understanding of and ability to assess poor irrigation water quality in golf course soils.

In 2015, we focused on identifying golf courses that had soil types that would be ideal for testing using the University of California Davis Soil Web http://casoilresource.lawr.ucdavis.edu/gmap/ and the USGS national water information system http://maps.waterdata.usgs.gov/mapper/index.html to identify where in South Dakota well water sampled had high sodium content. With these tools we narrowed down the golf courses we wanted to sample to six courses including Lee Park Golf Course (Aberdeen, SD), Olive Grove Golf Course (Groton, SD), Britton Country Club (Britton, SD), Leola Country Club (Leola, SD), Medicine Creek Golf Course (Presho, SD), and Fish Lake Country Club (Plankinton, SD). From our soil maps we determined the best possible locations to take five 1 m deep soil cores of two inches in diameter from each course. We did this with a truck-mounted Giddings soil probe. We also obtained five gallons of irrigation water from each course. Soil and water samples are being kept at 4°C in a walk-in cooler prior to hydraulic conductivity testing which will begin in early 2016.

Incorporating Cultivation Practices and Products to Reduce Salinity Parameters from Poor Quality Irrigation Water on Golf Course Fairways

USGA ID#: 2015-13-528

Prior to the initiation of the study, Lubbock received very heavy, leaching rainfalls during the fall and spring seasons that likely facilitated the leaching of accumulated salts from the previous drought years. However, no measurable rainfall occurred from the first week of July through mid-September (10 weeks), which increased the application and reliance of irrigation water to maintain fairways. Cultivation treatments (Image 1) were the primary factor that resulted in significant differences in 2015. The core-aerified treatments at Meadowbrook GC initially had poorer turf quality and cover, but all treatments were similar following four weeks of recovery. The volumetric water content within core-aerified treatments remained significantly lower than sliced or non-cultivated treatments throughout the trial. In contrast, core-aerified treatments at the Rawls Course exhibited poorer turf quality, cover, and color through most of the summer (Fig. 1). The individual aerification holes filled in with grass relatively quickly, but each hole remained visible throughout the summer (Image 2). Soil from the Rawls had a higher clay content and potentially poorer soil structure that may have caused this problem. In addition to the different soil characteristics, the very dense 'TifSport' hybrid bermudagrass fairways at the Rawls course may have altered recovery from aerification compared to the common bermudagrass fairways at Meadowbrook GC.

The products applied did impact the electrical conductivity (EC) of the treatments. The application of the granular products (gypsum, Vertical-G, or DG Gypsum) significantly increased the measured EC level (Fig. 2). August soil samples were obtained just one week after application, which resulted in a much higher EC than liquid products or the untreated control. However, significantly higher EC values were also observed at Meadowbrook GC for those treatments in October, five weeks after granular products were applied. The high level of calcium in these products that would be deposited into the soil once disassociated from the granule likely increased the EC. Analysis from the X-ray fluorescence gun (PXRF) will be helpful to identify the elements that may be present within these soil samples demonstrating the significant increase in EC.

Ratio vegetation index (RVI) data were obtained weekly using the handheld RapidScan CS-45 meter (Holland Scientific, Lincoln, NE). The RVI is similar to NDVI, but RVI is recommended when measuring complete canopy cover in a turf situation. Cultivation treatments significantly affected RVI at both locations. The core-aerified treatments at the Rawls Course had significantly lower RVI on 10 dates compared to other cultivation treatments (Fig. 3). Core-aerified treatments were initially lower at Meadowbrook, but the non-cultivated treatments exhibited significantly lower RVI in August once reliance on supplemental irrigation was greatest (Fig. 3). We are currently maintaining the study areas at both locations and will be applying the same cultivation and product treatments in 2016 to determine the potential to manage salinity in the upper surface of golf course fairways.

Summary bullet points:

- Core-aerified treatments were slower to heal, especially at the Rawls Course, which resulted in poorer turf quality, cover, and color throughout the summer and early fall.

- The ratio vegetation index (RVI) was significantly improved with cultivation practices on the common bermudagrass fairways at Meadowbrook Golf Club in August when rainfall was scarce and the reliance on supplemental irrigation was increased.
- Granular product applications increased measured electrical conductivity levels at both locations.
- Further analysis of soil with the portable X-ray fluorescence gun should determine the specific elements that were providing the increased electrical conductivity levels in these treatments.
- Continuing this research in 2016 will help us determine the additive effects of implementing these cultivation treatments and product applications as a long-term management solution to reducing salinity in the upper soil layer of golf course fairways.

Tables, Figures, and Images

Trt #	Product trt	Rate/1,000 ft^2	Application timing
1	Untreated control	None	None
2	Kelly's gypsum	10 lbs	Applied once a month
3	ACA 2994	8 fl oz	Applied once per two months
4	ACA 2786	4.5 fl oz	Every two weeks
5	ACA 1900 ACA 2786	8 fl oz 4.5 fl oz	Initial application and 6 wks after Two aps two weeks apart between ACA 1900
6	Oars PS	5 fl oz	Applied once a month
7	Vertical G	12 lbs	Applied once a month
8	Oars PS Vertical G	5 fl oz 12 lbs	Applied once a month with liquid applied over the top of granular
9	DG Gypsum	12 lbs	Applied once a month
10	Cal-Pull	6 fl oz	Applied once a month

Table 1. Products and rates applied to three replicates of each cultivation treatment [non-cultivated, AerWay Slicer, and core-cultivated (3/4 inch diam. tine on 2 inch spacing)]. Initial applications were made on 16 June 2015 with subsequent applications made on manufacture recommendation.

Image 1. Meadowbrook Golf Club (left) and Rawls Golf Course (right) following cultivation treatments [non-cultivated, AerWay Slicer, and core-cultivated (3/4 inch diam. tine on 2 inch spacing)] applied on 15 June 2015.

Image 2. Rawls Golf Course study area on 7 October 2015 at the conclusion of the research year. The lower left of the image illustrates the visible evidence remaining from core-aerification in June on the 'TifSport' hybrid bermudagrass fairways.

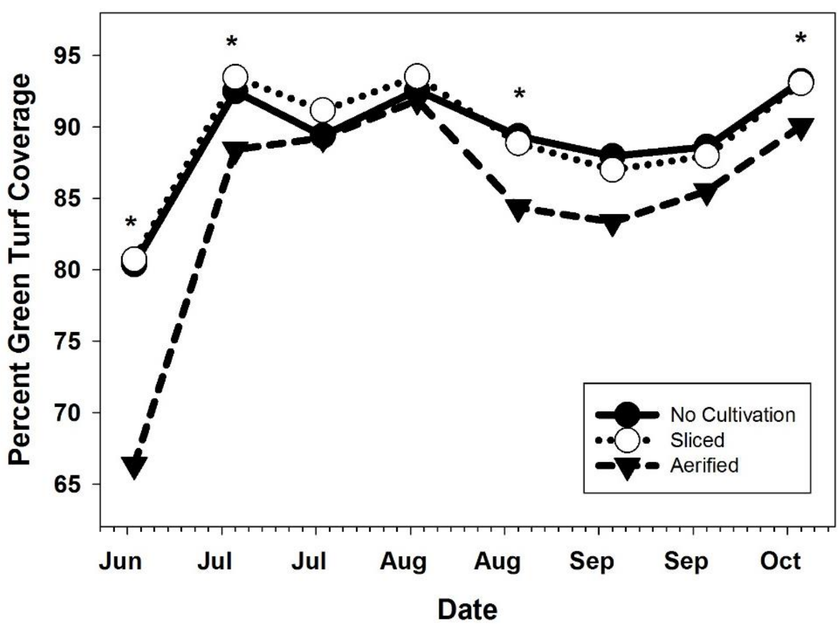


Figure 1. Percent green cover measured from digital image analysis at the Rawls Golf Course. Dates with asterisks are statistically different at $\alpha = 0.05$. Comparable to data for visual turf quality and color in the same area.

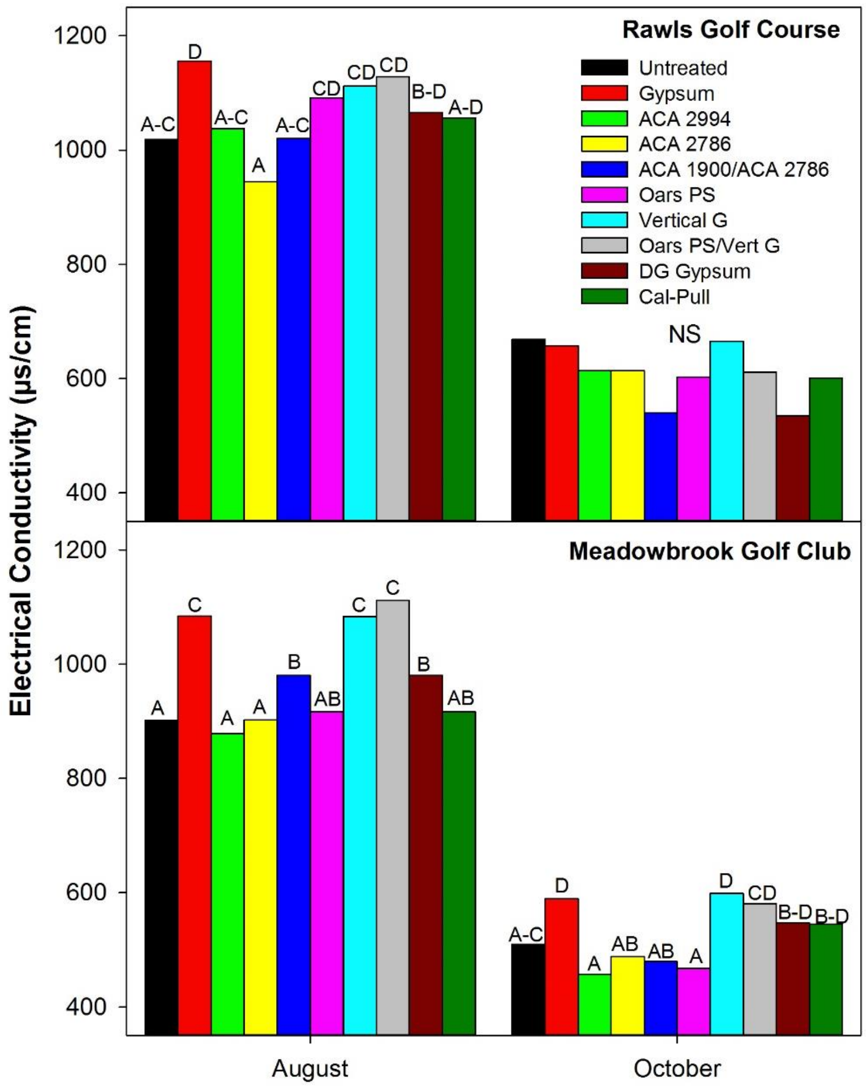


Figure 2. Soil electrical conductivity from samples obtained in August and October 2015. Three soil samples were obtained with a profile sampler (3 x 0.5 x 3.5 inch) from each experimental unit and combined for soil analysis. Mean values for the three replicates are provided. Bars sharing the same letter are statistically similar at $\alpha = 0.05$.

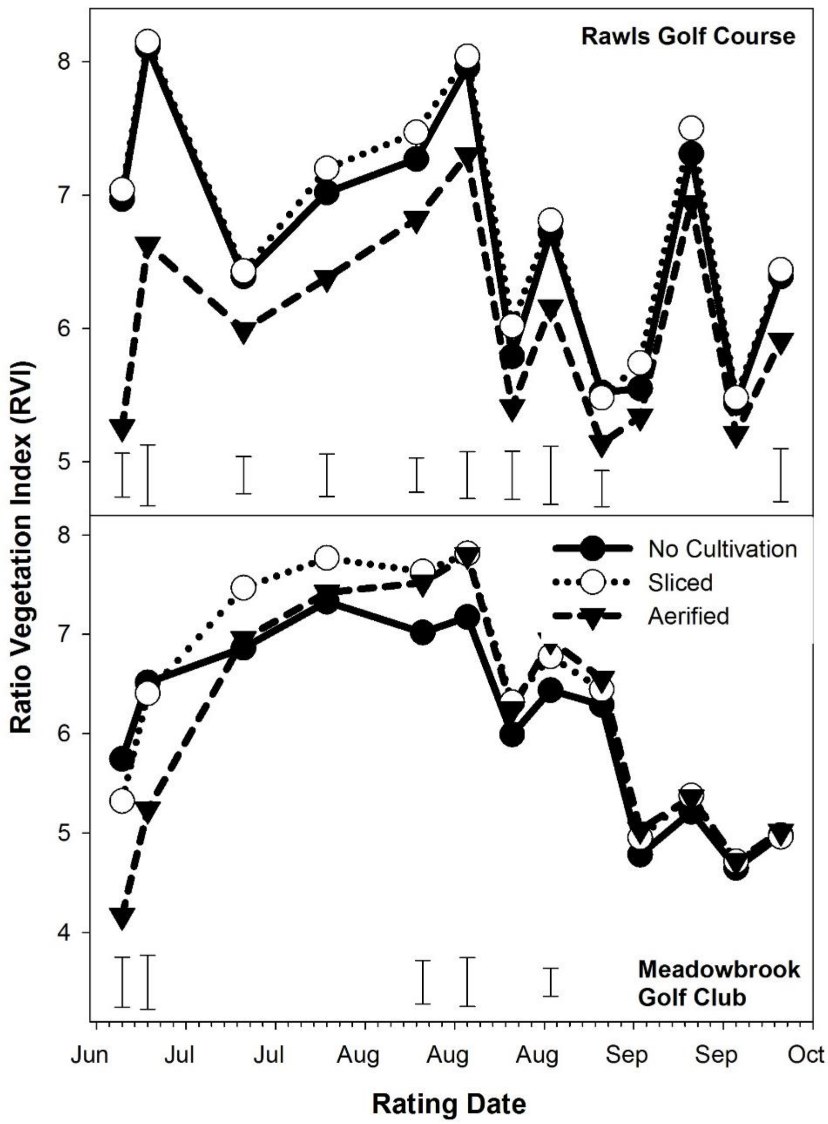


Figure 3. Ratio vegetation index (RVI) measured from the RapidScan CS-45 meter. A single measurement was taken from each plot and averaged over all product applications and the three replicate cultivation treatments. Error bars represent the least significance difference value for each significant rating date at α = 0.05.

Genesis and prevention of iron-cemented layers in sand putting green soil profiles
USGA ID#: 2015-14-529

Glen R. Obear and William C. Kreuser

- A column study was initiated in October 2015 to determine how root zone chemistry affects iron accumulation. The study will be completed in 2016 and will be replicated in a rhizotron facility in the field.
- Preliminary data show that putting greens with high pH gravel layers may be more prone to formation of cemented layers when high rates of iron are applied. Root zones with high pH sand may be less likely to form layers at the sand/gravel interface due to immobilization of Fe near the surface.
- In 2016, soil samples will be collected from at least 50 golf courses to determine the distribution of Fe-cemented layers, and to create and validate a model to explain their formation.

Iron-cemented layers form in putting greens, leading to decreased water infiltration and anaerobic conditions in the soil. These layers have been documented, but the factors that lead to their formation have not been studied. The objectives of this study are to determine 1) how root zone chemistry affects iron accumulation at different application rates, and 2) the distribution of these layers across the US, which will provide a dataset against which a model can be created and validated (beginning late 2016).

A column study (Fig. 1) was established in October 2015 as a 2x2x3 factorial design with three replications. The root zone was comprised of a silica sand from Florida (pH 5.5) or a calcareous sand from Wisconsin (pH 8.2); both met USGA particle size recommendations. The gravel layer was comprised of either limestone (pH 8.8) or granite (pH 5.4). After establishment of creeping bentgrass, columns will receive weekly applications of ferrous sulfate at a rate of 50 or 200 kg ha^{-2}, and these will be compared to untreated columns. All columns will be irrigated to replace 150% of water lost through evapotranspiration. After each iron application, x-ray fluorescence (XRF) will be used to measure the concentration of Fe inside columns in 2.5 cm depth increments. Air permeability will be measured weekly to track changes in pore space resulting from iron accumulation. This study will be replicated in a rhizotron facility in the field in 2016.

Data from a preliminary trial show that XRF can accurately track accumulation of iron (Fig. 2). After eight applications at a rate of 200 kg $FeSO_4$ ha^{-2}, a marked accumulation was observable at the interface of sand and gravel in a column with low-pH sand and high-pH gravel (Fig. 3). Iron oxidized above the gravel layer in columns with low pH sand and high pH gravel. In columns with high pH sand, the Fe became immobilized near the surface and never reached the gravel layer. These findings suggest that iron-cemented layers are more likely to form in root zones with high pH gravel. However, these layers may be less likely to form in putting greens with high pH sand, since the iron is immobilized before it reaches the gravel. The full-scale study will provide a wealth of information about how root zone chemistry affects iron accumulation.

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

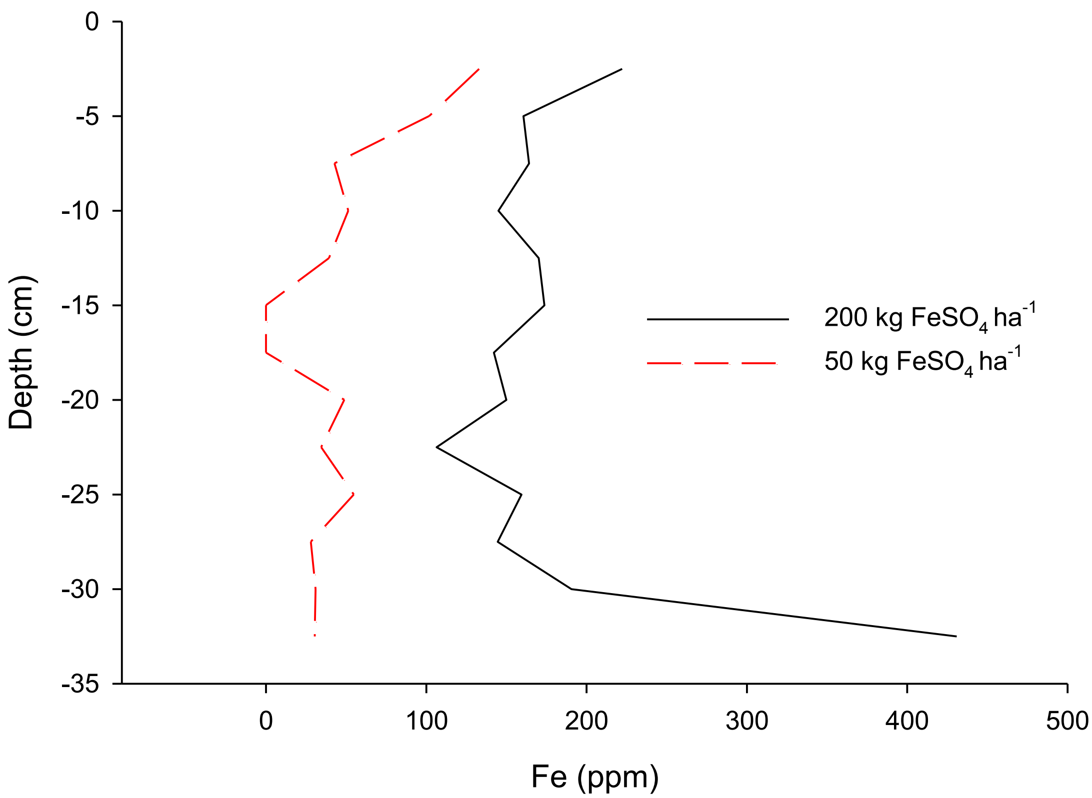


Figure 2. X-ray fluorescence measurements of iron in 2.5 cm depth increments in columns treated with 50 or 200 kg $FeSO_4$ ha^{-1}.

Figure 3. Iron-cemented layer at the sand/gravel interface of a root zone with a low-pH sand and a high-pH gravel. The column received eight total applications of Fe at a rate of 200 kg $FeSO_4$ ha^{-1}.

Excessive Winter Crown Dehydration Affects Creeping Bentgrass Cold Hardiness
USGA ID#: 2015-15-530
Darrell J. Michael and William C. Kreuser

- A field study was conducted during the winter of 2014-2015 to evaluate the effectiveness of commonly used desiccation prevention treatments. It is being replicated during the winter of 2015-2016.
- Heavy sand topdressing and covers provided a physical protective barrier from the environment which reduced desiccation, sustained crown moisture content, and accelerated spring green-up.
- The relationship between crown moisture and cold hardiness is currently being evaluated in a winter desiccation growth chamber.

The winters of ’13-14’ and ‘14-‘15 proved to be difficult winters for turf managers throughout much of the northern Great Plains region. Snow events were infrequent and vastly increased desiccation injury on high value turfgrass. The objective of this study was to evaluate the effectiveness of commonly used desiccation prevention treatments.

The study was replicated in Mead, Kearney, Mullen and Gering, NE (Fig. 1) as well as Sioux Falls, SD to maximize the potential for winter desiccation. Impermeable tarps were temporarily used to withhold precipitation at the Mead site to increase the likelihood of desiccation. The Kearney site received negligible snowfall and was subjected to desiccating conditions. Mullen received light-frequent winter irrigation while Gering and Sioux Falls sites sustained winter-long snow cover. Treatments included fall topdressing, GreenJacket™ permeable and impermeable covers (GreenJacket, Genoa City, WI), antitranspirant (Transfilm™ PBI-Gordon Corporation, Kansas City, MO), turf colorant (Foursome™ Quali-Pro, Pasadena, TX), horticultural spray oil (Civitas™ Petro-Canada, Mississauga, ON, CA), and wetting agent (Tournament Ready™ KALO, Overland Park, KS).

Crown moisture content (CMC) and electrolyte leakage (EL) were measured monthly from December to March at the Mead site. Crown moisture content was measured before visible green-up on 13 March at the other sites. Visual turf quality (TQ) was collected weekly to evaluate spring regrowth in the field at Mead and every other day in the greenhouse from a sample collected on 13 March from the other sites.

Sand topdressing and both covers were the best performing treatments at Mead and Kearney during March with CMC’s staying above 0.51 g H_2O g^{-1} fresh weight (Fig. 2, Fig. 4). Collectively, sprayable treatments yielded less consistent results and rarely provided benefit. Treatments that sustained CMC levels throughout the winter had a higher TQ in the spring and recovered faster at Mead and Kearney (Fig. 3, Fig. 5). Crown moisture contents at Mullen and Gering were not statistically different across treatments with CMC’s greater than 0.50 g H_2O g^{-1} fresh weight. Sand topdressing significantly reduced electrolyte leakage compared to other sprayable treatments and the untreated control. Cate-Nelson analysis found that a critical crown moisture value of 0.51 g H_2O g^{-1} fresh weight was necessary to achieve a TQ which would allow for the turf to recover in the spring. The growth chamber research is ongoing with expected results this spring.

Figure 1. Plot space at the Gering site. The plot space location was selected in an area that typically expereinces winter desiccation.

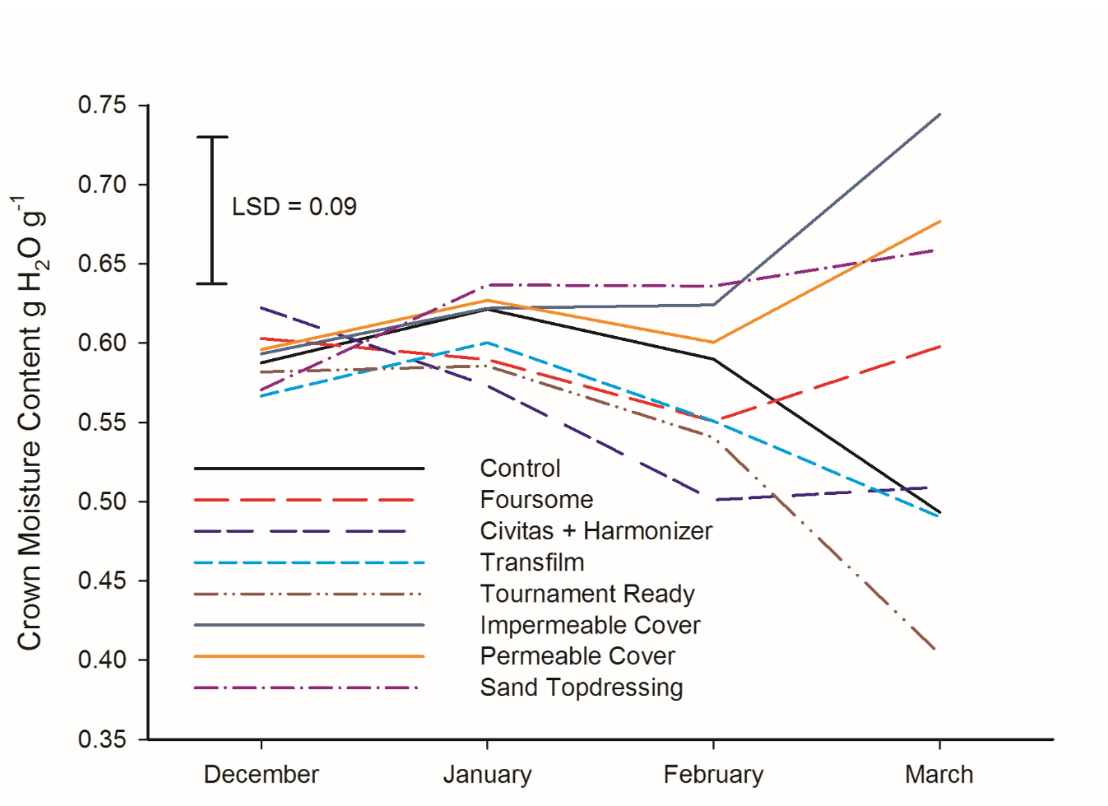


Figure 2. Crown moisture content monitored throughout the winter months at the John Seaton Anderson Turfgrass Research Center in Mead, NE.

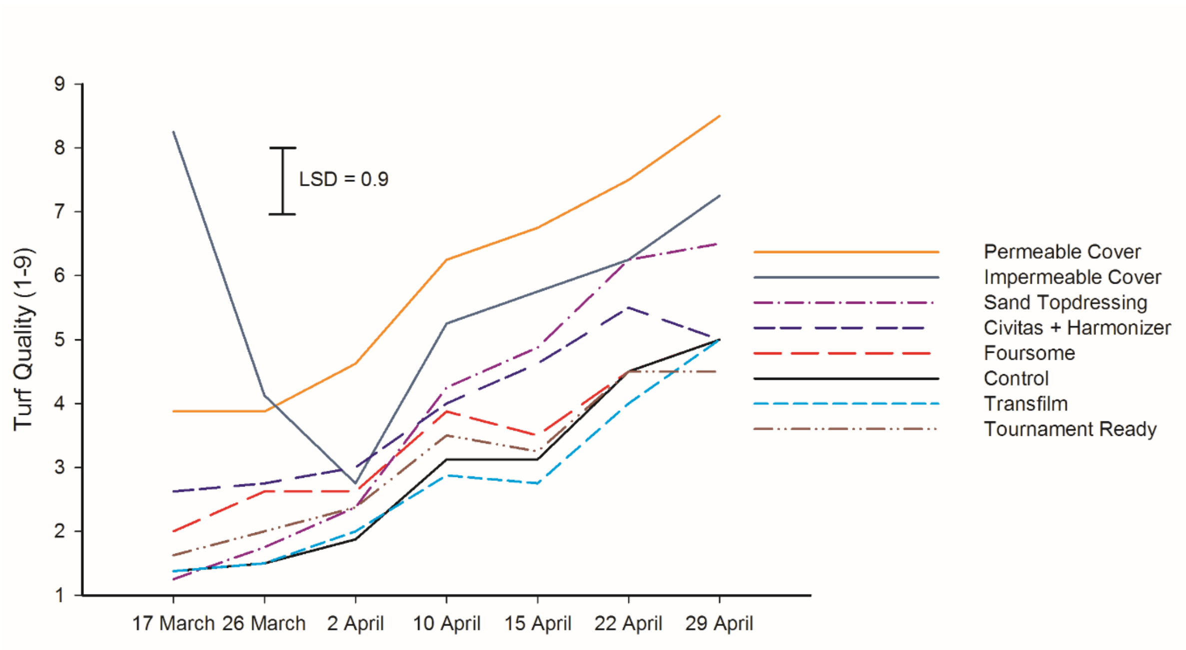


Figure 3. Turf quality at the John Seaton Anderson Turfgrass Research Center in Mead, NE. The sharp decline in turf quality for the impermeable cover is credited to premature regrowth in the spring and damage from -10°C night temperatures.

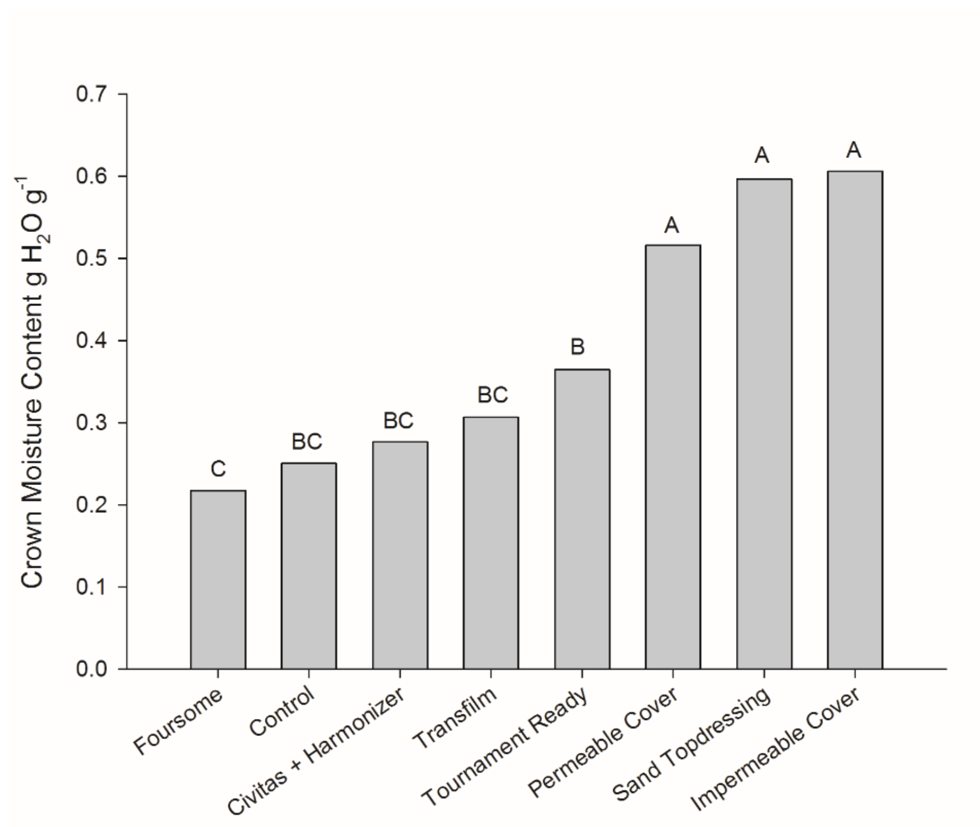


Figure 4. Crown moisture content on 14 March, 2015 at the Kearney, NE site. Different letters above treatment means denote significant difference.

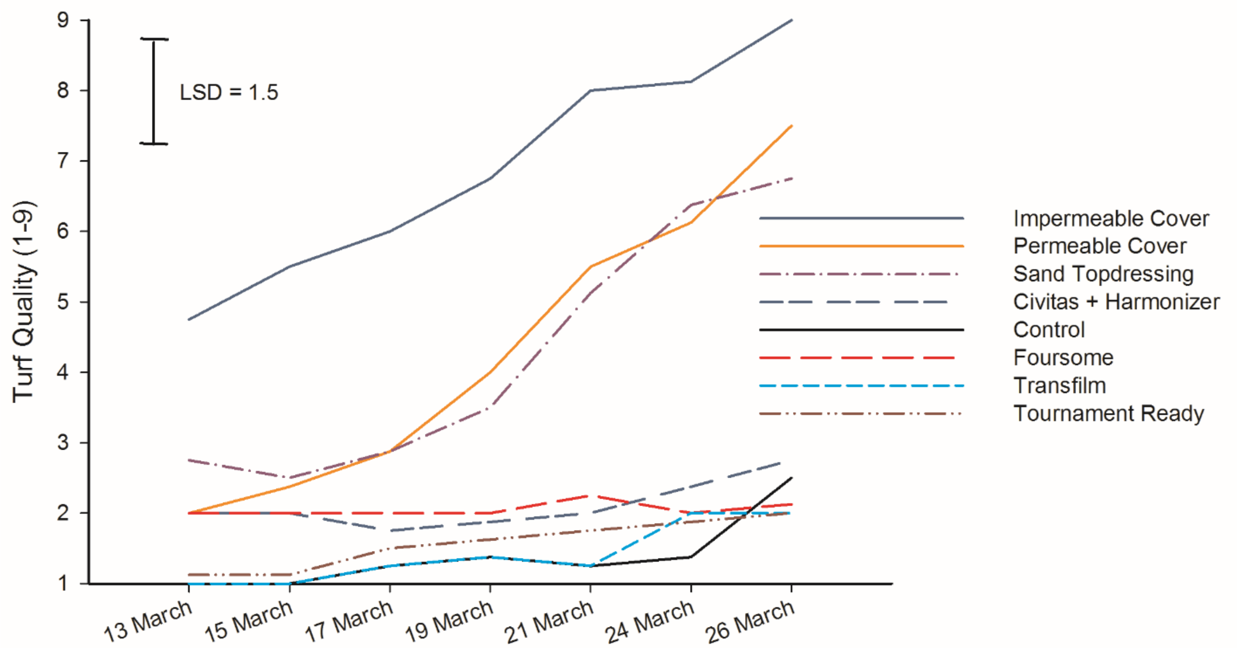


Figure 5. Turf quality at the Kearney, NE site. Field ratings were taken on 13 March, and a sample was removed and placed in the greenhouse to evaluate recovery.

Evaluating small unmanned aircraft systems for detecting turfgrass stress with an emphasis on drought

Dale Bremer, Deon van der Merwe, Jack Fry, Steve Keeley, Jared Hoyle, Megan Kennelly, Kevin Price

Recent advances in technology may offer potential for using small unmanned aircraft systems (sUAS) for turfgrass management. Small UAS utilize remote sensing to measure plant canopy properties and diagnose plant stresses, and can cover areas the size of an 18-hole golf course much more quickly than conventional handheld or ground-vehicle-based platforms.

Our objectives were to: 1) evaluate ability of sUAS technology to detect drought stress in turfgrass across a gradient of irrigation regimes from well watered to severe deficit irrigation, and compare measurements with traditional (handheld) techniques; and 2) evaluate sUAS measurements of a golf course during the summer and fall.

A field study was conducted from 29 June to 31 August, 2015, on creeping bentgrass mown at 16 mm under a rainout shelter (Fig. 1). Six irrigation treatments began as 150, 125, 100, 75, 50, and 25% evapotranspiration (ET) replacement (overwatered to severely stressed). We hypothesized sUAS technology may detect overwatered as well as deficit irrigated turfgrass. However, after 3 weeks treatments were adjusted downward to 100, 80, 65, 50, 30, and 15% ET replacement (17 July), because no differences were evident among 75 through 150% ET and drought stress was negligible in all but 25 and 50% ET. Measurements were taken weekly with a Canon S100 digital camera, modified to include near infrared (NIR), green, and blue bands. The camera was mounted on a S800 EVO hexacopter flown at 15 m within 3 hours of local solar noon. Images were processed using Agisoft PhotoScan Pro (Fig. 2), AgVISR, and ArcGIS (Figs. 3 and 4). Eight vegetation indices (combinations of NIR, green, and blue bands) and the three individual bands were evaluated for ability to detect drought stress. Additional measurements included soil moisture (7.5 cm depth; FieldScout TDR 300), visual quality, percentage green cover (digital image analysis); and NDVI (handheld, FieldScout 1000).

By the end of the study, after 64 days of irrigation treatments, soil moisture was highest in 100 and 80% ET and declined steadily through 65%, 50% and 30% ET; soil moisture was similar between 30 and 15% ET (Fig. 5A). Turfgrass quality was similar, and quality was acceptable (> 6), among 100 through 65% ET, but quality declined thereafter and was unacceptable at 50 through 15% ET (Fig. 5B). Green cover was similar among the 100 through 50% ET treatments, but it declined rapidly at 30 and 15% ET (Fig. 5C). Significant bare soil was visible in 15% ET, and less so in 30% ET. Measurements with handheld NDVI detected no differences among the 100 through 50% ET plots (Fig. 5D). Among the 8 vegetation indices and 3 individual bands, the near infrared (NIR) band and GreenBlue vegetation index [(Green – Blue)/(Green + Blue)] were most sensitive, and the only ones that detected differences between 65% ET and the two highest irrigation levels (Figs. 5E and 5F; Figs. 3 and 4).

Preliminary measurements of a functioning golf course revealed interesting differences in fairways, tees, and greens between summer and fall. Additional research will be conducted in 2016 (Fig. 6).

Bullet Points:

- At the end of the study (31 Aug), no differences in turf quality were visible between the 100 and 65% ET treatments (Fig. 5B and 5C).

- However, soil moisture was less at 65% than 100% ET (Fig. 5A).
- The only measurements that detected differences in vegetative properties between 100 and 65% ET treatments on 31 Aug. were the NIR band and GreenBlue vegetation index (Fig. 3, 4, 5E, and 5F).
- This indicates using ultra-high resolution remote sensing with small UAS has potential to detect drought stress before it is visible to the human eye.
- Preliminary measurements of a functioning golf course revealed interesting differences in the turfgrass between summer and fall (Fig. 6).

Figure 1. Aerial view of creeping bentgrass plots (top, highlighted with black border). Precipitation was excluded from plots by an automated rainout shelter (inset A), which covered plots during rainfall. This allowed precise irrigation amounts to be applied to individual plots (inset B).

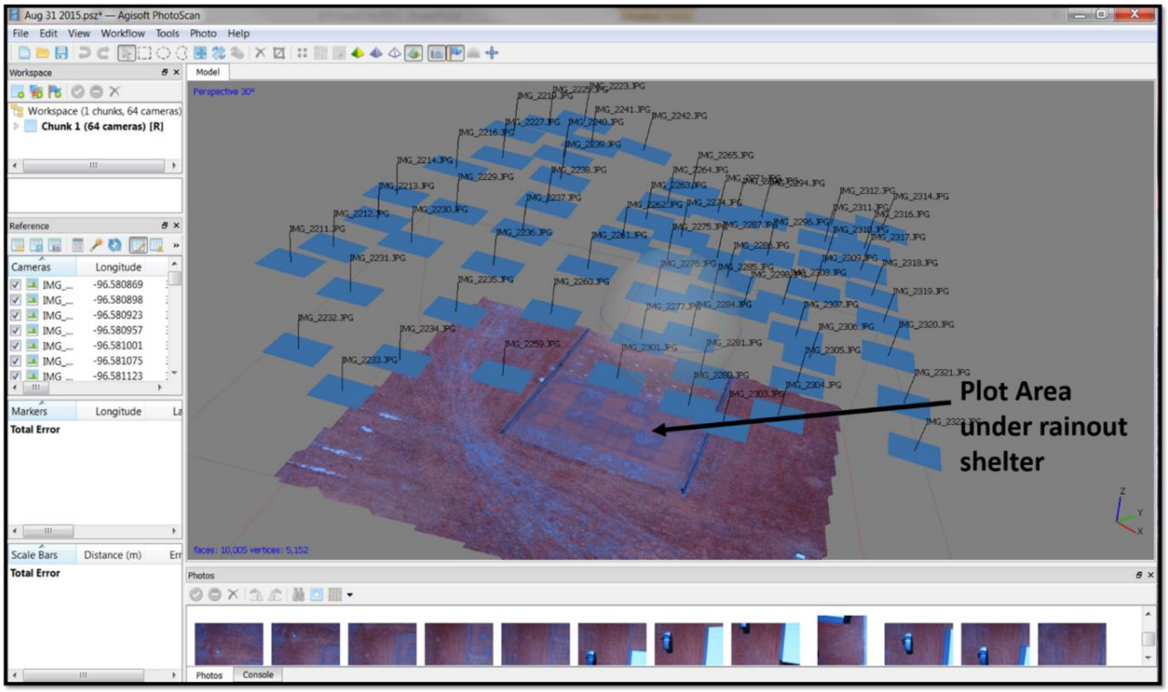


Figure 2. Building a model of the plot surface area using digital images taken from sUAS. Blue squares indicate position of camera during flyover of plots. Multiple images were "stitched" together to minimize angle effects and create an orthomosaic image, from which vegetation indices were developed.

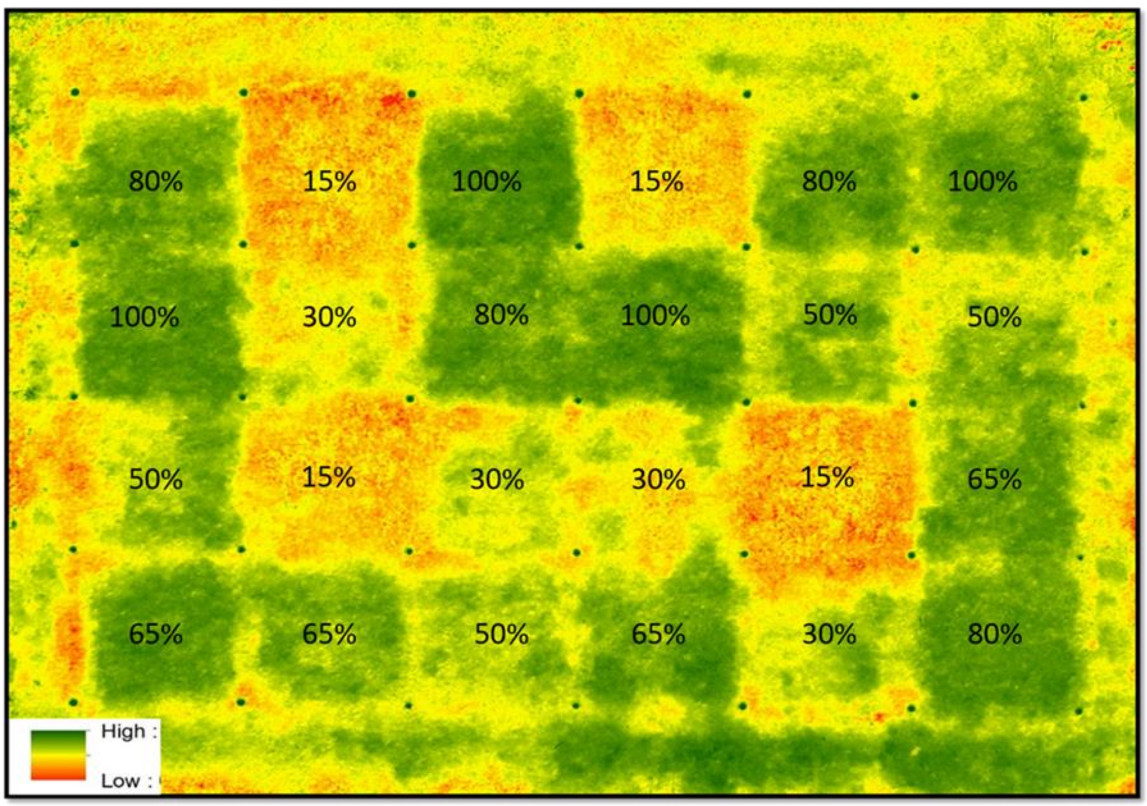


Figure 3. Color-enhanced image of plots in the near infrared (NIR) band. 31 Aug. 2015. Percentages denote ET replacement irrigation treatment. Dark green (high) indicates more turf biomass. Image created in ArcGIS.

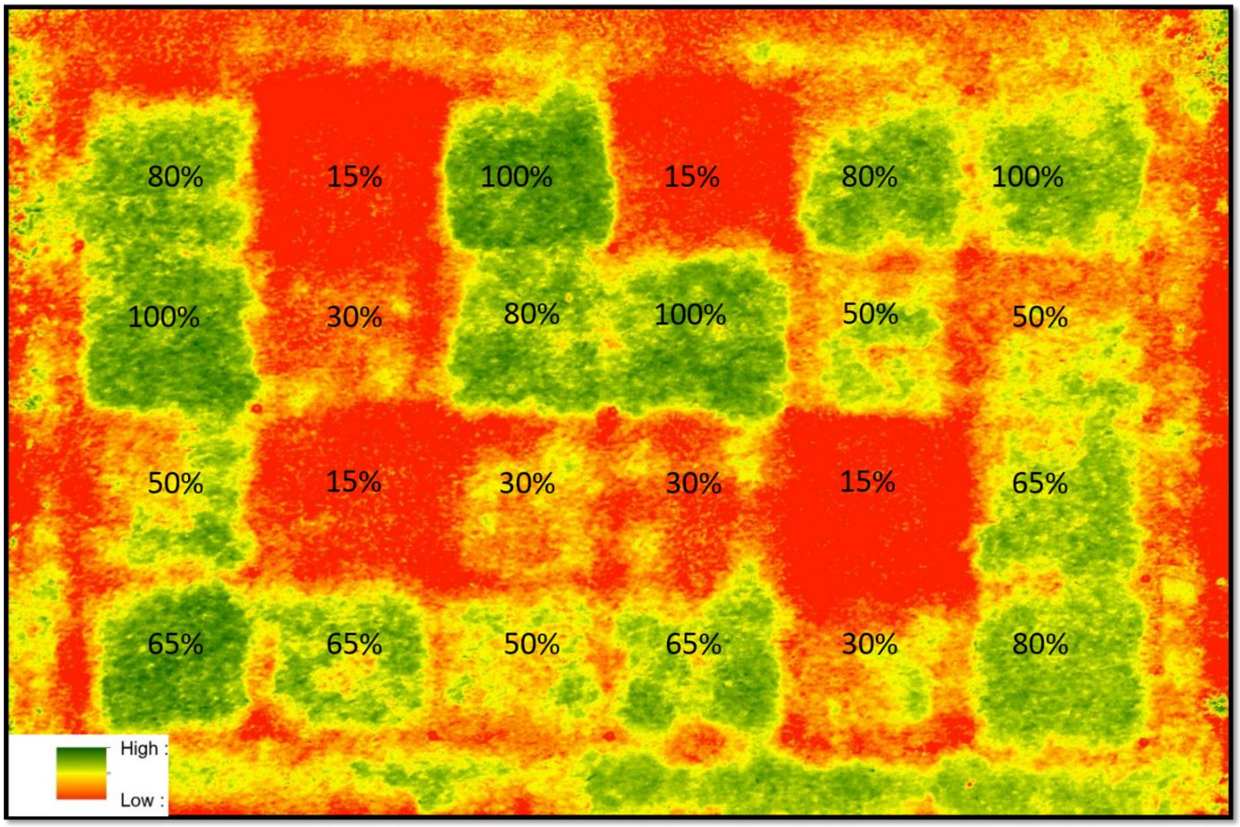


Figure 4. Color-enhanced image of plots in GreenBlue vegetation index [(Green-Blue)/(Green+Blue)]. 31 Aug. 2015. Percentages denote ET replacement irrigation treatment. Dark green (high) indicates more turf biomass. Image created in ArcGIS.

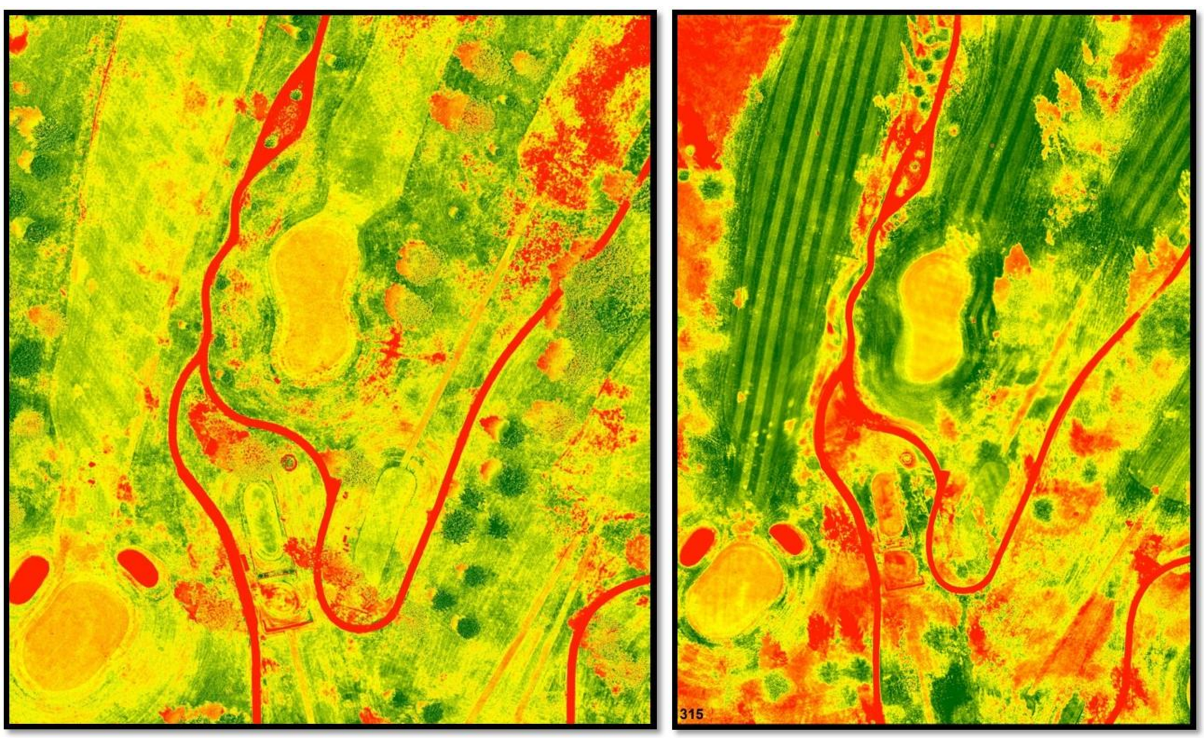


Fig. 6. Images of 3 partial fairways and 2 greens and tees on a functioning golf course in Manhattan, Kansas. Image on left was Aug. 3 and on right was Nov. 13

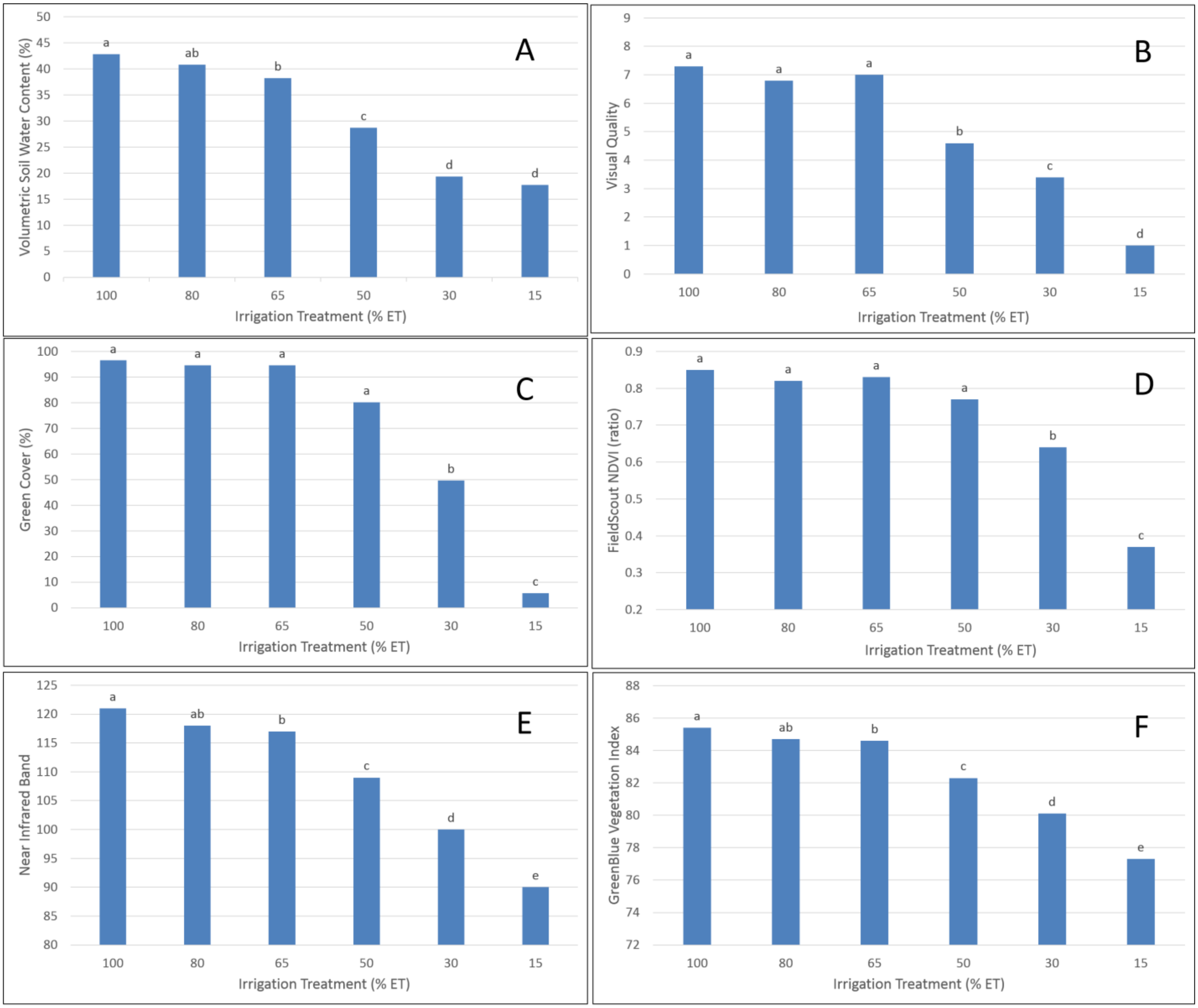


Figure 5. Measurements on the final day of the study of volumetric soil water content (A); visual quality (B); percentage green cover (C); NDVI with handheld instrument (D); near infrared (NIR) with modified digital camera mounted on sUAS (E); and GreenBlue vegetation index obtained with modified digital camera mounted on sUAS (F).

Low Maintenance Grasses for Water Conservation for Golf Course Roughs

D.M. Kopec, N. Leitner J. Gilbert and M. Pessarakli

University of Arizona

USGA ID#: 2015-18-533

In a continual effort to reduce irrigation amounts applied to golf course turfs, the concept of incorporating low maintenance grasses into secondary roughs is a plausible means of saving water on large acreage golf courses. Instead of totally removing grass and replacing it with hardscapes or other non-playable surfaces, investigating the use of low maintenance grasses which (1) use less water than the standard turfgrass species and (2) which would also yield a playable surface, is warranted. With this in mind, 7 grasses were selected which may be candidates to meet both criteria. From long term observations, bermudagrasses which survive prolonged drought almost always demonstrate the features of large scale rhizome development (in terms of girth) and their pronounced appearance at lower soil depths. Likewise, buffalograss usually demonstrates visible wilt after a greater number of drought days than bermudagrass (acute drought), but it is slower to recover once water is re-applied. Using a linear irrigation gradient field design, 4 low maintenance bermudagrass cultivars (Cheyenne II, Wrangler, Nu-Mex Sahara, and Jackpot) and 3 diverse generational cultivars of buffalograss (Bison, Top Gun and, SunDancer) were established in a replicated field trail (Linear Irrigation with 4 replications). Bison and TopGun were replacements for 'Viva' Galetta Grass and Sand Drop seed, which had either too high a degree of dormant seed (dropseed) or did not tolerate crown compression from mowing equipment (Galleta). During the establishment phase of the experiment, high salinity and sodicity occurred at the top one inch of the plot surfaces, first noticed in the spring of 2015. Plots were treated with gypsum (to reduce soil ESP) and leached (to decrease salinity) in July 2015, followed by seeding of SunDancer and TopGun buffalograsses. Percent plot cover was nominally related to surface soil salinity, both measured in late August. TopGun appears slightly more tolerant of surface soil salinity than SunDancer. TopGun averaged 50% ground cover at 2600 ppm TDS, while SunDancer averaged 50% ground cover at roughly 2100 ppm TDS. Shoot counts were not taken, but cover was estimated on the lack of visible soil present.

In the spring of 2016, the entire field will be irrigated to determine plot width for the applied irrigation levels, and also to achieve field capacity conditions for one month of active growth. The linear irrigation (main center line of heads) will start as the irrigation treatment in late May, and continue through the summer of 2016. This test should produce results which will:

(1) Identify the minimal amount of irrigation needed to maintain a green cover surface for each individual grass
(2) Identify which grass will produce an acceptable green cover surface at a low total water application amount
(3) Provide information on the response of applied water in terms of turfgrass quality and cover at each level of applied water for each grass.

Bullet Point Summaries:

- Four large rhizome-type bermudagrasses and three buffalograsses will be evaluated for grass cover when receiving less than optimum ET replacement irrigation amounts, and mowed at 3.0 inches (secondary rough or low maintenance turf cover).

- TopGun buffalograss is slightly more salinity tolerant than SunDancer, based solely on ground cover estimates correlated with surface soil salinity TDS at the soil surface (0-2.5 cm)

Fig 1.

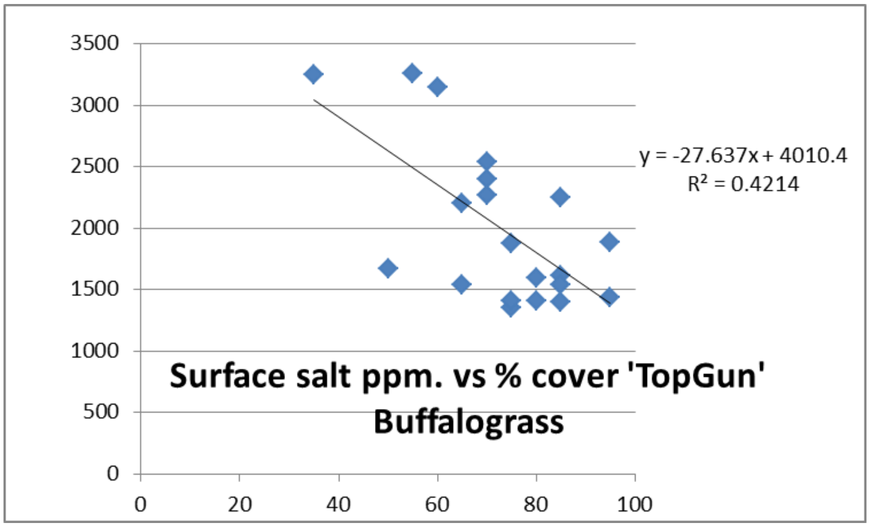


Fig 2

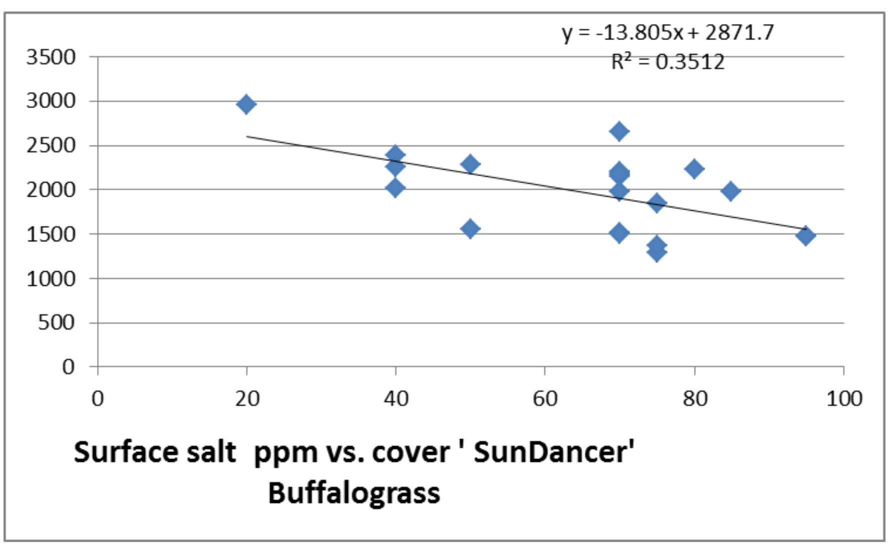


Fig 3. Seeding plots with sand mix.

Fig 4. Carefully hand raking small grass seeds into LIGA plots.

Fig 5. Established plots of low maintenance grasses in a Linear Irrigation design.

Evaluation of Fertilizer Application Strategies for Preventing or Recovering from Large Patch Disease of Zoysiagrass

Principal Investigator(s):
G. L. Miller[1], B.F. Fresenburg[1], and M. Kennelly[2]
University of Missouri[1] and Kansas State University[2]

Large patch caused by *Rhizoctonia solani* AG2-2 LP is a perennial disease that causes severe damage on zoysiagrass fairways in the United States transition zone. Control of this disease is difficult, and reliant on preventive fungicide applications in the fall and spring to achieve adequate control. Nitrogen fertilization during large patch development has been discouraged since brown patch in cool season turfgrasses, caused by a different *R. solani* anastomosis group, is more severe in over-fertilized turf. Recent research from Kansas State University, however, found fertilization with urea during the spring and fall resulted in less large patch severity. This information, along with the dramatic impact that ammonia-based nitrogen fertilization has had on reducing severity of other turfgrass diseases, necessitates a more thorough examination of nitrogen fertilization practices and the large patch pathosystem. The objectives of this research are to 1) determine the influence of nitrogen source on the growth and biology of the large patch pathogen, and 2) evaluate the impact of fertilization with different nitrogen sources on the large patch incidence and disease recovery in the greenhouse and field.

Laboratory assays utilizing ammonium sulfate as a sole nitrogen source consistently demonstrate a loss of hyphal pigmentation in large patch pathogen isolates. In pH buffered (with fumaric acid) and unbuffered media, subsequent studies have demonstrated increased mycelial growth of large patch pathogen isolates on calcium nitrate, intermediate growth on ammonium sulfate, and lowest growth on urea (**Fig. 1**). Greenhouse studies are being conducted to determine if these morphological changes subsequently result in a loss or reduction in pathogen virulence.

In 2013, a 3-year field experiment was initiated at the University of Missouri in Columbia, MO and Kansas State University in Manhattan, KS. Urea, calcium nitrate, and ammonium sulfate were applied to asymptomatic zoysiagrass at 0.75 lb N/1000 ft^2 when 5-day soil temperature averages taken at the 2" depth were either 60°F or 70°F in the spring, or 70°F in the fall. A standard program consisted of urea at 0.5 lb N/1000 ft^2 applied in June, July, and August.

Ammonium sulfate applied in fall and spring provided more green cover in spring 2014 on several rating dates during periods of large patch activity, providing some evidence an acidifying nitrogen source may reduce large patch severity compared to neutral or alkaline-inducing sources. Future studies are necessary to confirm this effect, however, since the result was inconsistent between the two sites in 2014, and was not observed again the following spring in Kansas. Fertilizer applications made in late spring to zoysiagrass (70°F soil temperature threshold) during active large patch epidemics resulted in decreased large patch severity (higher percent green cover) on several rating dates in Missouri, but was similar to the summer standard treatment in Kansas (**Fig. 2**). Though the nature of the difference among sites is unclear, spring nitrogen applications did not increase large patch severity at either site as previously believed. A fall application when soil temperatures declined to 70°F extended green color in the fall, but did not consistently promote earlier greenup in the spring or affect large patch severity.

A second field experiment was initiated in fall 2014 in Columbia, MO investigating the impact of timing, continued use of the same N source throughout the summer, and integration of a single spring fungicide application into a large patch control program. After the first year of study, spring nitrogen applications resulted in higher green cover percentage (i.e. lower large patch severity) during periods of large patch severity (**Fig. 3**). This finding substantiates our previous research indicating nitrogen applications made during the infection period do not result in increased large patch severity, but may instead encourage disease recovery or tolerance.

Bullet Points

- Fall and/or spring nitrogen applications at the soil temperature thresholds and rates examined in this study do not result in higher large patch severity.
- Conversely, these non-summer applications may result in desired effects of earlier spring greenup and sustained fall color, and on established 'Meyer' zoysiagrass can be used without the apprehension of increasing large patch damage or decreasing cold tolerance.
- The impact of nitrogen source on large patch severity is unclear, but usage of a particular source may need to be sustained over a longer period to impact disease occurrence.

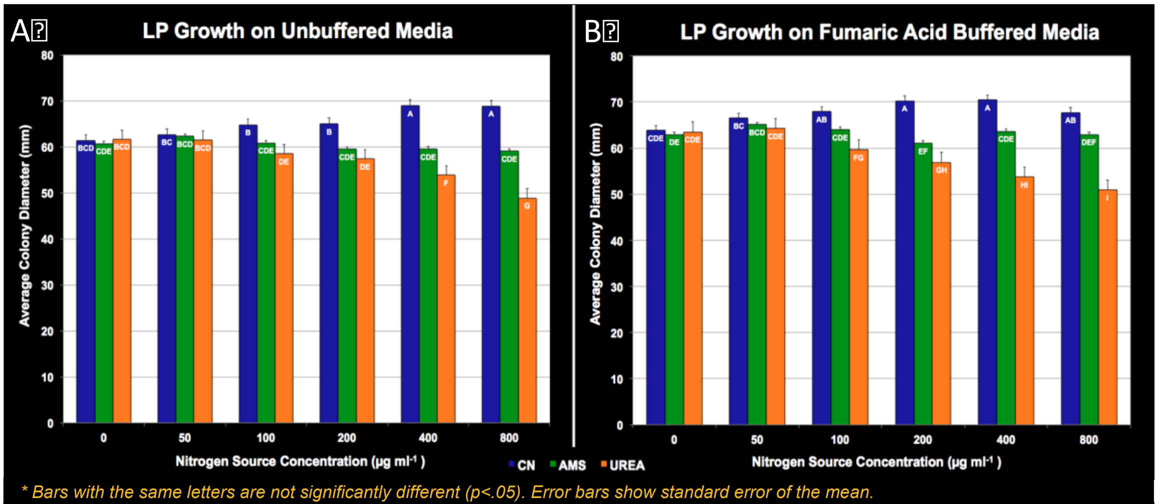


Figure 1. Growth of large patch isolates on nitrogen amended media.

A. Radial growth of *R. solani* AG 2-2 LP on media amended with either calcium nitrate, ammonium sulfate, or urea as the nitrogen source at concentrations from 0 to 800 µg ml^{-1}.

B. Radial growth of *R. solani* AG 2-2 LP on media buffered with 200 µg ml^{-1} of fumaric acid and amended with either calcium nitrate, ammonium sulfate, or urea as the nitrogen source at concentrations from 0 to 800 µg ml^{-1}.

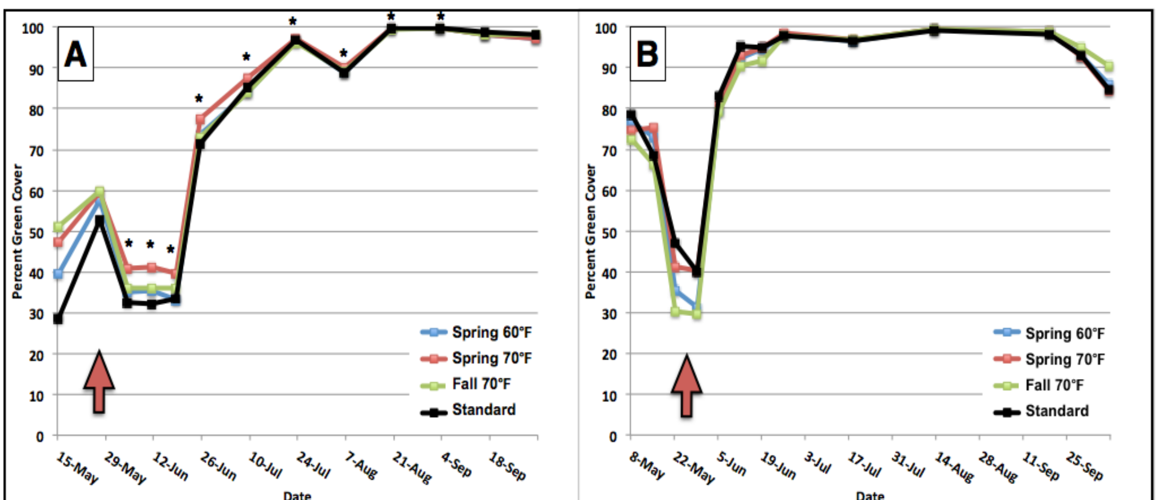
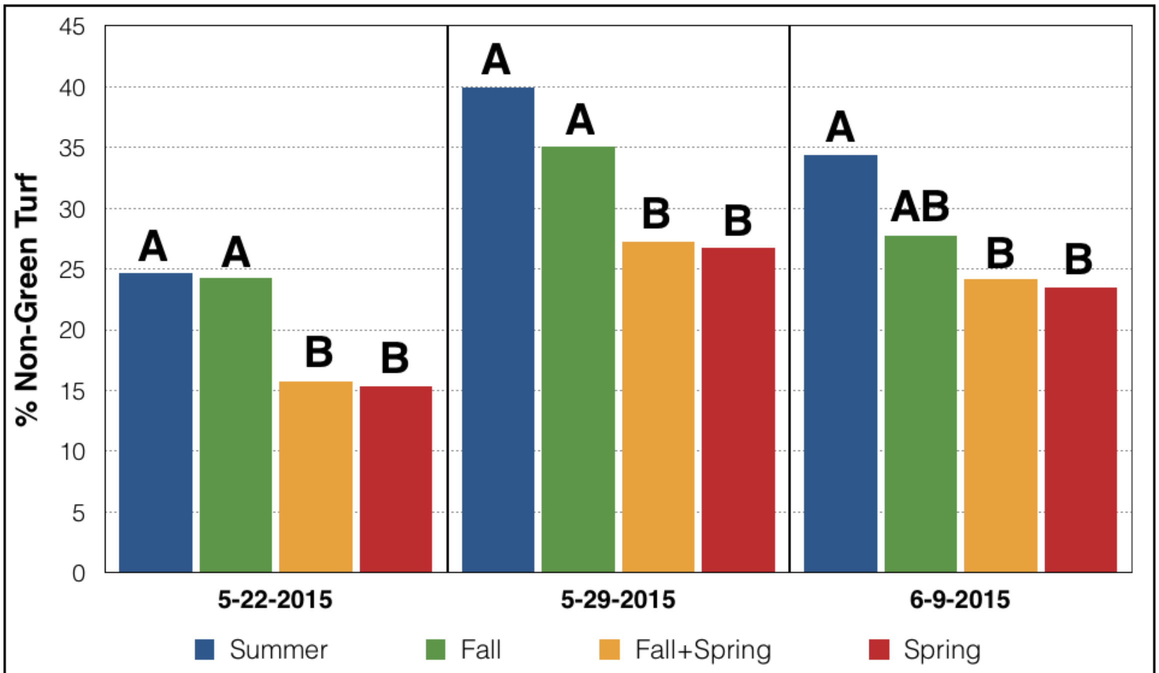


Figure 2: Effect of spring and fall nitrogen applications on large patch of zoysiagrass in A) Columbia, Missouri and B) Manhattan, KS in 2014. Nitrogen was applied at 0.75 lb N/1000 ft^2 at 60°F or 70°F soil temperatures in the spring or 70°F soil temperatures in the fall (5-day average @ 2 in). The summer (standard) treatment acted as a control, consisting of three summer applications of 0.5 lb N/1000 ft^2 in June, July and August. The total N applied to all plots was 1.5 lb N/1000 ft_2 per annum.
Adapted from Miller et al, 2016. Influence of nitrogen source and application timing on large patch of zoysiagrass. Crop, Forage & Turfgrass Management. First Look - doi: 10.2134/cftm2015.0189.



***Columns with the same letter do not significantly differ according to Fisher's Protected LSD (*P*=.05)**

Figure 3: Effect of fall, spring and fall + spring nitrogen applications on large patch of zoysiagrass. Nitrogen was applied at 0.5 lb N/1000 ft^2 in fall, spring, and fall + spring treatments at 65°F soil temperatures (5-day average @ 2 in). The summer (standard) treatment acted as a control, consisting of three summer applications of 0.66 lb N/1000 ft^2 in June, July and August 2014. The total N applied to all plots was 2 lb N/1000 ft_2 per annum.

Do Management Regimes of Organically and Conventionally Managed Golf Course Soils Influence Microbial Communities and Relative Abundance of Important Turf Pathogens?

University of Massachusetts

Elisha Allan and Geunhwa Jung

We believe the preliminary results of our study show success in characterizing the nematode and microbe community among golf course management types and areas for the first time in turf. In addition to the broader results that we have reported, we have seen some species-specific differences in important turf pathogens as well as potential beneficial microbes. For example, Glomus sp., a common mycorrhizae fungus, was significantly more abundant on the conventional putting green than the organic putting green. Microdochium nivale, the causal agent of pink snow mold, was significantly more abundant on the organic course than the conventional or hybrid courses. However, the results of sequence based studies reporting species differences must always be analyzed with caution. It is possible to get false positive and negative results if the DNA sequences of closely related species are not present in the database. Additionally we were surprised to find that Sclerotinia homoeocarpa was not detected in any of our soil samples. Therefore, we conducted species-specific qPCR for this pathogen on samples from the soil and thatch of the courses taken in the Spring and Fall of 2014. We found that there was highly significantly more S. homoeocarpa in the thatch (mean 3.00 pg/µl) than in the soil (mean 0.02 pg/ul, not detected in 36 of 54 samples) and no significant differences in the abundance of this pathogen among courses. We are preparing the manuscript of these results to be submitted to the journal Plant Disease later this month.

The purpose of our project extension was to complete the originally proposed sequencing replicates. Our current funds will allow us to replicate the pyrosequencing once. Any extension funds will allow us to pyrosequence the fall of 2013 and 2014 samples. This additional data will allow us to 1) determine if there is any seasonal variation between spring and fall for microbes, which we hypothesize there will be, and could have implications for timing future management strategies and 2) having two replicates for each season will allow us to verify that our results are consistent over time. The need for the additional funds was due to an increase in pyrosequencing cost since the original proposal and a miscommunication with our collaborator on the cost of one of the sequencing reagents. We are currently sequencing the Spring 2013 samples and will report the results when possible.

RE | SEARCH

CUTTING EDGE

Teresa Carson

A: *Acrobeles* species, a bacterivore nematode. **B:** *Hoplolaimus* species or "lance nematode," a plant-pathogenic nematode. **Photo by Elisha Allan-Perkins**

A plant growth regulator trial at Meadowbrook GC in Lubbock, Texas, illustrating darker green color observed with sequential applications (left) compared with the untreated control (right) at the conclusion of the trial on Sept. 8, 2015. **Photo by Joseph Young**

USGA

This research project was funded in part by the USGA.

Organic golf course had more bacterial-feeding nematodes

Golf course putting greens can be severely damaged by plant-pathogenic nematodes, and effective control products are limited. An increased understanding of nematode communities (plant pathogens and non-plant pathogens) may help develop novel control strategies or products. The aim of this study was to characterize nematode communities on golf courses maintained for more than 10 years with the course's respective management strategies: organic (no synthetic pesticides or fertilizers), lower-input conventional (fewer applications on fairway and rough but typical applications on putting greens) and conventional. Three courses were identified in Massachusetts, located within about 6 miles (10 km) of each other. Nematode samples were collected on three holes per course over two seasons and two years. The relative abundances of each feeding group were compared for each course and area. There were significantly more plant pathogenic nematodes on the greens of the conventional courses than on the organic putting greens. Bacterivores (nematodes that feed on bacteria) were considerably more abundant on the organic putting green than on the conventional putting greens. Nematode structure and enrichment indices are strong indicators of the overall soil community health. These indices indicated the organic putting green had a more stable soil community than the conventional putting greens. These results suggest that organic management maintains higher levels of free-living nematodes (beneficial for plants) and fewer plant pathogens (less potential for nematode damage), and creates a more stable soil environment, which may decrease plant stress and disease pressure. Future research studies will focus on determining which products affect nematode communities, to help develop new nematode management strategies. — **Elisha Allan-Perkins, M.S.; Geunhwa Jung, Ph.D. (jung@umass.edu); and Rob Wick, Ph.D., University of Massachusetts, Amherst; and Daniel Manter, Ph.D., USDA-ARS, Fort Collins, Colo.**

GDD models of PGR efficacy on bentgrass greens

In the Lubbock, Texas, area, plant growth regulators (PGRs) are used extensively on greens to reduce shoot elongation in summer. The three commercially available chemical PGRs are trinexapac-ethyl (TE) (Primo Maxx), flurprimidol (Cutless MEC) and paclobutrazol (Trimmit 2SC). Two newer PGRs are combination products: Legacy (TE + flurprimidol) and Musketeer (all three chemistries). Previous research has demonstrated reduced effectiveness with TE as temperatures increase; however, similar studies have not been conducted on other PGRs in the transition zone. The objective of this study was to construct growing degree day (GDD) models for commercially available PGRs. Treatments were applied from May to August, six to eight weeks apart in 2014 and 2015 to demonstrate their full progression at two locations in Lubbock. Clippings were collected from each plot twice per week, oven-dried, and then weighed to determine relative growth compared with untreated controls. Maximum suppression was achieved from 125 to 175 GDD following application with products. Treated plots reached equilibrium growth with untreated plots at 460 to 680 GDD. These values can be beneficial when determining reapplication windows. Using 50% of the complete suppression phase, reapplication would need to occur at 230 GDD for flurprimidol, 250 GDD for paclobutrazol, 260 GDD for TE, 300 GDD for TE + flurprimidol, and 340 for TE + flurprimidol + paclobutrazol. Many turf managers from this region have suggested that PGRs other than TE are chosen because they lack a rebound effect. In contrast, our data demonstrated a slight acceleration of shoot growth following suppression for all products. — **Ramzi White and Joseph Young, Ph.D. (joey.young@ttu.edu), Texas Tech University, Lubbock; and Bill Kreuser, Ph.D., University of Nebraska-Lincoln**

Teresa Carson (tcarson@gcsaa.org) is *GCM*'s science editor.

Effects of Sulfur, Calcium Source and pH on Microdochium Patch
USGA ID#: 2014-10-499

Alec Kowalewski, Brian McDonald and Clint Mattox
Oregon State University

Research Summary (Year 2)

- Sulfur applications reduced Microdochium patch on an annual bluegrass putting green.
- Sulfur applications resulted in fewer curative fungicide applications when using the development of infection centers as an action threshold to control Microdochium patch.
- Sulfur applications decreased turf color and increased Anthracnose activity when summer fungicides were not applied.

Introduction

Historically, more money is spent on fungicides to combat Microdochium patch (*Microdochium nivale*) in the Pacific Northwest and Western Canada than any other turfgrass disease. As a result of the financial burden and the potential for development of fungicide resistance associated with frequent fungicide applications, as well as growing pesticide bans and restrictions, turf managers as a whole are looking for methods to mitigate pesticide applications. Therefore, the primary objective of this research is to determine if sulfur applied with and without various calcium sources can reduce the number of annual fungicide applications necessary to manage Microdochium patch on annual bluegrass.

Year Two Findings

The results in 2015 were similar to those in 2014, albeit muted by the unusual dry winter. In comparison to the control which required 2.8 applications over an 8 month period, plots treated with 3.0 and 6.0 lbs. sulfur/1,000 ft^2 annually required 2.4 and 1.9 fungicides applications, respectively (Table 1). Medium and high rates of sulfur did reduce the number of infection centers in February, but the differences were small (1 infection center or less).

Sulfur applications reduced turf color ratings by 0.5 points in June 2015 (Table 2). Percent anthracnose disease was slightly higher in August of 2015 with the medium and high rates of sulfur averaging 0.75 and 2.5 percent disease, respectively, compared to the control which averaged 0.08 percent disease. No fungicides were applied for anthracnose.

Table 1: Effects of sulfur rate and calcium type on Microdochium patch infections centers observed in February 2015, and the number of fungicide applications made to control Microdochium patch from Oct 1, 2014 to May 31, 2015, Corvallis, OR.

Sulfur rate[z]	Microdochium patch infection centers (per 25 ft^2)		Number of Microdochium patch fungicide applications[y]	
0 lbs	1.4	a[x]	2.8	a
3 lbs	0.6	b	2.4	b
6 lbs	0.4	b	1.9	c
Calcium source[w]				
None	0.8	a	2.3	a
Calcium carbonate	1.0	a	2.7	a
Calcium sulfate	0.9	a	2.4	a
Calcium phosphate	0.6	a	2.1	a

[z] 0.0, 3.0 and 6.0 lbs. sulfur/1,000 ft^2 annually, applied at 0.25 and 0.5 lbs. sulfur/1,000 ft^2 per month x 12 months, respectively from Jan 2009 to Dec 2015. From Mar 2005 to Dec 2008, 0.0, 1.5 and 3.0 lbs. sulfur/1,000 ft^2 annually, applied at 0.125 and 0.25 lbs. sulfur/1,000 ft^2 per month x 12 months, respectively.

[y] Fungicide applications of propiconazole plus PCNB (2.0 fl. oz + 6.0 fl. oz/1,000 ft^2) were made on a per plot basis using the following infection threshold, 5 small spots or one spot exceeding 1 inch in diameter, from Oct 1, 2014 to May 31, 2015.

[x] Means followed by the same letter within each factor of S rate and calcium source are not significantly different according to Fishers' Protected LSD (α=0.05).

[w] All calcium sources were applied after core cultivation in May and Sep from 2005 to 2015 at a rate of 12.5 lbs product/1,000 ft^2, totaling 25.0 lbs. product/1,000 ft^2 annually.

Table 2: Effects of sulfur rate and calcium source on turf color observed in June 2015 and percent Anthracnose cover (0-100%) observed in August 2015 in Corvallis, OR.

Sulfur rate[z]	Turf color (1-9)	Percent Anthracnose cover (0-100%)[y]
0 lbs	7.0a[x]	0.08a
3 lbs	6.6ab	0.75b
6 lbs	6.4b	2.50b
Calcium source[w]		
None	6.5b	1.5a
Calcium carbonate	7.1a	0.5a
Calcium sulfate	6.7ab	1.6a
Calcium phosphate	6.4b	0.9a

[z]0.0, 3.0 and 6.0 lbs. sulfur/1,000 ft2 annually, applied at 0.25 and 0.5 lbs. sulfur/1,000 ft2 per month x 12 months, respectively from Jan 2009 to Dec 2015. From Mar 2005 to Dec 2008, 0.0, 1.5 and 3.0 lbs. sulfur/1,000 ft2 annually, applied at 0.125 and 0.25 lbs. sulfur/1,000 ft2 per month x 12 months, respectively.

[y]No fungicides were applied to these plots after the conclusion of the 1 Oct 2014 to 31 May 2015 Microdochium patch scouting cycle.

[x]Means followed by the same letter within each factor of S rate and calcium source are not significantly different according to Fishers' Protected LSD (α=0.05).

[w]All calcium sources were applied after core cultivation in May and Sep from 2005 to 2015 at a rate of 12.5 lbs product/1,000 ft^2, totaling 25.0 lbs. product/1,000 ft^2 annually.

Project Title: Fungicide and Insecticide Combinations for Management of Nematodes on Putting Greens

Principal Investigator(s): Dr. William T. Crow

University: University of Florida

Objectives:

1) To determine if labeled rates of the fungicides iprodione and thiophanate methyl are effective against plant-parasitic nematodes in the field
2) To determine of combinations and rotations of iprodione and thiophanate methyl with abamectin (Avid) can improve nematicide effects.

Start Date: 2014

Duration: 2 years

Total Funding: $17,260

2014 Summary: A putting green at the University of Florida Plant Science Research Unit is being used for this trial. This green is planted with 'Jonesdwarf' bermudagrass and is naturally infested with sting nematode and root-knot nematode. The experiment was laid out in a randomized block design, blocks were based on initial sting nematode population density, with 5 replications. Plots were 16 ft^2 with 2-ft untreated borders between adjacent plots. Applications of all treatments were made using a CO^2-powered backpack sprayer with TJ-08 nozzles delivering 6 gallons/1000 ft^2. After each application all plots were irrigated with 1/8-inch water.

The initial treatments were made on 22 April, 2014. Nematode samples consisted of nine 3/4-inch-diameter and 4-inch-deep soil cores collected from each plot. Nematodes were extracted from a 100 cm^3 subsample by the sugar-flotation/centrifugation method. Nematode samples were collected on 20 March (before treatment), 3 June, and 29 July. Root samples were two 1.5-inch-diameter cores taken 6-inches deep from each plot (174 cm^3 of soil from each core). Roots were extracted manually in water with a sieving technique. Root lengths were measured using WinRhizo equipment and software. Roots samples were collected on 22 April and 29 July. Turf percent green cover was a measure of how much of the plot area was covered by live turf. Percent green cover is determined by importation of a digital image from each plot into SigmaScan software and using a macro to determine the percentage of green pixels in the image. Green cover data was collected every two weeks.

Statistical analysis: All data was subjected to analysis of covariance with the initial measurement used as the covariant. Differences indicated are comparisons with the untreated controls using the actual *P*-value generated (P = 0.1, 0.05, 0.01), where no differences are indicated $P > 0.1$.

Results: Nematode numbers declined in all plots after the initiation of the experiment. While at the final sampling date nematode counts were lower in some of the treatments than in the untreated, it is difficult to say whether or not the treatments were effective against sting nematode. I believe that the turf improvement observed was from control of root-knot nematodes that were also present at the site. However, to accurately measure treatment effects on root-knot nematodes we would have had to use a different extraction method. Only treatments programs that included abamectin increased turf percent green cover after the early part of 2014. Only treatment programs that received abamectin improved root lengths. The best plant health responses occurred from program G, that included abamectin tank-mixed with a rotation of the two fungicides. Therefore, these results indicate that the fungicides alone were not effective as stand-alone programs against nematodes, but can enhance turf effects from abamectin.

Table 1. Treatment regimens used in a two-year field trial evaluating effects on sting nematode (*Belonolaimus longicaudatus*) and plant health of 'Jones Dwarf' bermudagrass.

Code	Treatment	Trade Name	Rate a.i ha^{-1}	Applications on Week
U	Ethylene Glycol Butyl Ether	Lesco Wet Plus	22.6 kg	0, 2, 4, 6, 8, 10, 12
B	Iprodione	Iprodione SPC	6.1 kg	0, 4, 8, 12
	Ethylene Glycol Butyl Ether	Lesco Wet Plus	22.6 kg	0, 2, 4, 6, 8, 10, 12
C	Thiophanate-Methyl	Cleary's 3336 Plus	6.1 kg	0, 2, 4, 6, 8, 10, 12
	Wetting Agent	Lesco Wet	22.6 kg	0, 2, 4, 6, 8, 10, 12
D	Abamectin	Avid 0.15 EC	17.5 g	0, 2, 4, 6, 8, 10, 12
	Ethylene Glycol Butyl Ether	Lesco Wet Plus	22.6 kg	0, 2, 4, 6, 8, 10, 12
E	Iprodione	Iprodione SPC	6.1 kg	0, 4, 8, 12
	Thiophanate-Methyl	Cleary's 3336 Plus	6.1 kg	0, 4, 8, 12
	Ethylene Glycol Butyl Ether	Lesco Wet Plus	22.6 kg	0, 2, 4, 6, 8, 10, 12
F	Iprodione	Iprodione SPC	6.1 kg	0, 4, 8, 12
	Thiophanate-Methyl	Cleary's 3336 Plus	6.1 kg	2, 6, 10
	Ethylene Glycol Butyl Ether	Lesco Wet Plus	22.6 kg	0, 2, 4, 6, 8, 10, 12
G	Iprodione	Iprodione SPC	6.1 kg	0, 4, 8, 12
	Thiophanate-Methyl	Cleary's 3336 Plus	6.1 kg	2, 6, 10
	Abamectin	Avid 0.15 EC	17.5 g	0, 2, 4, 6, 8, 10, 12
	Ethylene Glycol Butyl Ether	Lesco Wet Plus	22.6 kg	0, 2, 4, 6, 8, 10, 12
H	Iprodione	Iprodione SPC	6.1 kg	0, 4, 8, 12
	Thiophanate-Methyl	Cleary's 3336 Plus	6.1 kg	0, 4, 8, 12
	Abamectin	Avid 0.15 EC	17.5 g	2, 6, 10
	Ethylene Glycol Butyl Ether	Lesco Wet Plus	22.6 kg	0, 2, 4, 6, 8, 10, 12

Table 2. Effects of the treatment regimens shown in Table 1 on population density of sting nematode (*Belonolaimus longicaudatus*) in a field trial conducted on 'Jones Dwarf' bermudagrass in 2014 and 2015.

Code	2014		2015	
	Pi	Pf	Pi	Pf
U	30	4	14	9
B	28	9	11	5
C	31	8	5	3**
D	28	14**	15	2***
E	31	8	17	3***
F	28	10	9	2***
G	28	13*	6	4
H	32	11	7	4*

Data are means of 5 replications.

Code for treatment regimen listed in Table 1.

Pi = initial population density of sting nematode 100 cm^3 of soil-[1].

Pf = final population density of sting nematode 100 cm^3 of soil-[1].

*,**,***Different from the untreated control according to analysis of covariance ($P \leq 0.1$, $P \leq 0.05$, $P \leq 0.1$, respectively).

Table 3. Effects of the treatment regimens shown in Table 1 on root length in a field trial conducted on 'Jones Dwarf' bermudagrass infested with sting nematodes in 2014 and 2015.

Code	2014		2015	
	Initial	Final	Initial	Final
U	231	209	388	526
B	209	293	252	637
C	277	251	324	651
D	267	219	345	935***
E	300	229	312	560
F	262	241	316	551
G	275	273	337	878**
H	221	269	358	856***

Data are means of 5 replications.

Code for treatment regimen listed in Table 1.

Root length 350 cm^3 of soil-^{1}.

*,**,***Different from the untreated control according to analysis of covariance ($P \leq 0.1$, $P \leq 0.05$, $P \leq 0.1$, respectively).

Table 4. Effects of the treatment regimens shown in Table 1 on turf percent green cover in a field trial conducted on 'Jones Dwarf' bermudagrass infested with sting nematodes in 2014 and 2015.

Code	2014									2015							
	4/22	5/6	5/20	6/3	6/16	7/1	7/15	7/29	8/12	4/1	4/15	4/28	5/13	5/27	6/10	6/24	7/8
U	7	14	11	21	36	15	16	10	10	5	34	42	27	48	1	44	41
B	6	13	16***	31***	44*	18	20*	12	11	4	36	41	31	53	2	50	43
C	7	12	12	22	42	18	15	10	6	5	34	42	38	55	2	54	43
D	7	11	12	26	52**	24**	41***	25***	28***	6	37	49	39	60	2	64**	61**
E	6	13	11	27**	43*	15	21**	13	10	6	27	33	26	41	2	39	34
F	6	8	10	20	39*	14	15	6	5	5	28	40	29	43	2**	37	31
G	6	12	12	30***	63***	28***	49***	32***	26***	4	35	47	37*	63**	2	69***	62***
H	5	8	9*	20*	44***	23***	32***	21***	13**	5	32	42	34	54**	2	58**	51*

Data are means of 5 replications.

Code for treatment regimen listed in Table 1.

Percent green cover (0-100%).

*,**,***Different from the untreated control according to analysis of covariance ($P \leq 0.1$, $P \leq 0.05$, $P \leq 0.1$, respectively).

Title: Large Patch Control on Zoysiagrass Affected by Fungicide and Target Site of Application

Objective: Determine the amount of protection provided by four fungicides of differing modes of action applied on the leaf, sheath, or stem parts of zoysiagrass plants.

Authors: J.J. Benelli and B.J. Horvath

Body:
Large patch, caused by *Rhizoctonia solani* AG 2-2 LP, is the most severe disease of zoysiagrass in the transition zone United States (Fig. 1). The disease affects the stems and sheaths of susceptible plants when temperatures are cool-to-mild with frequent rainfall (Fig. 1). Symptom expression is most visible during the fall and spring months as zoysiagrass approaches and exits winter dormancy. Large patch is often called a perennial disease because the patches reappear in the same location each year and progressively gets more severe.

Golf course superintendents often rely on fungicide applications to reduce large patch severity. However, large patch is difficult to control using traditional fungicide sprays. Much of the fungicide solution is intercepted before it makes its way into the lower plant canopy where infection occurs. Improved large patch control, and more efficient use of fungicides, could be achieved with identifying the optimal target site of application.

Greenhouse experiments were conducted in 2015 in Knoxville, TN, to evaluate large patch control using fungicides deposited on three target sites of zoysiagrass (leaf, sheath, and stem). The fungicides Heritage (0.4 oz/1000 ft^2), Torque (0.6 fl oz/1000 ft^2), Prostar (2.2 oz/1000 ft^2), and Daconil Ultrex (3.2 oz/1000 ft^2) were applied using a pipette as 2.5 microliter droplets that were dispensed singly on the leaf, sheath, or stem. Plants were inoculated with *R. solani* and kept in a growth chamber under high humidity. Measurements of visual disease severity (0-100%) and photochemical efficiency (*Fv*/*Fm*) were collected every 7 days.

In both experimental runs, zoysiagrass treated with fungicides applied on the sheath or stem exhibited significantly lower large patch severity and higher *Fv/Fm* values compared to zoysiagrass receiving leaf applications on most rating dates (Fig. 2). Large patch control of Heritage treated zoysiagrass was most affected by the site of application. At 28 days after treatment in the first experimental run, leaf applications of Heritage exhibited 74% disease severity, whereas the sheath and stem applications both exhibited <5% disease severity (Fig. 3,4). Daconil Ultrex, a contact fungicide, was least affected by the site of target application on most rating dates. Applications of Torque and Prostar also performed well and reduced large patch severity when applied on the sheath or stem (Fig. 3).

In conclusion, this research demonstrates that more effective use of fungicides can be achieved when the active ingredient is deposited lower in the plant canopy. These results may help explain why variable large patch control is observed on many golf courses. The selection of nozzle types, water carrier volume, spray adjuvants, and spray pressure may influence the quality and deposition of pesticide sprays.

Future research is needed to improve lower canopy fungicide deposition under field conditions. One such method may be the inclusion of surface active agents (surfactants) in spray mixtures. Surfactants are commonly used with herbicides and insecticides to improve surface coverage and plant uptake. However, the effects of surfactants mixed with commonly used fungicides are unclear. Field and spray chamber experiments will be conducted to determine the usefulness of surfactants to improve fungicide sprays targeting large patch.

Bullet points:

- Fungicides applied on the sheath or stem provided greater large patch protection compared to fungicide applied on the leaf
- Heritage, a xylem mobile fungicide, was most affected by site of application. Daconil Ultrex, a contact fungicide, was least affected by site of application.
- Future research is needed to improve lower canopy fungicide deposition under field conditions.

Figure captions:

Figure 1 caption:
Fig. 1. Large patch is a severe disease of zoysiagrass in the transition zone United States.

Figure 2 caption:
Fig 2. Fungicides applied on the sheath or stem, where the infection occurs, may improve large patch control.

Figure 3 caption:
Fig. 3. Effect of application placement (pooled across fungicides) on large patch severity and Fv/Fm.

Figure 4 caption:
Fig. 4. Effect of fungicide treatments and site of application on large patch severity and Fv/Fm.

Figure 5 caption:
Fig. 5. Differences in large patch severity affected by Heritage applied onto the stem, sheath, or leaf.

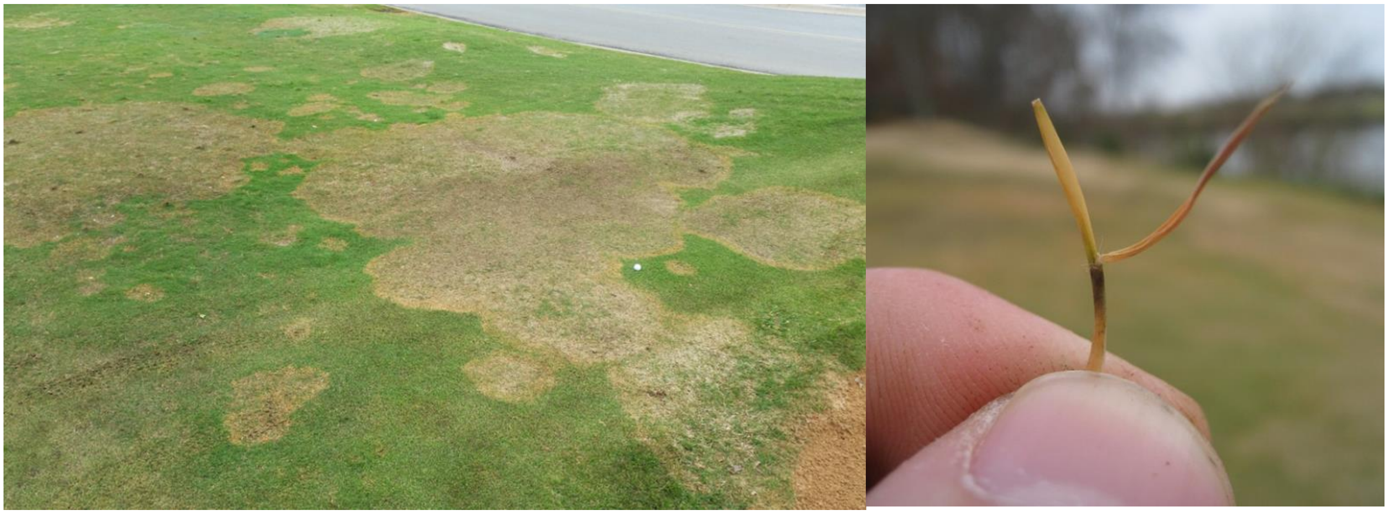


Fig. 1. (Left) Large patch is a severe disease of zoysiagrass in the transition zone United States. (Right) Fungicides applied on the sheath or stem, where the infection occurs, may improve large patch control.

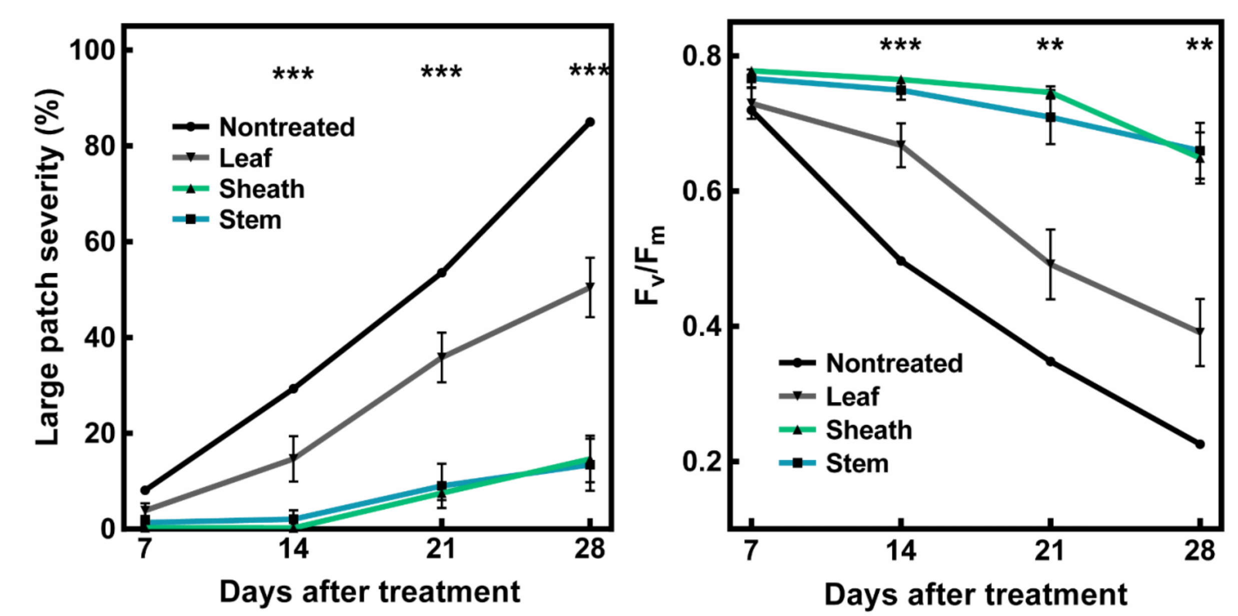


Fig. 2. Effect of application placement (pooled across fungicides) on large patch severity and Fv/Fm.

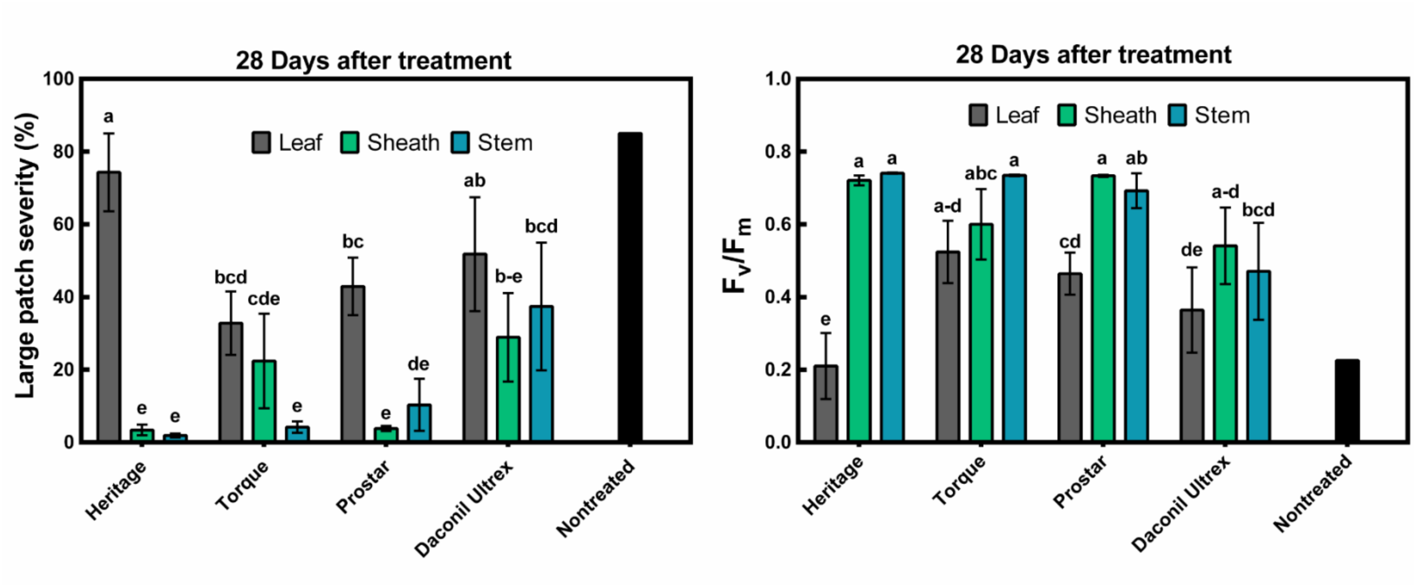


Fig. 3. Effect of fungicide treatments and site of application on large patch severity and Fv/Fm.

Fig. 4. Differences in large patch severity affected by Heritage applied onto the stem, sheath, or leaf

Title: Insecticide resistant annual bluegrass weevil: Understanding, managing, alleviating, and preventing a superintendent's nightmare

Project leader (or co-leaders): Albrecht M. Koppenhöfer, Olga S. Kostromytska, Shaohui Wu

Affiliation: Department of Entomology, Rutgers University, New Brunswick, NJ

Objectives: The overall goal is to develop a better understanding of the degree and scope of insecticide resistance in ABW populations as a basis for the development of recommendations on resistance management. This will be achieved through the following objectives:

1. Establish baseline susceptibility of ABW to selected insecticides and determine possible diagnostic doses to detect resistant populations in the field.
2. Determine resistance and cross resistance patterns and possible mechanisms.
3. Compare efficacy of selected insecticides against ABW adults and larvae of susceptible and resistant populations.

Start Date 2014

Project Duration 2 years

Total Funding *$19,642*

Summary text

Pyrethroid resistance of annual bluegrass weevil (ABW), *Listronotus maculicollis*, is a growing problem on golf courses in the Northeast (Ramoutar et al. 2009, Koppenhöfer et al. 2012). Our previous findings demonstrated that pyrethroid resistance is widely spread among ABW populations. Moreover, populations resistant to pyrethroids have an elevated tolerance to insecticides of other chemical classes (RR_{50} range 3-15). The broad nature of the resistance strongly suggest involvement of detoxification enzymes as a resistance mechanism.

To determine involvement of enzymatic detoxification in ABW resistance to pyrethroids, combinations of synergists (oxidase inhibitor PBO, glutathione transferase inhibitor DEM, esterase inhibitor DEF) and bifenthrin or chlorpyrifos were tested in laboratory bioassays against adults from seven ABW populations. Bifenthrin toxicity was significantly increased in presence of PBO (8-20 fold) and DEF (9-39 fold) which indicates involvement of oxidase and esterase systems as possible resistance mechanisms (Table 1). DEM had a weak effect on bifenthrin toxicity for most populations. Synergists did not significantly affect chlorpyrifos toxicity in our study (Table 1).

To determine and compare level of adult and larval resistance selected insecticides of different chemical classes (Table 2) were tested against susceptible and resistant ABW populations in the greenhouse experiments. Ten adults were caged in the *P. annua* pots 2 h before treatments (Fig. 1A). Treatments were applied using a Generation III Research sprayer

(Fig. 1D,E). For larval assays, adults (3 pairs) were caged in containers with established *P. annua* (Fig. B,C) for 1 week. Treatments were applied 10 days after adult removal (average larval stage ~3-3.5 instar), and mortality evaluated 10 days after application. Results of our greenhouse adult bioassays corresponded to results obtained in other assays types (Table 3,4). The LI population had the highest RR_{50} for bifenthrin and chlorpyrifos. The HP and PB populations were most susceptible for both tested insecticides.

Larvae of the resistant populations were less susceptible to chlorantraniliprole, bifenthrin, chlorpyrifos compared to susceptible populations. These insecticides provided higher percent reduction in susceptible populations (80-90%) compared to resistant populations (up to 57% reduction) (Fig. 2,3). Percent reduction provided by spinosad and indoxacarb differed only between the most resistant LI population and susceptible populations.

Petri dish and vial bioassays were further evaluated as possible diagnostic assays for resistance detection and monitoring. Five concentrations of formulated bifenthrin (Talstar Pro) and chlorpyrifos (Dursban) were tested against susceptible and resistant populations in Petri dish assays and corresponding AI concentrations in vial assays (Fig. 4). Resistance ratios obtained from different assays types were proportionally similar (Table 3,4). The population with the highest resistance level (LI) in the topical assays was also the most resistant in the Petri dish and vial assays. Lowest LD_{50} were observed in the population previously considered susceptible (PB). Vial assays were consistent with other assays and effectively separated resistant and susceptible populations (Tables 3, 4).

- Moderate to high levels of resistance ($RR_{50} > 20$) were repeatedly observed among ABW populations which did not change significantly over the 2 years of our study.
- Resistance levels of tested ABW populations were significantly reduced in presence of the enzyme inhibitors PBO and DEF, suggesting that enzymatic detoxification plays important role in ABW resistance to pyrethroids.
- Larvae of the resistant population were less susceptible to most insecticide compared to susceptible populations.
- Any of the tested diagnostic assay could be used for resistance diagnostic. A petri dish assay with formulated products is likely the best option for resistance diagnostics and monitoring due to the assay's simplicity, practicality and discriminating power.

Figure and table captions:

Table 1. Effect of synergists on toxicity of bifenthrin and chlorpyrifos to susceptible and resistant ABW populations.

Table 2. Active ingredients and products of insecticides tested against ABW population in a greenhouse assay.

Table 3. LD_{50} and RR_{50}-values (LD_{50} resistant / LD_{50} susceptible) for bifenthrin obtained in the different types of bioassays in 2014-2015.

Table 4. LD_{50} and RR_{50}-values (LD_{50} resistant / LD_{50} susceptible) for chlorpyrifos obtained in the different types of bioassays in 2014-2015.

Figure 1. Experimental set up for the greenhouse assays: cages for adult greenhouse assays (A), cages for adult oviposition for larval assay (B, C), spray system used in the greenhouse assays in 2015 (D, E).

Figure 2. Comparative efficacy of selected insecticides against susceptible and resistant ABW populations. Means with the same letter are not significantly different within insecticides.

Figure 3. Efficacy of selected insecticide against larvae of four ABW populations (resistant and susceptible).
[1] Means with the same letter are not significantly different within populations.
[2] Means marked with an asterisk differ significantly from the untreated control.

Literature cited

1. Koppenhöfer A.M., Alm S.R., Cowles R.A., McGraw B.A., Swier S., Vittum P.J. 2012. Controlling annual bluegrass weevil: optimal timing and rates. Golf Course Manag., March 2012, 98-104.

2. Ramoutar D., S.R. Alm, R.S. Cowles. 2009. Pyrethroid resistance in populations of *Listronotus maculicollis* (Col.: Curculionidae) from south. New England golf courses. J. Econ. Ent. 102, 388–392.

Table 1. Effect of synergists on toxicity of bifenthrin and chlorpyrifos to susceptible and resistant ABW populations.

	LD_{50}	SR^{2}_{50}	LD_{50}	SR_{50}	LD_{50}	SR_{50}	LD_{50}	SR_{50}	LD_{50}	SR_{50}	LD_{50}	SR_{50}	LD_{50}	SR_{50}
ABW populations	**PB**		**HP (1.3)[1]**		**GB (8.1*)**		**CN (10.9*)**		**EW (24.3*)**		**JC (37.2*)**		**LI (222.7*)**	
Bifenthrin	**8.9**	NC	**11.4**		**71.6**		**96.6**		**215.9**		**215.9**		**1982**	
Bifenthrin+PBO	1.1	7.9*3	0.7	16.3*	3.8	18.8*	9.4	10.3*	19.3	11.2*	19.3	7.9*	216.9	9.1*
Bifenthrin+DEM	10.5	0.8	3.5	3.3*	29.5	2.4	61.7	1.6	113.8	1.9	113.8	3.1*	1611.0	1.2
Bifenthrin+DEF	0.9	9.9*	1.1	10.4*	5.1	14.2*	6.6	4.6*	5.6	8.6*	5.6	13.4*	127.5	15.5*
ABW populations	**PB**		**HP (2.08)**		**GB (1.66)**		**CN (4.2*)**		**EW (3.8*)**		**JC (1.4*)**		**LI (12.9*)**	
Chlorpyrifos	**214.5**		**102.9**		**357.5**		**894.9**		**823.2**		**308.4**		**2783**	
Chlorpyrifos+PBO	242.2	0.81	63.9	1.6	310.3	1.15	442.4	2.02	899.9	0.91	239.9	1.29	2006	1.39
Chlorpyrifos+DEM	211.5	1.01	108.5	0.9	176.7	2.02	899.9	0.99	735.7	1.12	255.3	1.21	2568	1.08
Chlorpyrifos+DEF	192.9	1.11	136.6	0.8	172.4	2.07	525.7	1.7	836.6	0.98	137.2	2.25	2662	1.05

[1] Population tested followed by resistance ratios in parenthesis. RR_{50} (resistance ratios) were calculated with PB population as susceptible (LD_{50} of susceptible/LD_{50} resistant). RR ≥ 20 reflect moderate to high level of resistance.

[2] SR_{50} (synergist ratios) were calculated using following formula LD_{50} of bifenthrin (or chlorpyrifos) alone /LD_{50} of bifenthrin (or chlorpyrifos)+synergist (PBO, DEF or DEM)

[3] RR_{50} marked with an asterisk differ significantly from the susceptible population. SRs marked with asterisks represent significant reduction of resistance level in presence of the synergist.

Table 2. Active ingredients and products of insecticides tested against ABW populations in a greenhouse assay

Insecticide class	Active ingredient	Trade name	Company/ manufacturer
Pyrethroid	Bifenthrin	Talstar	FMC, Princeton, NJ
	λ-cyhalothrin	Scimitar	Syngenta Crop Prot., Greensboro, NC
Organophosphate	Chlorpyrifos	Dursban	Dow AgroSciences, Indianapolis, IN
	Trichlorfon	Dylox	Bayer, Research Triangle Park, NC
Spinosyn	Spinosad	Conserve	Dow AgroSciences, Indianapolis, IN
Oxadiazine	Indoxacarb	Provaunt	DuPont, Wilmington, DE
Anthranilic diamide	Chlorantraniliprole	Acelepryn	DuPont, Wilmington, DE
Neonicotinoid	Clothianidin	Arena	Valent, Walnut Creek, CA

.

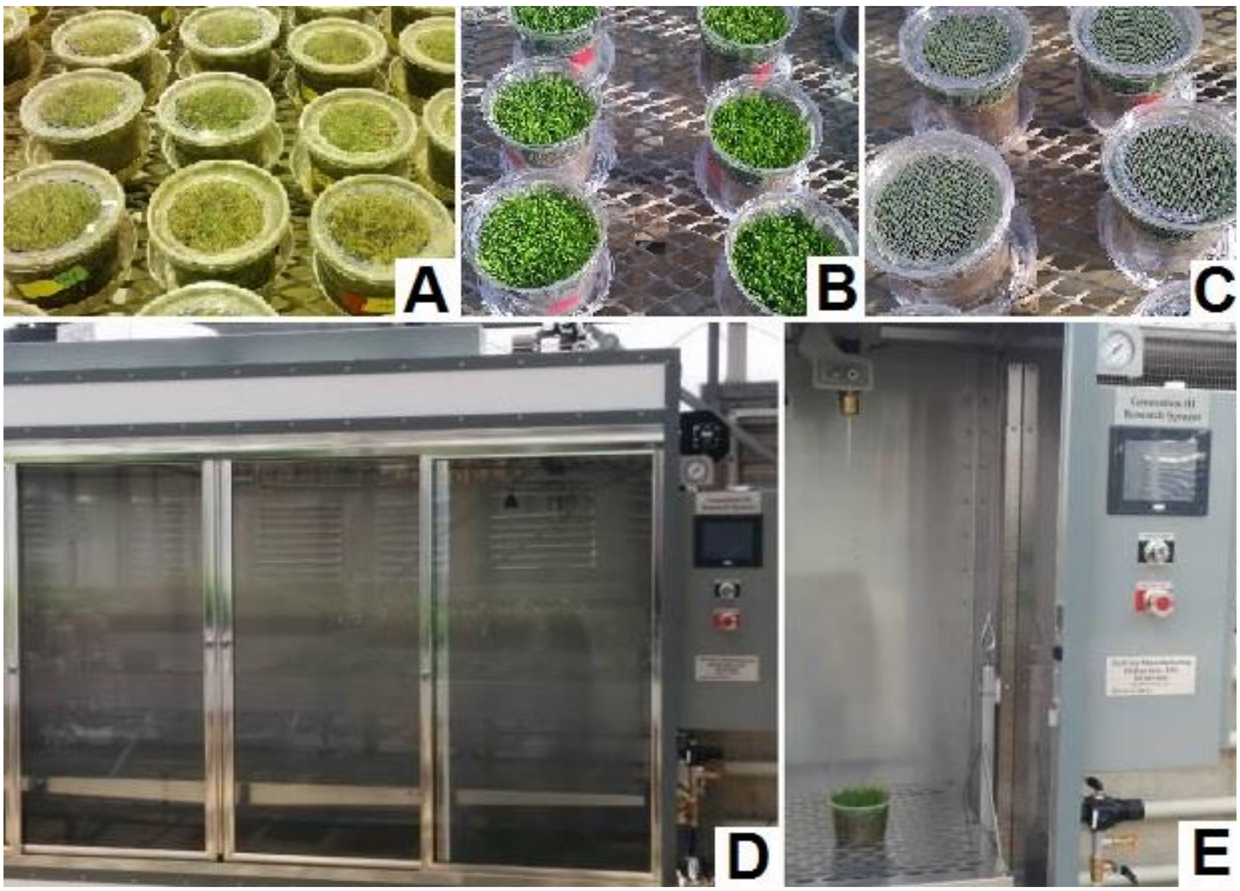


Figure 1. Experimental set up for the greenhouse assays: cages for adult greenhouse assays (A), cages for adult oviposition for larval assay (B, C), spray system used in the greenhouse assays in 2015 (D, E).

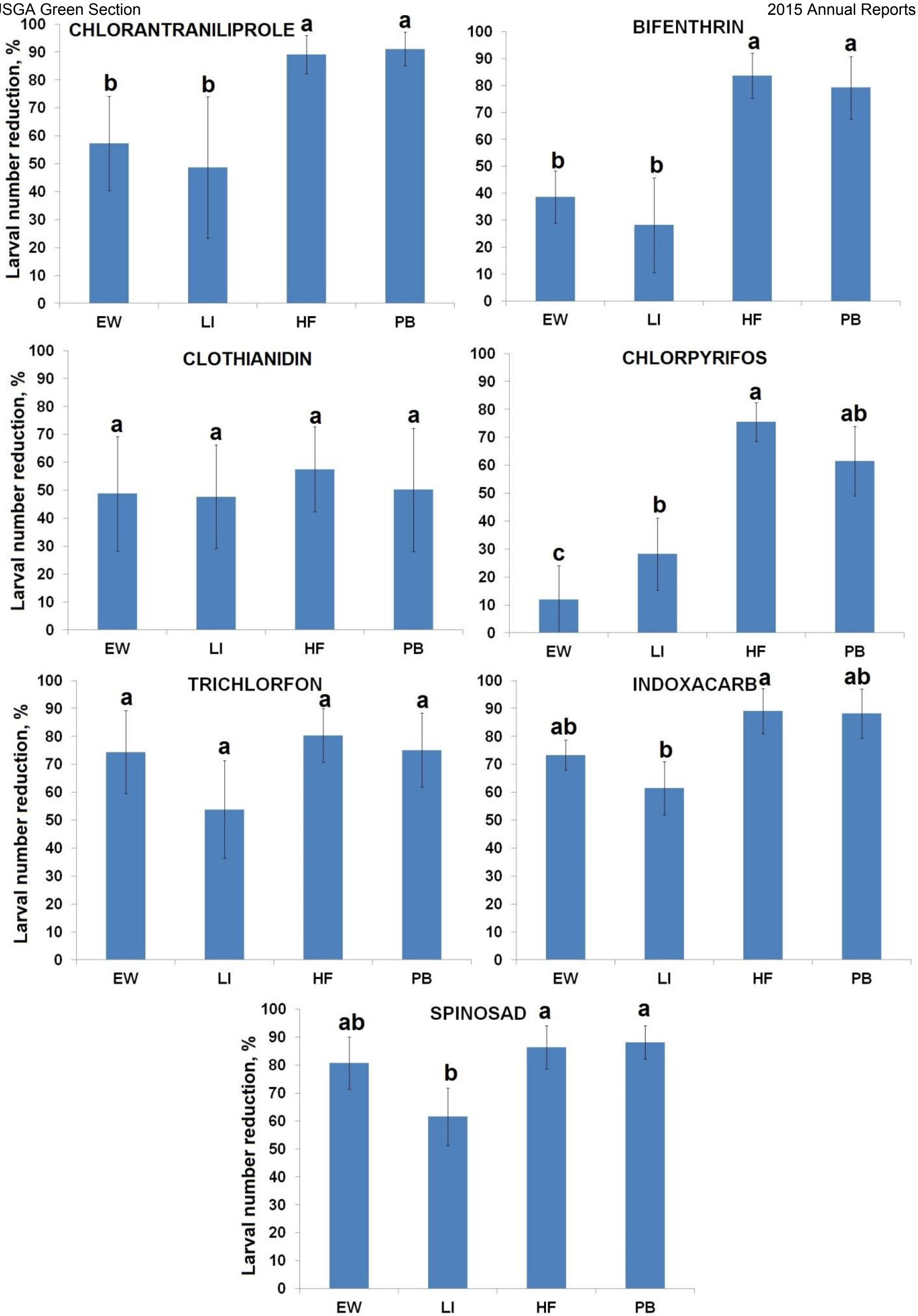


Figure 2. Comparative efficacy of selected insecticides against susceptible and resistant ABW populations. Means with the same letter are not significantly different within insecticides.

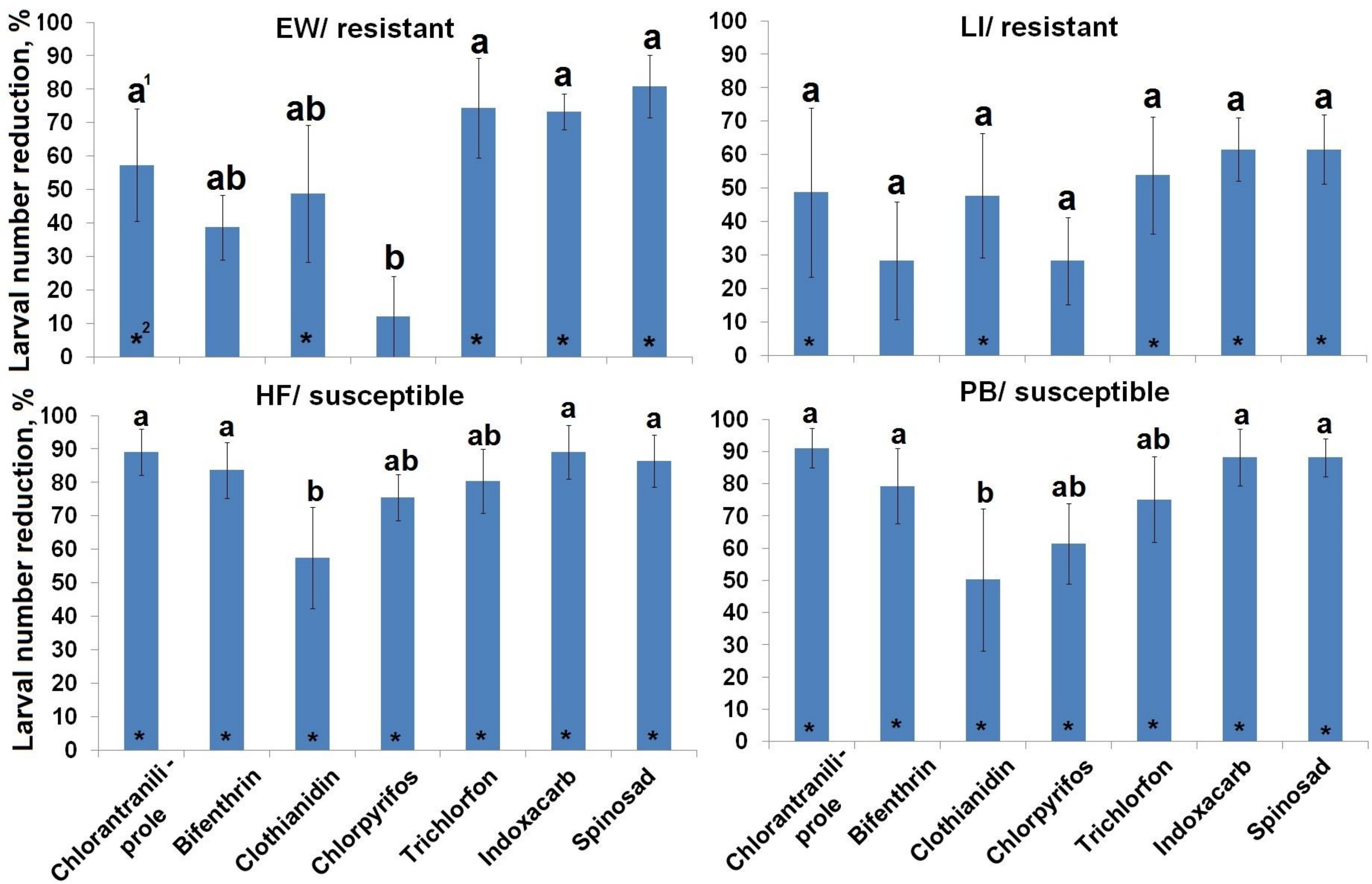


Figure 3. Efficacy of selected insecticide against larvae of four ABW populations (resistant and susceptible).
1 Means with the same letter are not significantly different within populations.
2 Means marked with an asterisk differ significantly from the untreated control.

Table 3. LD_{50} and RR_{50}-values (LD_{50} resistant / LD_{50} susceptible) for bifenthrin obtained in the different types of bioassays in 2014-2015.

	Vial (24h)		**Petri dish (24h)**		**Greenhouse (72h)**		**Topical (72h)**			
							2014		**2015**	
	LC_{50}	**RR_{50}[1]**	**LC_{50}**	**RR_{50}**	**LD_{50}**	**RR_{50}**	**LD_{50}**	**RR_{50}**	**LD_{50}**	**RR_{50}**
PB	3.2	**2.8**	0.4	**3.7**	0.1	**1.1**	5.1	**NC**	8.9	**NC**
HP	1.1	**NC**	0.1	**NC**	0.1	NC	NT	**NT**	11.4	**1.3**
GB	28.2	**25*[2]**	3.4	**31.4*[2]**	0.7	**7.8***	72.7	**14.3***	71.6	**8.1***
CN	51.8	**45.9***	3.3	**30.2***	3.9	**43.3***	123.1	**24.1***	96.6	**10.9***
JC	NT	**NT**	NT	**NT**	4.8	**53.3***	225.8	**44.3***	215.9	**24.3***
EW	7.0	**62.9***	5.9	**54.2***	5.9	**65.6***	326.9	**64.1***	331.1	**37.2***
LI	294.6	**261.3***	43.1	**392.0***	47.3	**525.6***	819.1	**160.6***	1982.0	**222.7***

RR_{50} were calculated using population with the lowest LC 50 as most susceptible.
[2] RR_{50} marked with an asterisk differ significantly from the most susceptible population.

Table 4. LD_{50} and RR_{50}-values (LD_{50} resistant / LD_{50} susceptible) for chlorpyrifos obtained in the different types of bioassays in 2014-2015.

	Vial (24 h)		**Petri dish (24 h)**		**Greenhouse (72 h)**		**Topical (72h)**			
							2014		**2015**	
	LC_{50}	**RR_{50}[1]**	**LC_{50}**	**RR_{50}**	**LD_{50}**	**RR_{50}**	**LD_{50}**	**RR_{50}**	**LD_{50}**	**RR_{50}**
PB	0.000		0.001	**NC**	0.04	**NC**	299	**NC**	214.5	**2.1**
HP	0.001	**2**	0.002	**2**	0.05	**1.3**	NT	**NT**	102.9	**NC**
GB	0.003	**6*[2]**	0.005	**5***	0.28	**3.8***	852	**2.8**	357.5	**1.7**
CN	0.003	**6***	0.010	**10***	0.48	**12.0***	1118	**3.7**	894.9	**4.2***
JC	NT	**NT**	NT	**NT**	0.15	**7.0**	688	**2.3**	823.2	**3.8***
EW	0.002	**4***	0.006	**6***	0.49	**12.3***	683	**2.3**	308.4	**1.4**
LI	0.010	**20***	0.182	**182***	1.09	**27.3***	3203	**10.7**	2783	**12.9**

[1] RR_{50} were calculated using population with the lowest LC 50 as most susceptible.
[2] RR_{50} marked with an asterisk differ significantly from the most susceptible population.

Title: Biorational control of important golf turf insect pests

Project leader (or co-leaders): Albrecht M. Koppenhöfer, Olga S. Kostromytska, Shaohui Wu

Affiliation: Department of Entomology, Rutgers University, New Brunswick, NJ

Objectives: The overall goal is to develop a better understanding of the role that biorational insecticides can play in the management of important golf turf insect pests with particular emphasis on the annual bluegrass weevil to facilitate insecticide resistance management in this difficult-to-control pest.

The annual bluegrass weevil (ABW), *Listronotus maculicollis*, is a serious and expanding golf course pest with demonstrated ability to develop resistance to a range of insecticides. The primary purpose of this project is to develop biorational alternatives for the management of ABW as safer and more sustainable alternatives to traditional synthetic insecticides that will also facilitate better insecticide resistance management. Biorational materials are being tested on golf course fairways against insecticide-susceptible and -resistant ABW adults and larvae. They are also being tested against larvae of white grubs and black cutworm because treatments against these pests could be done at the same time as for ABW, increasing chances of adoption of the biorational controls and further decreasing insecticide applications.

The four biorationals tested are Grandevo (based on *Chromobacterium subtsugae* strain PRAA4-1 and its fermentation products), Venerate (based on heat-killed *Burkholderia* spp. strain A396 bacteria and their fermentation products), BotaniGard ES (based on the entomopathogenic fungus *Beauveria bassiana* GHA strain), and Molt-X (based on the botanical azadirachtin). These products have reasonable costs, product stability, and relatively long shelf lives at room temperature, and have very different modes of action unlikely to be affected by the broad insecticide resistance observed with ABW.

All experiments presented here were conducted with a pyrethroid-resistant ABW population with a resistance ratio (RR_{50}) of around 100x compared to the most pyrethroid-susceptible population determined by us. Molt-X showed some promise when applied when eggs and first to second instar larvae peaked (38 - 49% control) but was ineffective when applied against third and fourth instars (Tables 1, 2). BotaniGard applied against third and fourth instars was ineffective, whether applied alone or in combination with Merit or Molt-X (Table 1).

BotaniGard was unreliable when applied when densities of overwintered adults peaked (0 - 42%) (Figs. 1, 2). The pyrethroid-based product Talstar (AI bifenthrin) alone also was ineffective (0 - 34%) as was the organophosphate-based product Dursban (AI chlorpyrifos). Talstar but not Dursban interacted synergistically with BotaniGard with the BotaniGard-Talstar combinations providing up to 84% control (Figs. 1, 2). Combinations of BotaniGard and Talstar may offer an effective control option in the management of insecticide-resistant ABW populations. The mechanism of this interaction is being studied in the laboratory.

BotaniGard, Molt-X, and their combination were also tested against a white grub population consisting primarily of oriental beetle and Asiatic garden beetle. BotaniGard (1.2 lbs AI/acre) and Molt-X (0.04 lbs AI/acre) were applied twice 1 week apart in late July targeting primarily 1st instars or in mid-August targeting primarily 2nd instars. However, none of the treatments provided statistically significant control and there were no consistent trends apparent among the different white grub species, products, and application timings.

- The pyrethroid bifenthrin (Talstar) and the organophosphate chlorpyrifos (Dursban) were ineffective against insecticide-resistant ABW adults.
- BotaniGard (AI: *Beauveria bassiana*) was ineffective against ABW larvae and adults.
- Talstar and BotaniGard interacted synergistically providing effective control of ABW adults.
- Molt-X (AI: azadirachtin) is ineffective against larger ABW larvae but shows promise when applied against eggs and young larvae.

Table 1. Densities (± SE) of annual bluegrass weevil developmental stages in early June (peak 4th to 5th instar) in a golf course fairway treated with Merit 75WP, sequential applications of Molt-X and BotaniGard ES, and their combinations.

Treatment	Rate (lb AI/acre)	ABW stage targeted	No. of stages / ft^2 (% control)
Untreated Control	---	---	44.1 ± 9.6
Molt-X	0.04[a] 0.04	E[c] L1	22.5 ± 14.1 (49)
Molt-X	0.04 0.04	L3 L3-4	47.7 ± 16.5 (0)
Merit 75WP	0.30	L3	27.0 ± 6.0 (39)
BotaniGard	0.65[b] 0.65	L3 L3-4	52.2 ± 22.5 (0)
BotaniGard + Molt-X	0.65 + 0.04 0.65 + 0.04	L3 L3-4	45.0 ± 15.4 (0)
BotaniGard + Merit	0.65 + 0.30 0.65	L3 L3-4	48.6 ± 19.4 (0)

No significant difference were observed among treatments (P = 0.48).
[a] 0.5 fl oz product/1,000 ft^2; [b] 2 fl oz product/1,000 ft^2; [c] E = egg; L1 - L4 = 1st - 4th instar larvae

Table 2. Densities (± SE) of annual bluegrass weevil developmental stages in early June in a golf course fairway treated with sequential applications of Molt-X.

Treatment	Rate (lb AI/acre)	ABW stage targeted	No. of stages / ft^2 (% control)
Untreated Control	---	---	90.0 ± 22.3 a
Molt-X	0.04[a] 0.04	E[b] L1	54.0 ± 17.0 b (40)
Molt-X	0.04 0.04	L1 L2	55.5 ± 15.2 b (38)

Means with same letter are not signficantly different (*P* > 0.05).
[a] 0.5 fl oz product/1,000 ft^2.
[b] E = egg; L1 - L2 = 1st - 2nd instar larvae

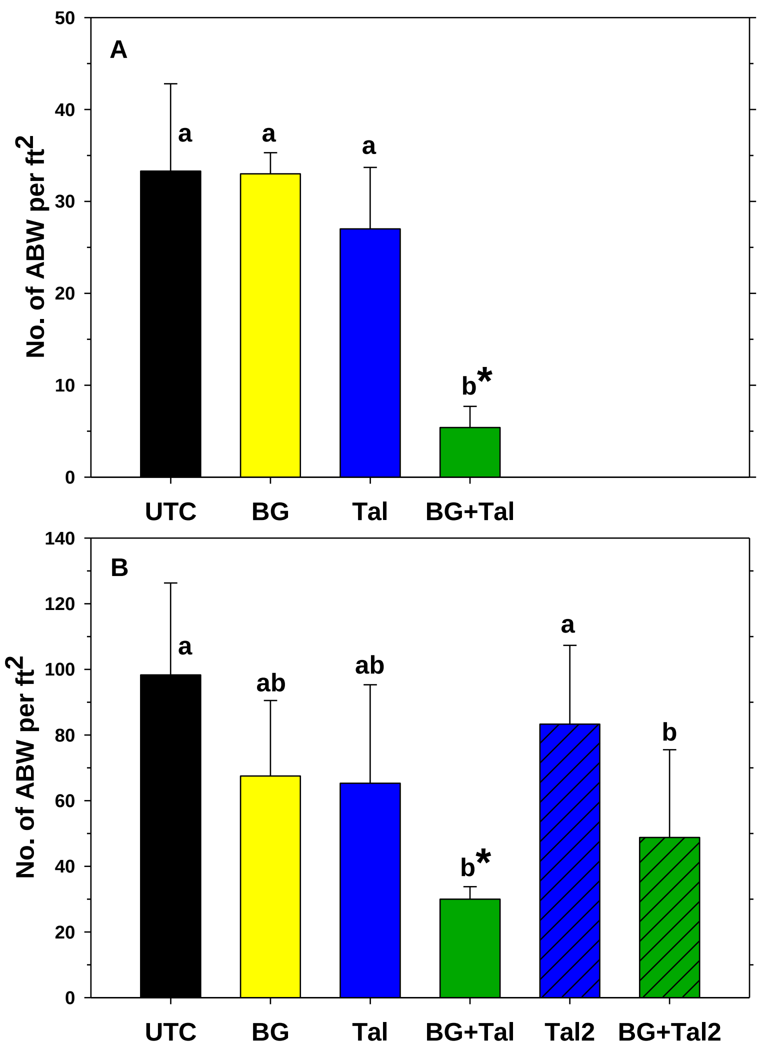


Fig. 1. Densities of annual bluegrass weevil developmental stages in early June (peak 4th to 5th instar) in two golf course fairways (A, B) treated with BotaniGard (BG) (0.65 lbs AI/acre), Talstar (Tal) (0.1 lbs AI/acre), and their combination (BG+Tal). Talstar was applied just before peak densities of overwintered adults, Botanigard just before peak adult densities and again 1 week later. In fairway B, Talstar was also tested applied at half rate 1 week apart, alone (Tal 2) and in combination with BotaniGard. Means with the same letter did not differ significantly (P > 0.05). An asterisk indicates a synergistic interaction.

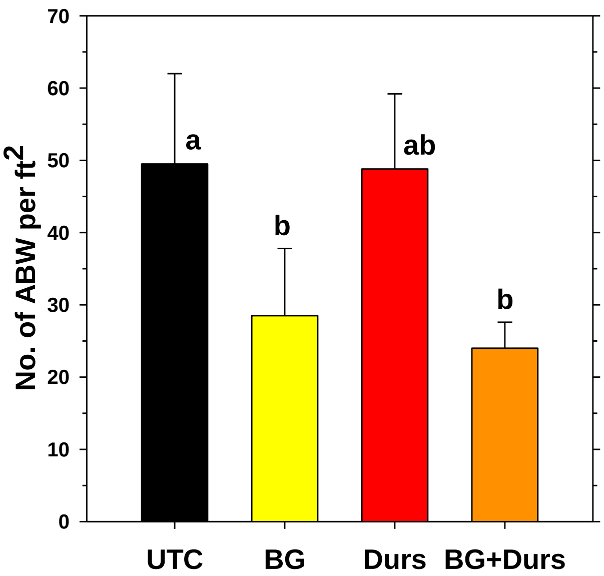


Fig. 2. Densities of annual bluegrass weevil developmental stages (peak 5th instar) in early June in a golf course fairways treated with BotaniGard (BG) (0.65 lbs AI/acre), Dursban (Durs) (1.0 lbs AI/acre), and their combination (BG+Durs). Dursban was applied just before peak densities of overwintered adults, Botanigard just before peak adult densities and again 1 week later. Means with the same letter did not differ significantly ($P > 0.05$).

Annual report on USGA ID# 2015-08-523

Selection of Insecticides Applied at Different Timings for Control of Billbug Species on Zoysiagrass Fairways

Bruce A. Barrett and Xi Xiong, University of Missouri

Objectives: The overall objective is to evaluate insecticides for efficacy and appropriate application timing for the control of billbug damage on zoysiagrass fairways.

Billbug (*Sphenophorus* spp.) damage on zoysiagrass (*Zoysia japonica* Steud.) is becoming an emerging problem in recent years. Among possibly nine billbug species, both hunting (*S. venatus vestitus* Chittenden) and bluegrass billbug (*S. parvulus* Gyllenhal) could potentially injury zoysiagrass (Fig 1).

Fig 1. Bluegrass (left) and hunting billbug (right) adult.

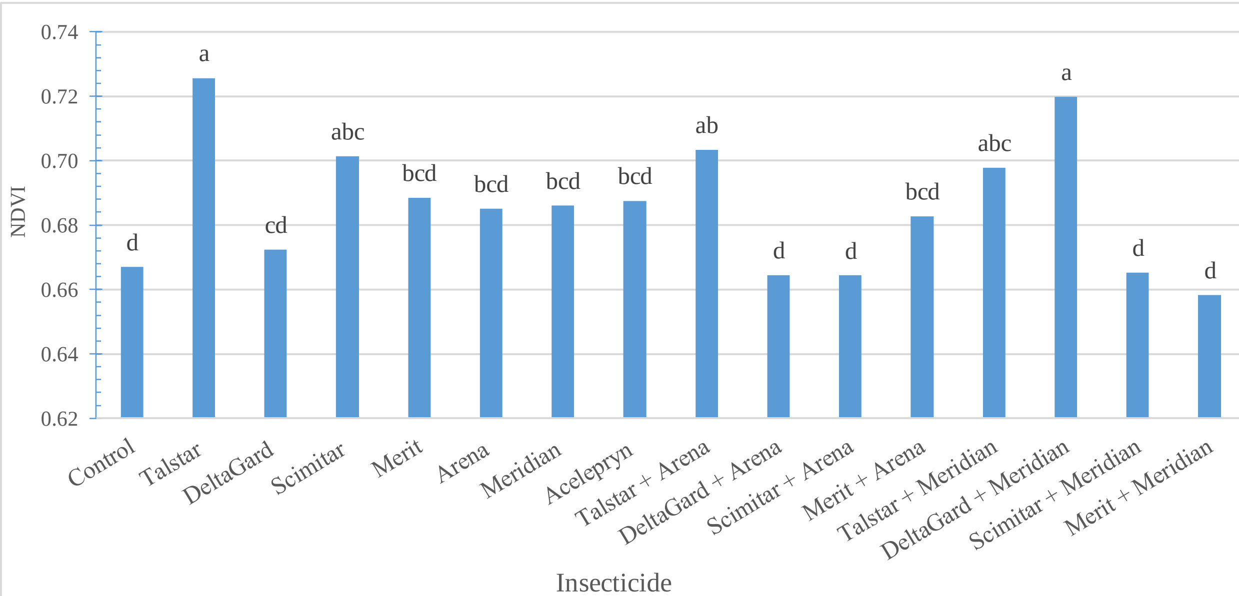
Field plots were established adjacent to the area where heavy billbug damage has been previously documented at a local golf course (Fig 2). Insecticides included bifenthrin (Talstar®), deltamethrin (DeltaGard®), lambda-cyhalothrin (Scimitar®), and imidacloprid (Merit®) for control adults, clothianidin (Arena®) and thiamethoxam (Meridian®) for control larvae, and chlorantraniliprole (Acelepryn®) for control both adults and larval. Compound, alone or in combination, were applied as single (5/22), or sequential (6/19) at the highest label suggested rates.

Fig 2. Insecticide application on the 11th fairway of A. L. Gustin Golf Course, Columbia, Missouri.

The experiment design was a split-plot in RCBD with four replications. The whole-plot (5 × 10 ft with 10 ft boarder) variable was insecticide and the sub-plot (5 × 5 ft) variable was application timing. Pitfall traps (total 128) were installed at the center of each sub-plot. Weekly evaluations included turf quality and normalized difference vegetation index (NDVI), and billbugs counts to the species. All data were subjected to ANOVA (Proc Mixed in SAS 9.4).

Turf performance were significantly affected by main effect of evaluation date and insecticide without interaction. All applications maintained or improved turf quality, indicated by NDVI, compared to control (Fig 3). Insecticide Talstar®, alone or in combination, maintained supreme turf performance compared to control, in addition to other compounds such as Scimitar®.

Fig 3. Insecticide main effect on normalized difference vegetation index (NDVI). Data were collected at 4, 9, 13, and 17 weeks after initial treatment application (WAIT; 6/20, 7/29, 8/28, and 9/16, respectively). Data were pooled over application as no significant application effect was found. Bars labeled by the same letters were not significantly different based on Fisher's Protected LSD (*P*<0.05).



Hunting billbugs dominated the population, and two peak adult activities were found with one occurred 6/12 (3 WAIT), and another and bigger peak occurred on 9/11 (16 WAIT). The highest amount of billbugs collected were 47 from the plot area. Significant interaction between insecticide and application was detected, and Scimitar®+Arena® seemed to yield the lowest billbug counts (up to 90% reduction compared to control). The full extent of treatment effect, however, is yet to be determined after spring greenup, when most damage to turf and over-winter billbug population can be assessed.

Summary:

- Hunting billbugs in our region might be 1.5 or 2 generations per year;
- Some of the insecticide combinations targeting on both adult and larvae billbugs might provide better and year-round billbug control;
- Assessment of overwinter population in spring likely reveal full extent of insecticide efficacy.

Title: Biological control of black cutworm in turf with baculovirus

Project Leader: Robert Behle

Affiliation: USDA-ARS-NCAUR, 1815 N. University Ave., Peoria, IL

Co-Investigators: Doug Richmond (Purdue University, Department of Entomology, West Lafayette, IN)

Objectives:

1) Determine effective application rates and formulations of the virus required for efficacious control of larvae,
2) Compare baculovirus treatments with alternative control treatments when applied under field conditions,
3) Evaluate compatibility of virus applications to fit with integrated management strategies for pest control within the golf-turf environment.

Start Date: Spring 2015

Project Duration: 3

Total Funding: $60,000

Bullet Points

- Experimental treatments of baculovirus to creeping bentgrass successfully killed medium-sized black cutworm larvae when applied at a rate of 2.3×10^{10} virus particles per $1000ft^2$, but not when applied at a lower rate of 4.6×10^9 virus particles per $1000ft^2$.
- Successful treatments of baculovirus formulations provided levels of control similar those provided by the chemical standard, Talstar S (bifenthrin).
- Cutworm feeding damage in baculovirus treated plots demonstrated that the slow speed of kill by the experimental virus treatments may require applications that target younger larvae
- Initial evaluations suggest reasonable storage stability of experimental formulations of *Agip*MNPV

Summary text:

A newly discovered baculovirus, *Agip*MNPV, may be developed as a biological insecticide for control of black cutworm (BCW) larvae in turf. Only BCW and a few closely related insects are susceptible to infection by the virus, and this specificity makes it a desirable biological control agent. The first year of this research focused on two objectives; to determine efficacious rates of virus and compare virus formulations applied under field conditions.

Virus production and formulation

*Agip*MNPV was produced in the laboratory by infecting BCW larvae, harvesting disease-killed larvae, and grinding the cadavers to from a slurry containing high concentrations of virus particles known as occlusion bodies (OBs). Initial laboratory experiments demonstrated that virus OBs may be processed to create a variety of liquid and dry formulations with little effect on insecticidal activity. These formulations were prepared as indicated in Table 1.

Laboratory evaluations for storage stability

Experimental formulations are being evaluated for stability when refrigerated or stored at room temperature. Bioassays evaluate a single dosage of virus that is expected to cause 80% mortality of newly-hatched BCW larvae. With the exception of the clay formulation, initial activity for experimental formulations was near expected levels (Figure 1). After four months storage, refrigerated samples showed no loss of activity and only the glycerin formulation displayed reduced activity when stored at room temperature. These evaluations will continue for up to one year of storage.

Field efficacy experiments – Purdue University

Treatments were applied to field plots of creeping bentgrass measuring 0.3 × 2.1 m. Plots were maintained at 3/16 inch height and were arranged in a randomized complete block design with four replications. All treatments were applied as aqueous sprays using a hand-held CO_2 boom sprayer calibrated to deliver 2 gallons/1000 ft^2. After applications dried, a PVC cage (8 inch diameter) was installed in each plot and artificially infested with five 2^{nd}- 3^{rd} instar BCW larvae. Infestations were created in a different section of each plot at 0, 3 and 14 DAT (Figure 2). Larvae were allowed to feed within the cages for seven days before being flushed from the turf using a standard soapy water solution. Larval survival in treated plots was compared with that in untreated control plots and plots treated with a chemical standard, Talstar S (bifenthrin) (Tables 2 and 3).

To determine the effective field application rate, two formulations (glycerin and lignin) were applied to field grown bentgrass plots at three rates. The low rate of virus (2 x 10^{11} PBs/A) did not control artificial infestations of medium-sized larvae. Medium (1 x 10^{12} OBs/A) and high rates (5 x 10^{12} OBs/A) of virus provided level of control equal to the Talstar S treatment. Control diminished over time for all treatments with only the chemical and lignin formulated virus providing significant control relative to the untreated plots at14 DAT. The expected slow speed of kill by virus treatments (3-5 days after ingestion) allowed larvae to cause significant damage to the grass and demonstrates the need to target younger larvae with virus applications.

Table 1. Ingredients used to prepare experimental formulations of the black cutworm baculovirus intended for aqueous spray application to turfgrass

Formulation	Form	Reasoning
Unformulated	Liquid	Technical product used to prepare other formulations included for comparison
Glycerine	Liquid	Added to reduce growth of contaminating microbes
Skim Milk Powder	Dry	Added to product the virus during the spray drying process
Montmorillonite Clay (K-10)	Dry	Common carrier used for wettable powder formulations for flow and mixing characteristics
Lignin	Dry	Known to encapsulate the virus to provide protection from sunlight degradation
Blankophor	Dry	Chemical brightener known to enhance insecticidal activity of some other baculovirus

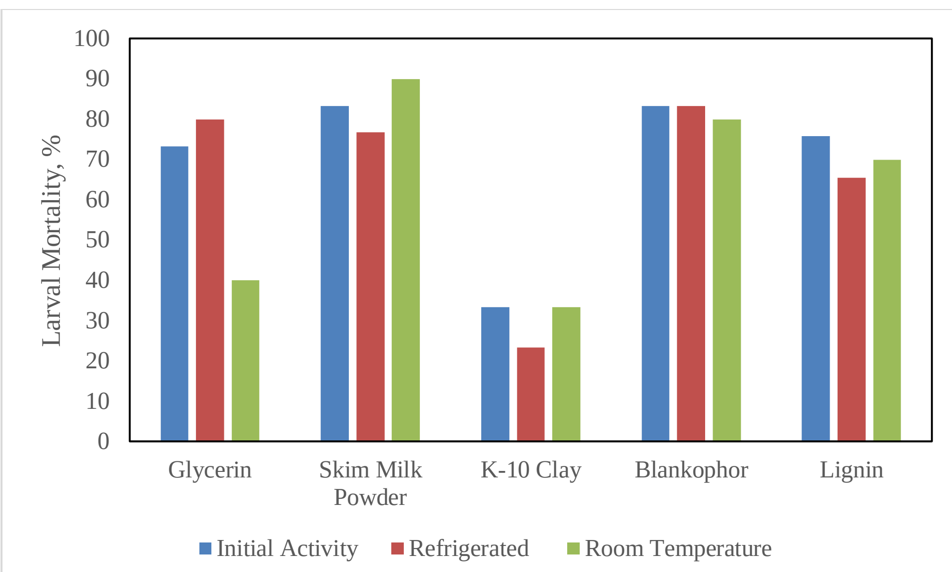


Figure 1. Stability of *Agip*MNPV formulations stored for four months under refrigeration and at room temperature. All treatments expected to cause 80% larval mortality.

Figure 2. Infesting cages with black cutworm larvae after the turf was treated with formulations of *Agip*MNPV, 2015.

Table 2. Mean (±SE) number and percent control of black cutworm larvae in plots of creeping bentgrass treated with different formulations and rates of baculovirus (*Agip*MNPV) or Talstar S (bifenthrin). Five 2nd and 3rd instar larvae were placed on plots at 0, 3 and 14 days after treatment (DAT) and number of surviving larvae (n/5) was recorded at 7, 10 and 21 DAT, respectively.

Treatment	Rate	BCW Survival 7 DAT	% Control 7 DAT	BCW Survival 10 DAT	% Control 10 DAT	BCW Survival 21 DAT	% Control 21 DAT
Untreated	---	4.5±0.3e	---	4.3±0.5d	---	4.8±0.3c	---
Talstar S	0.25 oz/M	0.0±0.0ab	100.0	1.5±0.3abc	64.7	2.5±0.3a	47.4
AgipMNPV unformulated	1 x 10^{12}	1.8±0.5b	61.1	1.5±0.6abc	64.7	4.3±0.9bc	10.5
AgipMNPV powder milk	1 x 10^{12}	1.0±0.4ab	77.8	1.5±0.6abc	64.7	4.3±0.5bc	10.5
AgipMNPV k10 clay	1 x 10^{12}	1.8±0.3b	61.1	2.5±0.6abcd	41.2	4.5±0.3c	5.3
AgipMNPV blankophore	1 x 10^{12}	2.0±0.4bc	55.6	2.0±0.4abc	52.9	4.0±0.4abc	15.8
AgipMNPV glycerin	2 x 10^{11}	3.0±0.6cd	33.3	2.8±0.8bcd	35.3	4.5±0.3c	5.3
AgipMNPV glycerin	1 x 10^{12}	0.3±0.3a	94.4	1.3±0.5ab	70.6	3.3±0.5abc	31.6
AgipMNPV glycerin	5 x 10^{12}	0.3±0.3a	94.4	1.0±0.7ab	76.5	4.0±0.7abc	15.8
AgipMNPV lignin	2 x 10^{11}	3.8±0.5de	16.7	2.8±0.9bcd	35.3	2.8±0.9ab	42.1
AgipMNPV lignin	1 x 10^{12}	1.8±0.8b	61.1	2.0±0.7abc	52.9	4.0±0.4abc	15.8
AgipMNPV lignin	5 x 10^{12}	0.0±0.0a	100.0	0.8±0.5a	82.4	2.8±0.3ab	42.1

*Numbers in same column followed by different letters are significantly different at $\alpha=0.05$. Virus application rate reported as OBs/A, 1×10^{12} OB/A = 2.3×10^{10} OB/1000ft^2.

Table 3. Mean (±SE) % damage resulting from black cutworm larvae in plots of creeping bentgrass treated with different formulations and rates of baculovirus (AgipMNPV) or Talstar S (bifenthrin). Five 2nd and 3rd instar larvae were placed on plots at 0, 3 and 14 days after treatment (DAT) and damage was assessed at 7, 10 and 21 DAT, respectively.

Treatment	**Rate**	**% Damage 7 DAT**	**% Damage 10 DAT**	**% Damage 21 DAT**
Untreated	---	55.0±5.0f	28.8±6.6bc	33.8±4.7cd
Talstar S	0.25 oz/M	0.0±0.0a	5.0±0.0a	3.5±0.9a
AgipMNPV unformulated	1×10^{12}	32.5±10.3bcde	28.8±5.2bc	35.0±2.9d
AgipMNPV powder milk	1×10^{12}	15.0±2.9abc	25.0±3.5bc	33.8±2.4cd
AgipMNPV k10 clay	1×10^{12}	32.5±2.5bcde	41.3±5.9c	33.8±2.4cd
AgipMNPV blankophore	1×10^{12}	35.0±10.4cdef	23.8±3.1b	33.8±3.8cd
AgipMNPV glycerin	2×10^{11}	45.0±8.7ef	32.5±4.8bc	25.0±2.9bcd
AgipMNPV glycerin	1×10^{12}	22.5±7.5bcd	33.8±9.9bc	23.8±3.1bc
AgipMNPV glycerin	5×10^{12}	22.5±7.5bcd	17.5±4.3ab	30.0±7.1cd
AgipMNPV lignin	2×10^{11}	55.0±8.7f	30.0±3.5bc	18.8±4.3b
AgipMNPV lignin	1×10^{12}	40.0±12.2def	31.3±9.7bc	28.8±4.3bcd
AgipMNPV lignin	5×10^{12}	12.5±2.5ab	22.5±3.2b	27.5±2.5bcd

*Numbers in same column followed by different letters are significantly different at α=0.05. Virus application rates reported as OBs/A, 1×10^{12} OB/A = 2.3×10^{10} OB/1000ft^2.

Evaluation of Warm-Season Grasses for Putting Greens

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

START DATE: 2013

PROJECT DURATION: Five years

TOTAL FUNDING: $90,000

SUMMARY TEXT

With the increased interest in the use of bermudagrass on greens, a project was developed to evaluate three warm-season grass species on USGA specification putting greens at eleven locations across the southern and mid-western U.S. Trial sites include university locations (7) and golf courses (4). The trial parameters dictate a higher mowing height and a less intensive management regime as compared to typical ultradwarf bermudagrass management, while targeting green speeds of 9-10 feet.

The trial consists of twenty-eight total entries, with fourteen bermudagrass, eleven zoysiagrass and two seashore paspalum entries. Trials were planted anywhere from mid-June to mid-August 2013. The bermudagrass and seashore paspalum entries established very quickly in 2013, while the zoysiagrass entries were much slower to establish, with ground cover was no more than 50-60% for any entry by the end of 2013.

The winter of 2013/14 was historically cold across much of the U.S., breaking records for low temperatures, snow/ice amounts and duration in many locations. Even though protective covers were utilized, winter damage was significant. Therefore, NTEP and the cooperators at Fayetteville, AR, Bloomington, IN, Lexington, KY and Richmond, VA agreed to replant damaged entries (28, 14, 7 and 1 entry, respectively). The winter of 2014/2015 was also severe in some locations, but no more replanting was allowed.

Data was collected by cooperators on initial establishment in 2013 and in some cases, 2014. Data was also collected on turfgrass quality, genetic color, leaf texture, fall color, density, ball roll and at some locations, winter survival. Data was analyzed separately based on location and also species.

Bermudagrass and zoysiagrass performance differed based on location, as well on as the experimental selection or cultivar. Several bermuda entries, including *MSB-285, MSB-264, Sunday* and *JK 110521* showed improved establishment and turf quality over the standard cultivar *Tifdwarf*. Entries such as *08-T-18*, *OKC-13-78-5* and *OKC-16-13-8* also performed well with good turf quality at several locations. Significant variation was also noted in genetic color, density and fall color retention ratings among bermudagrass entries. At this point in the study, ball roll speed measured at six sites showed only one site (Richmond, VA) with ball roll reaching the 9-10 foot threshold.

Zoysiagrass use on putting greens is only recently being considered in the U.S. A limiting factor is that most entries required the entire 2014 growing season to fully cover their plot area. However, several new zoysiagrasses appear to have potential for use, particularly under this lower input regime. *L1F*, *DALZ 1305* and *DALZ 1038* are three of the entries that produced good turf quality, if not better overall than *Diamond*, the standard cultivar. In addition, turf quality of some zoysias compares favorably to bermuda. Despite these initial encouraging results, it is too early to determine if the 9-10 foot green speeds can be achieved with these new zoysia experimentals.

Seashore paspalum use has been increasing, due to its superior salt tolerance. To date, however, the two entries of seashore paspalum demonstrated little performance differences.

SUMMARY POINTS

- 28 entries, including bermudagrass, zoysiagrass and seashore paspalum were planted at eleven trial locations across the southern and mid-western U.S. Entries of the same species were planted in separate blocks to facilitate the management differences needed among the species.
- Bermuda entries were the fastest to cover, followed by the seashore paspalum entries. Zoysia plots in many cases, took most of the 2014 growing season to achieve 100% coverage.
- The winter of 2013/14 damaged entries at four locations, requiring NTEP to resend, and cooperators to replant some or all entries at those sites.
- Bermuda, zoysia and seashore paspalum entry performance varied based on trial location. Several bermuda entries established faster, achieved higher turf quality, with better density, fall color ratings and ball roll speeds than standard cultivars.
- Several zoysia entries produced turf quality similar to bermuda. However, ball roll speeds were not yet comparable to most bermuda entries. There was no significant difference in performance among the two seashore paspalum entries.

PROGRESS REPORT – October 1, 2015

"Efficacy of Registered and Novel Fumigants Applied Via Multiple Application Methodologies for Control of Bermudagrass (*Cynodon* spp.) and Other Hard-to-Control Weed Species"

Principal Investigator:
J. Bryan Unruh, Ph.D.
Extension Turfgrass Specialist
University of Florida
West Florida Research and Education Center
4253 Experiment Drive, Hwy. 182
Jay, FL 32565
(850) 983-7105
fax (850) 995-3723

1.1 PROJECT TITLE

Efficacy of Registered and Novel Fumigants Applied Via Multiple Application Methodologies for Control of Bermudagrass (*Cynodon* spp.) and Other Hard-to-Control Weed Species

1.2 PROJECT OBJECTIVE

Determine the efficacy of registered and novel fumigants applied via multiple application methods including conventional and drip applied to control bermudagrass (*Cynodon spp*) and other hard-to-control weed species.

1.3 PROGRESS TO DATE

Fumigant Screening Trials & Demonstrations

Pike Creek Turf – On July 10, 2014, a screening trial was initiated at Pike Creek Turf in Adel, Georgia (Figures 1 and 2). Mixtures of fumigants including one that has not been evaluated before in turf applications were screened for their efficacy. This trial employed large plots without replication and each fumigant was evaluated at three different rates under two types of plastic tarps that differed in their retentive ability. The best performing treatments from this study were included in a replicated field study at SMR Farms, Bradenton, Florida.

SMR Farms – On November 20, 2014, a 2.0 acre study was initiated at SMR Farms near Bradenton, FL (Figure 3). The objective of this trial was to compare novel fumigants including the experimental compounds tested at Pike Creek Turf. This very large replicated trial included 14 treatments and three different sprigging dates. Plant back was evaluated in this study to assess the influence the fumigants may or may not have on the newly planted sprigs. Pest pressure was not sufficient in this trial to fully document the efficacy of the tested products.

Talis Park Golf Club – A demonstration trial was conducted at Talis Park Golf Club, Naples, Florida (Kevin Shields, Superintendent). One of the combination treatments identified in the Pike Creek trial and included in the SMR trial was chosen as the representative treatment. Treatments were applied May 5-6, 2015 and the tarp was removed from the treated area on May 13, 2015. The treated site will continue to be monitored for twelve months (Figure 4). Anecdotal information suggests that the grow-in of the site occurred more rapidly than areas treated with methyl bromide. This suggests that the fumigant is not negatively impacting the vegetative planting material.

University of Florida, GC Horn Turf Plots – On May 7, 2015, approximately 8,000 ft^2 of research plot area was treated with an experimental combination treatment that was identified as “promising” in work conducted at Pike Creek Turf and SMR Farms (this is the same treatment that was used at Talis Park Golf Club). This site housed accessions from the UF Turf Breeding program and was allowed to remain fallow following fumigation for several months to monitor for regrowth/contamination. During the fallow period, the site remained free of vegetative propagules. Private industry is conducting due diligence on the feasibility of registering this and bringing it to the market.

University of Florida – an additional replicated field trial to test the combination treatment identified in the Pike Creek trial and tested at SMR Farms and demonstrated at Talis Park Golf Club and at the UF Turf Research Facility. Scouts are trying to find a suitable site in south Florida for this trial. We hope to initiate this trial in the fall of 2015 or spring 2016.

Steam Injection Technology

We are closely monitoring the development of a large output steam generator prototype by researchers at the University of California – Davis. They are building a new prototype now with a direct fire steam generator acquired from Johnson's Gas Appliance Company in Cedar Rapids IA. California researchers received funding from the California Department of Pesticide Regulation to build the unit. They hope to be operational fall 2015 but are experiencing delays in the production of the steam generator. UC-Davis researchers are working with TriCal, Inc. on this project. Precision Combustion Incorporated (PCI), the company in which this PI had earlier conversations with, are still interested in developing a steam generator for agricultural purposes but, as a small company, they are looking for others to invest in the development.

The USDA-NIFA Methyl Bromide Alternatives Program (http://nifa.usda.gov/funding-opportunity/methyl-bromide-transitions) provides approximately $2,000,000 in funding for methyl bromide alternatives research. The request for proposals is generally issued in mid-March with an early-May closing date. I chose not to submit a proposal in 2015 since the prototype equipment has yet to be developed and historically the funding is used to test or evaluate available technology.

Since only $2,000,000 is available and the indirect costs are 30%, only $1,400,000 is available for direct cost funding. Our original proposal, which included equipment cost engineering of $150,000, was $336,297.26 – approximately 25% of the total direct costs available nationally. We opted to not submit the proposal due to our feeling that the proposal would not be reviewed favorably since the equipment we were proposing to test was not developed yet. Furthermore, the program requires a 100% cost sharing or matching requirement and this level of cost share simply wasn't available.

Given the current state of equipment development, we are hopeful that we can submit under the 2016 request for proposals – assuming this program continues to exist. With the equipment in place, approximately one-half of the requested budget can be removed thus making it more favorable in the eyes of the review panel. The cost share requirement will still be a challenge and will require that industry commit funds to move the project forward.

Drip-Applied Fumigation

A drip-applied fumigant study, as described in the original proposal, is still being planned and should be initiated during 2015. We will continue to assess whether or not fumigants applied through drip technology will work for golf course putting greens (simulated).

Dazomet (Basamid™) Efficacy Study

With the stockpile of methyl bromide nearly exhausted, dazomet is now being marketed and used. Dazomet is generally surface applied, sometimes rototilled, and then covered with high-barrier film or watered in. Efficacy data for this method is lacking but anecdotal information is prevalent. We are planning to conduct a trial with the goal of documenting efficacy.

1.4 PROJECT TIME LINE

Studies will continue to be conducted throughout 2015 and 2016.

Figure 1 - Fumigation study conducted at Pike Creek Turf in Adel, GA. Photo taken July 10, 2014.

Figure 2 - Fumigation Study at Pike Creek Turf, Adel, Georgia. Photo taken September 22, 2014.

Figure 3 - Fumigation study conducated at SMR Farms near Bradenton, FL. Photo taken November 20, 2014.

Figure 4 - Talis Park Golf Club (Naples, FL) rough area treated with an experimental fumigant. Photo taken June 16, 2015.

Assessment and Use Strategies of Bacculovirus for Control of Fall Armyworm and Black Cutworm

R. Chris Williamson (University of Wisconsin-Madison), David Held (Auburn University) and Ben McGraw (Penn State University)

Three independent bioassays were conducted at the University of Wisconsin-Madison, Auburn University and Penn State University to assess the effectiveness of the bacculovirus product Exilon (0.6% *Agrotis ipsilon* multinucleopolyhedrovirus, Andermatt Biocontrol AG, Swtizerland) for control of black cutworm (*Agrotis ipsilon*) and fall armyworm (*Spodoptera frugiperda*). This product contained $5x10^{11}$ viral occlusion bodies per liter and is currently labeled as a insect virus for Black cutworm (BCW), but not fall armyworm (FAW). Both are in the same family (Lepidoptera: Noctuidae) while sod webworm is in the Lepidopteran family Pyralidea, consequently we hypothesized that the bacculovirus would likely have little impact on sod webworm. As a result, we elected to not include sod webworm in this study. BCW and FAW were assessed on creeping bentgrass, at the University of Wisconsin-Madison and Penn State University, respectively and FAW was assessed on bermudagrass at Auburn University. Our results suggest that the baclovirus (Exilon) has little to no effect on FAW in the field or laboratory, regardless of application rate or turfgrass species reared on. The Exilon did however provide measurable control (mortality) of BCW larvae in the field when larvae were placed in turf treated with the bacculovirus 7 days after treatment (DAT) at the manufacturer's label rate (i.e., medium rate for bioassay; 33,945,000 occlusion bodies/m^2) and high rate (500,000,000 occlusion bodies/m^2) and exposed for 7 days. However, no meaningful differences were observed at 1, 3 or 14 DAT, these results may be attributed to the relatively high mortality (> 40%) that occurred in the untreated controls in the field. In summary, the bacculovirus Exilon appears limited to efficacy against BCW.

Field Trials

Penn State University: Fall Armyworm (Creeping Bentgrass)- recovery was poor from all treatments, including untreated checks

- No differences in mortality were observed between treatments
- Larvae recovered from field plots (all treatments) declined rapidly in laboratory

Auburn University: Fall Armyworm (Bermudagrass)-recovery was good

- At 1 DAT, there was no significant rate effect for the Exilon treatments, but survival was significantly lower than untreated control for larvae exposed to the label rate of Exilon

University of Wisconsin-Madison: Black Cutworm (Creeping Bentgrass)- mortality was relatively high in 1, 3 and 14 days after treatment in the untreated checks

- Exilon exhibited measurable control (mortality) of BCW larvae at 7 DAT at the label rate (i.e., medium) and high rate
- The performance of Exilon at 14 DAT, regardless of application rate, was not significantly different from the untreated control at 14 DAT

Laboratory Trials

Penn State University: Fall Armyworm (Creeping Bentgrass)

No mortality was observed with any of the bacculovirus treatments when larvae fed on treated diet

No statistical differences were observed between bacculovirus-treated and untreated checks for larval or pupal weight

The proportion of larvae developing into pupae by 8 DAT was high in all treatments (> 90%). Despite this, significantly fewer pupae were found in the high bacculovirus treatments.

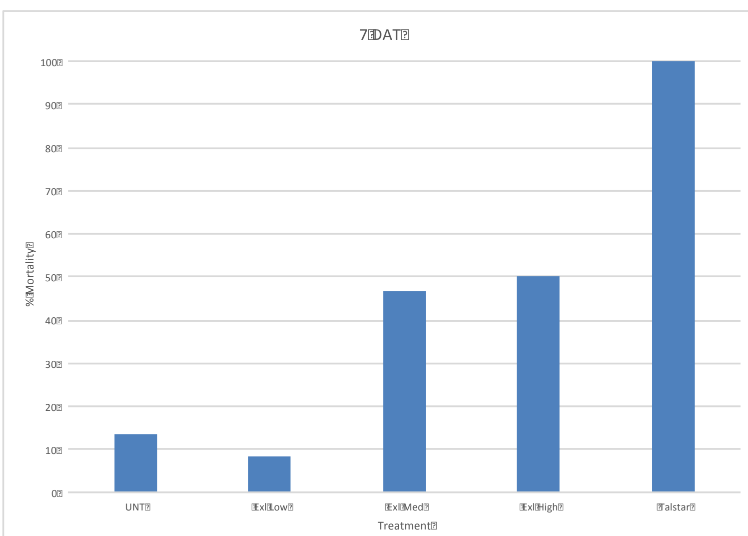
Auburn University: Fall Armyworm (Bermudagrass)

Recovered larvae that survived rearing in the lab had >95% pupation and no malformations in pupation were noted

University of Wisconsin-Madison: Black Cutworm (Creeping Bentgrass)

No significant mortality was observed with any of the bacculovirus treatments

University of Wisconsin-Madison: Percent (%) mortality of black cutworm larvae when placed in turf treated with the bacculovirus (Exilon) 7 days after treatment (DAT) and exposed for 7 days



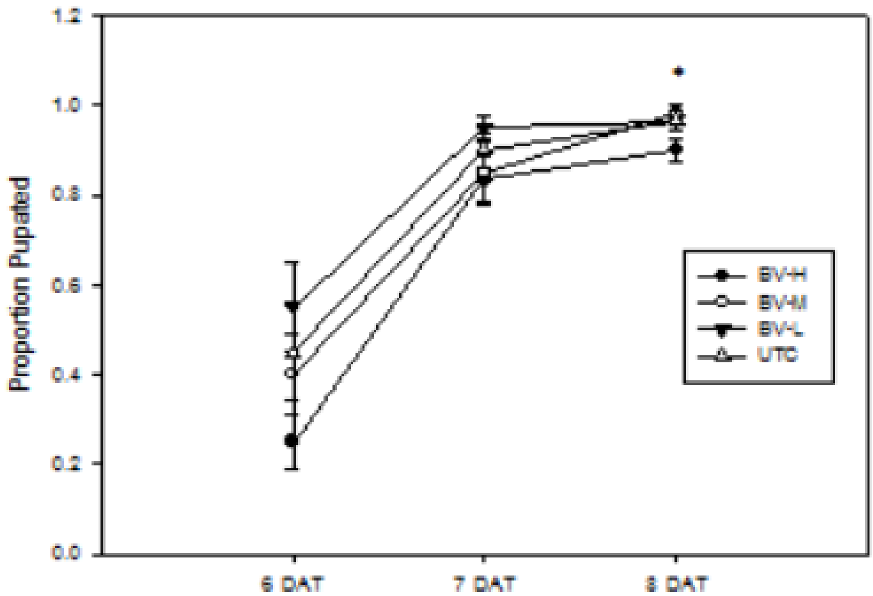
Auburn University: Percent survival of fall armyworm larvae exposed for 24 h exposure to bacclovirus (Exilon) treated bermudagrass then reared in the lab for 7 d

Treatment	Rate (amt product per 36 ft^2)	Percent survival of larvae exposed to residues at: 1 DAT	3 DAT	7 DAT	15 DAT
Exilon label	220 µl	33 ± 7b	40 ± 13a	53.6 ± 8a	87.3 ± 3a
Exilon low	33.4 µl	64.2 ± 8ab	45.2 ± 14a	49.1 ± 7a	90.7 ± 5a
Exilon high	3.34 ml	66.7 ± 13ab	49.4 ± 17a	68.3 ± 8a	92.3 ± 2a
Talstar S	0.27 ml	67.9 ± 11ab	62.1 ± 8a	65.7 ± 8a	74.3 ±10a
UTC	NA	87.5 ± 21a	69.4 ± 14a	80 ± 13a	94 ± 7a
Average (range) % recovery		23.7% 11-41%	62.1% 55-72%	77.1% 71-82%	81.1% 74-88%
Statistics					
F		1.82	0.85	1.05	0.64
Df		4,12	4,12	4,12	4,12
P		0.30	0.52	0.42	0.65

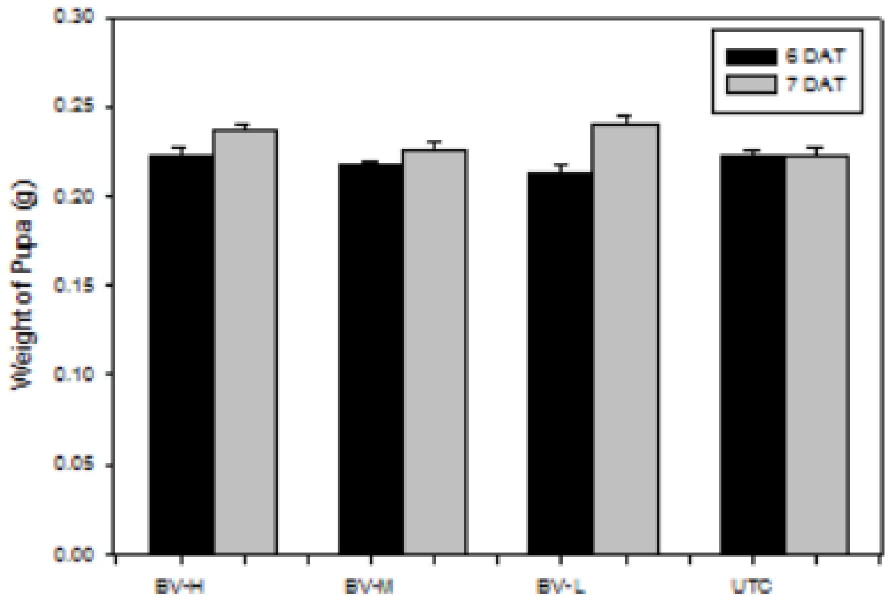
Means separation by Student's t test (JMP)

Penn State University

Effects of Baculovirus-treated Artificial Diet on Fall Armyworm Days-to-Pupation



Effects of Baculovirus-treated Artificial Diet on Fall Armyworm Pupal Weight



The Effects of Mowing Delay on Proxy Efficacy for Poa annua Seed Head Suppression

USGA ID#: 2015-19-534

Alec Kowalewski and Brian McDonald
Oregon State University
December 1, 2015

Research Summary (Year 1)

- Proxy applications significantly reduced seed head formation and size vs. untreated.
- Mowing on the date of Proxy application reduced Proxy effectiveness on only one rating date – 5 weeks after initial treatment and 11 days after the second application.
- Proxy applications lightened turf color slightly.
- Proxy applications improved turf quality vs. control by significantly reducing visible seed heads.

Introduction

Annual bluegrass seed head production on putting greens results in a number of detrimental effects including, but not limited to, reduced putting green speed and consistency, and reduced aesthetics. As a result, herbicides and plant growth regulators are often used to suppress seed head flushes. Research and practical field applications have shown that Embark (mefluidide) and Proxy (ethephon) provide the best reduction in seed head production. However, because of the phytotoxicity that often occurs with Embark (and it was recently removed from the market), Proxy has become the product of choice for suppression of annual bluegrass seed heads, however, its effectiveness - especially in the Midwest - is often inconsistent. Recent research conducted in the greenhouse has shown that Proxy absorption and translocation from the flag leaf substantially improves seed head suppression. However, daily mowing removes the flag leaf. The objective of this research was to determine if mowing delays prior to and following the application of Proxy will affect the seed head suppression of annual bluegrass during the spring flush (See Figure 1 for mowing schedule).

Treated, mowed every day (Left); Untreated, mowed every day (Center); Treated, only mowed 3 days Before & 3 Days after (Right)

April 20 – 18 Days after 2nd Proxy Application (5.0 oz/1,000 ft^2)

Year 1 Findings

The application of Proxy PGR significantly reduced seed head production on April 6th – 4 weeks after treatment and all dates following (Table 1). The main effect of mowing delay **before Proxy application** was only significant on one rating date – April 13th – 5 weeks after the initial application of Proxy and 11 days after the second Proxy application. Mowing on the day of application reduced the effectiveness of the Proxy application on ratings taken April 13th, which resulted in a 36.5 percent reduction in seed head counts versus the control and was significantly worse than the other three mowing treatments which had a 48.8, 51.2 and 53.8 percent reduction when the last mowing occurred 3, 2, and 1 day before application, respectively. The main effect of mowing delay **after Proxy application** was not significant on any date.

Although there were much fewer seed heads in plots treated with Proxy, the actual number was much higher than expected. As you can see from Table 1 (April 13th and after), generally more than 200 seed heads per square foot were present on the plots treated with Proxy, but their size was much smaller and thus less visible than the seed heads on the untreated plots. As a result, the visual seed head ratings on plots treated with Proxy were relatively low (Table 2).

The Proxy application reduced turfgrass quality by ½ a point on the rating scale because of a slight lightening of color (Table 3). However, because seed head production increased over time on the untreated plots, the plot quality on these plots decreased over time, and as a result, rated much worse than the plots, treated with Proxy, regardless of mowing timing. The difference in seed head counts on April 13th was not enough to affect the quality ratings of the plots because of the small size of the seed heads, as mentioned above.

Future Research

In 2016 the protocol will be include an increased number of mowing delay treatments **prior to Proxy application** (6, 5, 4, 3, 2 and 1 days prior) and mowing delay treatments **after Proxy application** (1, 2, 3, 4, 5 and 6 days after). Hopefully increasing the number of mowing delay days prior to and/or after application will allow for a more mature flag leaf; therefore, generating the anticipated increase in seed head suppression provided by Proxy applications.

Figure 1: Mowing Timing – Days Before and After Proxy Application (5.0 fl. oz. per 1,000ft^2)

Days Mowed (Shaded in Blue)
Before (-) or After (+) Proxy Application

Trt #	Proxy?	- 3 Days	- 2 Days	- 1 Day	0	+ 1 Day	+ 2 Days	+ 3 Days
1	Yes	■				■	■	■
2	Yes	■					■	■
3	Yes	■						■
4	Yes	■	■			■	■	■
5	Yes	■	■				■	■
6	Yes	■	■					■
7	Yes	■	■	■		■	■	■
8	Yes	■	■	■			■	■
9	Yes	■	■	■				■
10	Yes	■	■	■	■	■	■	■
11	Yes	■	■	■	■		■	■
12	Yes	■	■	■	■			■
13	No	■	■	■	■	■	■	■

Note: After this schedule, the plots were mowed 7 days a week until the end of the trial.

Table 1: Poa annua Seed Head Counts per Square Foot

(Proxy Treatments applied March 9th and April 2nd – Mowing Treatments began March 6th and March 30th).

Trt #	Last Mowing Before Proxy App (Days)	First Mowing After Proxy App (Days)	Proxy?	4/27 7 WAIT** 3 WA 2nd Trt**	4/20 6 WAIT 2 WA 2nd Trt	4/13 5 WAIT 1 WA 2nd Trt	04/06 4 WAIT 4 DA 2nd Trt	03/30 3 WAIT	3/23 2 WAIT	03/16 1 WAIT	03/09 0 DAT
1	3	1	Yes	251	409	295	168	96	128	71	36
2	3	2	Yes	281	325	351	218	198	154	87	14
3	3	3	Yes	248	335	302	161	171	78	102	9
4	2	1	Yes	313	302	315	128	241	125	72	9
5	2	2	Yes	257	315	328	143	198	85	61	7
6	2	3	Yes	287	370	257	196	177	99	61	13
7	1	1	Yes	273	257	214	121	135	75	66	5
8	1	2	Yes	244	370	305	203	169	111	108	18
9	1	3	Yes	190	303	332	155	236	110	95	8
10	0	1	Yes	288	433	385	180	174	78	87	20
11	0	2	Yes	264	314	351	159	181	93	85	8
12	0	3	Yes	281	377	434	205	181	88	108	15
13	0	1	No	1,263	964	639	428	223	170	59	23
		LSD @ .05		**177**	**136**	**136**	**147**	**ns**	**ns**	**ns**	**ns**

**** Note: "WAIT" = Weeks after initial Proxy treatment. "WA 2nd Trt" = Weeks after second Proxy treatment.**

Table 2: Visual Seed Head Ratings 1 – 9; 1 = None, 9 = 100% Cover

Trt #	Days Before Proxy App	Days After Proxy App	Proxy?	Visual Seed Head Rating 1 - 9; 1 = None; 9 = 100% Cover							
				03/09	**03/16**	**03/23**	**03/30**	**04/06**	**04/13**	**04/20**	**04/27**
1	3	1	Yes	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.3
2	3	2	Yes	1.5	2.0	2.0	2.0	2.3	2.5	2.3	2.3
3	3	3	Yes	1.5	2.0	2.0	2.0	2.5	2.3	2.0	2.0
4	2	1	Yes	1.5	2.0	2.0	2.0	2.8	2.3	2.3	2.3
5	2	2	Yes	1.5	2.0	2.0	2.0	2.5	2.3	2.0	2.0
6	2	3	Yes	1.5	2.0	2.0	2.0	2.5	2.0	2.0	2.0
7	1	1	Yes	1.5	2.0	2.0	2.0	2.3	2.0	2.0	2.3
8	1	2	Yes	1.5	2.0	2.0	2.0	2.3	2.3	2.0	2.0
9	1	3	Yes	1.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0
10	0	1	Yes	1.5	2.0	2.0	2.0	2.0	2.3	2.0	2.0
11	0	2	Yes	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
12	0	3	Yes	1.5	2.0	2.0	2.0	2.5	2.3	2.0	2.0
13	0	1	No	1.6	2.0	2.3	3.0	4.3	4.0	6.0	6.8
		LSD @ .05		**ns**	**ns**	**ns**	**0.32**	**0.66**	**0.41**	**0.42**	**0.45**

Table 3: Turfgrass Quality 1 – 9; 9 = Best

Trt #	Last Mowing Before Proxy App (Days)	First Mowing After Proxy App (Days)	Proxy?	Quality Ratings 1 - 9; 9 = Best							
				03/09	03/16	03/23	03/30	04/06	04/13	04/20	04/27
1	3	1	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
2	3	2	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
3	3	3	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
4	2	1	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
5	2	2	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
6	2	3	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
7	1	1	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
8	1	2	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
9	1	3	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
10	0	1	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
11	0	2	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
12	0	3	Yes	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5
13	0	1	No	8.0	8.0	8.0	7.9	7.1	7.0	6.4	6.0
		LSD @ .05		**ns**	**ns**	**ns**	**0.1**	**0.1**	**ns**	**0.1**	**ns**

Suppression of shoot growth and improved putting green performance traits with use of plant growth regulators

USGA ID#: 2015-20-535a

This study evaluated extended growing degree day (GDD) models and sequential applications of plant growth regulators (PGRs) (Table 1) to 'Dominant' creeping bentgrass in Lubbock, TX. Growing degree day accumulation was determined by calculating the average daily temperature in Celsius (min + max/2) with base temperature of 0°C. Modelling applications were made on 6-8 week intervals following the accumulation of 1,000+ GDD. Sequential applications were made every two weeks to simulate a calendar-based PGR strategy implemented by golf course superintendents.

The modelling applications effectively demonstrated the complete suppression and rebound phases expected from PGR applications (Fig. 1). Cutless (flurprimidol) provided the least amount of suppression (24% at 153 GDD), but the manufacturer suggested that multiple applications of the product may be required for the chemical to effectively suppress shoot growth. Primo Maxx (trinexapac-ethyl) provided greater suppression (32%), but reached peak suppression at only 125 GDD. Trimmit (paclobutrazol) and the combination product Legacy (trinexapac-ethyl and flurprimidol) both provided 33% maximum suppression at 162 and 170 GDD, respectively. Musketeer, containing all three chemistries, provided the greatest suppression (39%) peaking at 170 GDD. Evaluating the complete cycle of these PGR's can provide an approximate reapplication window for golf course superintendents using two thirds of the period to reach equal growth rates of untreated controls (Fig. 1). Based on these calculations, the following GDD accumulations could be used to determine appropriate reapplication windows: Cutless (230 GDD), Trimmit (250 GDD), Primo Maxx (260 GDD), Legacy (300 GDD), and Musketeer (340 GDD).

The ultimate goal of sequential PGR applications should be to maintain a consistent shoot growth rate lower than nontreated areas. Applying these PGR's every two weeks to the area did not manage consistent growth throughout the summer months. Initially, lower rates of PGR's were applied to minimize severe phytotoxicity that can occur with slower growth rates early in the summer. The lower rates did not sufficiently suppress shoot growth following the final two applications when growth rates began to increase (Fig. 2). Similarly, the sequential applications at moderate rates during peak growth periods resulted in large suppression and rebound swings (Fig. 3). This corresponds well with the application intervals suggested from modelling applications as peak growth periods accumulated over 300 GDD in the two weeks between applications. Our data suggest it takes 2-4 days to observed suppression following PGR application, so this may allow for greater rebound potential when using calendar-based sequential applications. Once a treatment rebounded, it was difficult to regain the level of suppression initially observed with the product unless growth rates were reduced allowing for greater suppression.

Trimmit and the combination products generally provided greater suppression than Primo Maxx and Cutless, but some of these products resulted in phytotoxicity that may reduce the visual quality of the putting green. Playability would not be affected unless serious canopy thinning occurred. The products containing paclobutrazol can cause severe phytotoxicity and thinning if applied when bentgrass is not growing quickly (Fig. 4). This can also lead to problems due to the slow recovery following application.

Summary bullet points:

- Calendar-based PGR applications will likely result in high variations in shoot growth and a greater potential for rebound.

- Phytotoxicity and thinning of the turf canopy may be a concern with PGR's containing paclobutrazol, especially if applied to creeping bentgrass in a slower growth period.
- Modelling applications indicated that reapplication of all PGRs would be required from 230 to 340 GDD
- During peak growth during summer months, GDD accumulation exceeded 300 GDD between 2-week sequential applications in this study

Tables, Figures, and Images:

Trade name	Active Ingredient	AI (%)	Low Rate	Moderate Rate
			-lb/acre-	-lb/acre-
Untreated	N/A	N/A	N/A	N/A
Primo Maxx	Trinexapac-ethyl	11.30	6	6
Trimmit 2SC	Paclobutrazol	22.90	6	6
Cutless MEC	Flurprimidol	16.00	12	16
Legacy	Trinexapac-ethyl Flurprimidol	5.00 13.26	6	10
Musketeer	Trinexapac-ethyl Paclobutrazol Flurprimidol	1.40 5.60 5.60	12	18

Table 1. Plant growth regulators applied to 'Dominant' creeping bentgrass putting greens in Lubbock, TX. Low rate was initially applied due to the slower growth rate to limit severe phytotoxicity and sustain growth. Moderate rates were applied rapid growth occurred during hotter summer months.

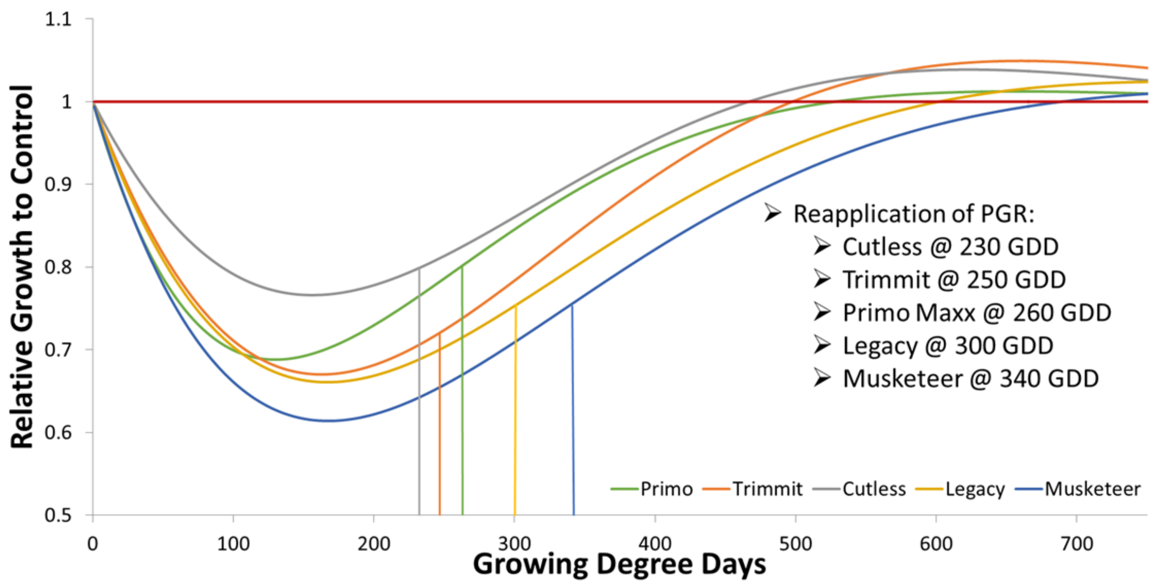


Figure 1. Modelling applications of all five plant growth regulators demonstrating the suppression phase, equilibrium point with untreated controls, and rebound phase. Two thirds of the equilibrium point can be an effective interval to maintain applications, and these values are indicated in the figure.

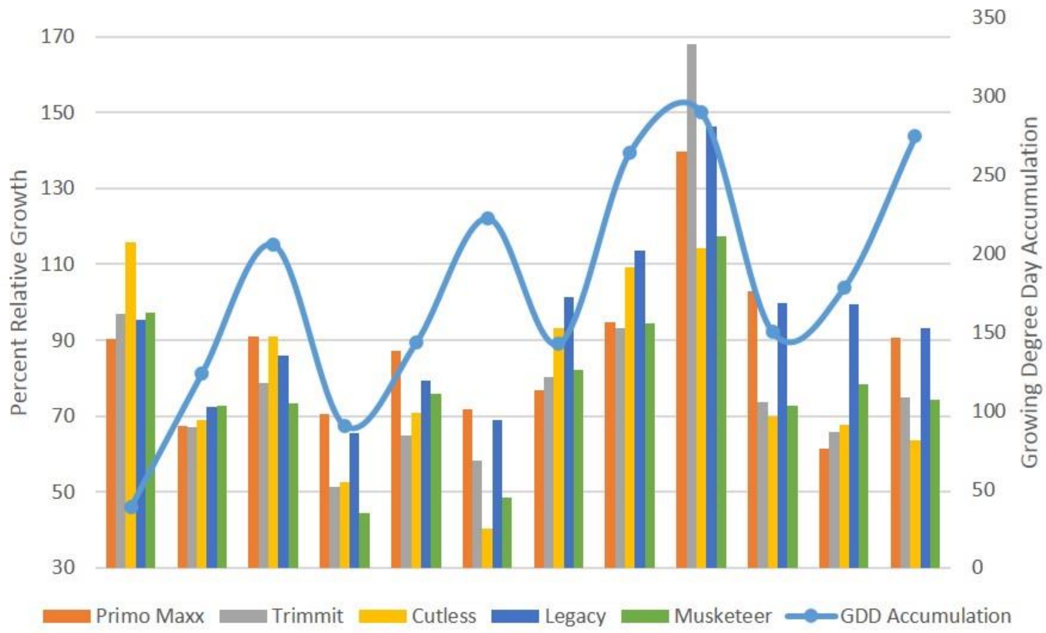


Figure 2. Sequential plant growth regulator applications from Rawls Golf Course applied every two weeks from 23 April to 15 June 2015. Each group of bars represents relative clipping yield compared to untreated control on a single clipping collection date. Growing degree day accumulations were calculated by determining the average temperature (°C) (min + max/2) using a base temperature of 0°C. At the lower rate, suppression is limited as the growth of creeping bentgrass is increasing.

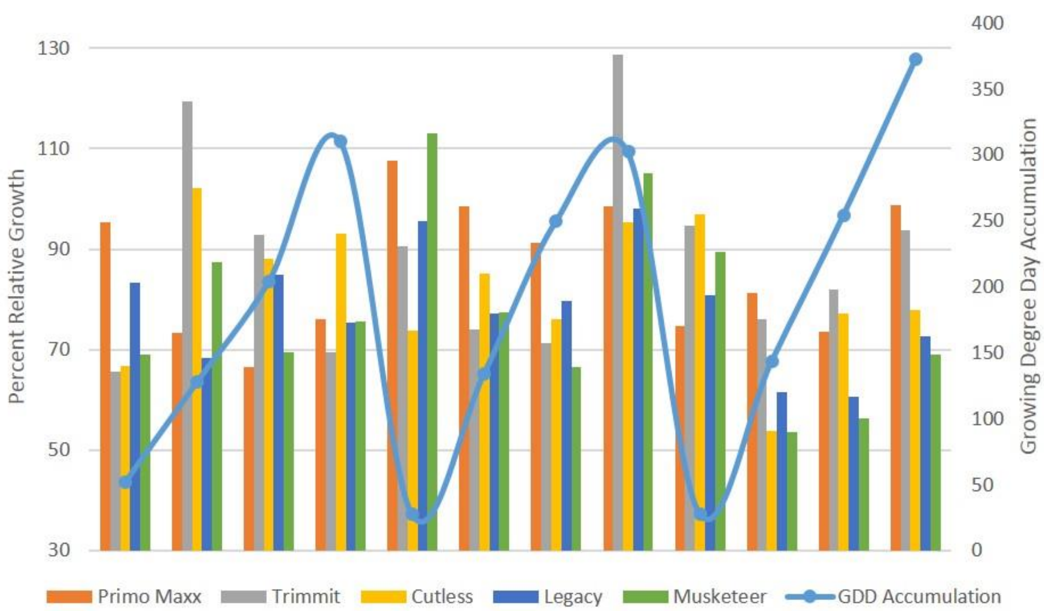


Figure 3. Sequential plant growth regulator applications from Rawls Golf Course applied every two weeks from 17 June to July 27 2015. Each group of bars represents relative clipping yield compared to untreated control on a single clipping collection date. Growing degree day accumulations were calculated by determining the average temperature (°C) (min + max/2) using a base temperature of 0°C.

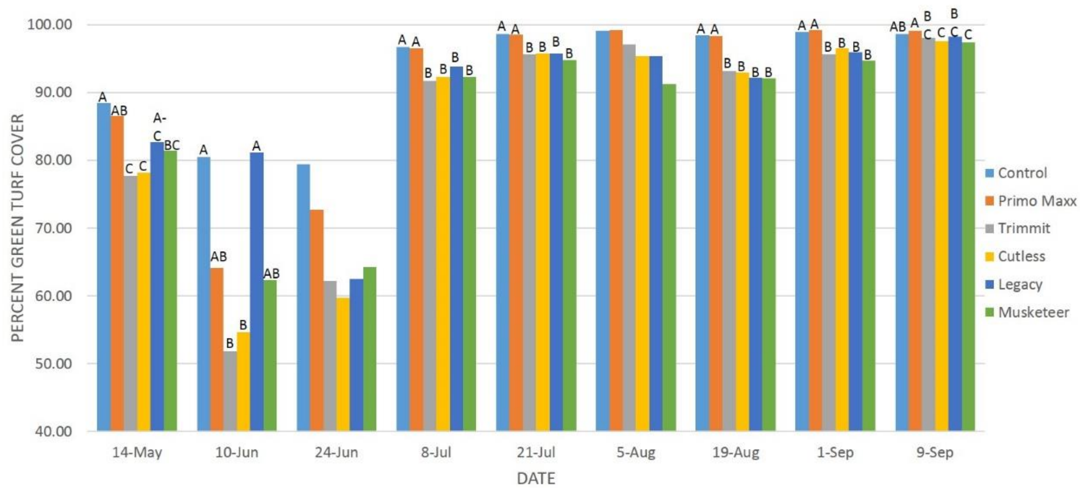


Figure 3. Percent green turf cover calculated from digital image analysis from the Rawls Course. Bars sharing the same letter are statistically similar at α = 0.05. Plant growth regulators other than Primo Maxx result in phytotoxicity; however, the level of phytotoxicity is much greater early in the growing season prior to the increased growth rate of the creeping bentgrass.

Image 1. Plant growth regulator trial at Meadowbrook Golf Club illustrating darker green color observed with sequential applications at the conclusion of the trial on 8 September 2015. Treatment labels describe the product applied sequentially to the plot.

RESEARCH REPORT I

Project Title: Water Treatment and Remediation using a Bioreactor

Principal Investigator(s): Dr. Klaus Doelle

University: State University of New York, College of Environmental Science and Forestry (SUNY-ESF)

Address: 1 Forestry Drive, Syracuse, NY 13210, Walters Hall 416

Objectives:

- Investigate if bacteria cultures of a constructed wetland can remediate pharmaceutical compounds in waste water.
- Investigate the best treatment sequence for pharmaceutical removal.
- Investigate a treatment sequence for the removal and degradation of pharmaceutical, chemical, and organic compounds in various waste water types.

Introduction:

Golf courses require an average of 48.2 acre feet to 386.2 acre feet of water for irrigation purposes annually, depending on location and regional availability. Water used for irrigation purposes might come in the future from: **(i)** storm runoff from impervious surfaces captured in retention ponds, **(ii)** high flow (flood) water diversion into storage ponds, **(iii)** secondary or tertiary effluent from a waste water treatment plant (WWTP), **(iv)** grey water, and **(v)** treated or raw water from a local public water supply distribution system. All of the above WW types might contain chemical and pharmaceutical compounds that can have a dramatic and disconcerting effect on humans and local wildlife, while placing a huge burden on the entity for effective water treatment.

Sub**s**urface **B**io**r**eactors **(**S2BR) operated under a gravity feed drain system could provide the solution to treat the used waste water (WW) and provide a functional design, natural appearance, low cost in operation and maintenance, and can be operated year round in any US climate. S2BR operated under an advance dynamic fill and drain cycle could allow the removal of carbon, nitrogen, phosphorous and pharmaceuticals and personal care products (PPCPs) that have been discharged into the environment unchecked for many years. It is expected that applying S2BR technology to a golf course's infrastructure and operation requirements will allow treating any WW for irrigation purposes, as well as runoff water from golf courses that is discharged into environmentally critical water sheds.

Laboratory Installation:

The experimental S2BR laboratory cell 1 and cell 2 were designed out of a 55 gallon plastic drum split in half. Each cell's dimensions were 0.52 m x 0.86 m x 0.25 m with a surface area of 0.44 m² and 52 l of water holding capacity after the media was installed (Figure 1). Gravel media from an existing constructed wetland (CW) (Figure 2) at CERF was used to mimic the bacteria consortium, porosity, particle size, and sludge composition. The media was taken from the beginning, the middle, and the end of the CW and placed accordingly into the laboratory cells.

As a WW feed tank, a 1000 l industrial bulk container tank (IBC) was used. A metering pump was used to transfer the WW from the 1000 l IBC feed tank to cell 1, and from cell 1 to cell 2. The treated WW was discharged from cell 2 into a large pan by opening a 3/4”valve. The S2BR system was installed in a barn at the CERF facility where the temperature was maintained at 70°C.

Figure 1: Laboratory S2BR

Figure 2: CERF Constructed Wetland

Laboratory Tests:

To determine the functionality of the laboratory S2BR, the ammonia (NH_3) concentrations of the influent and effluent WW were measured immediately after the samples were collected with a Hach DR/2000 Spectrophotometer. The NH_3 concentration can be directly related to BOD and COD removal of the WW. The system was considered functional if the ammonia effluent concentrations were found at a level below 4.5 mg/l. The influent NH3 level in the WW tested between 15.42 mg/l and 18.58 mg/l with a pH between 6.52 and 7.24 and temperature of 16.2 and 17.1 °C.

For the laboratory tests, the pharmaceuticals ibuprofen and naproxen were chosen because they are two of the most commonly used pharmaceuticals and can be found in the wastewater available at concentrations of 7.51 µg/l to 40.32 µg/ depending on the week day.

To test the pharmaceutical removal rate, a total system hydraulic retention rate (HRR) of 2 days, 1 days and 0.5 day was tested. The HRR is the time the WW needs to pass through the S2BR system.

Tests were conducted using U.S. EPA established standard methods (Methods 1694, U.S. EPA 2007), used for the measurement of more than 70 pharmaceuticals and personal care products (Methods 1694, U.S. EPA 2007). Tests were conducted using a HPLC-MS/MS.

All samples were tested in triplicate and the average was calculated.

Evaluation of the Experimental Laboratory S2BR

The S2BR laboratory evaluation had various influent levels of pharmaceuticals with a range of 7.51 µg/l to 40.32 µg/l, depending on the day of the week. Figure 3 shows the Ibuprofen and Naproxen remediation rate. Ibuprofen remediation was found to be 40.76%, 26.17, and 38.79% for the 2 day, 1 day and 0.5 day HRR respectively. Naproxen remediation was found to be 30.26%, 26.42, and 83.13% for the 2day, 1 day and 0.5 day HRR respectively. The variation in removal efficiency can be related to the different influent levels of pharmaceutical compounds in the waste water as well as effects of sorption and microbial degradation during the testing phase.

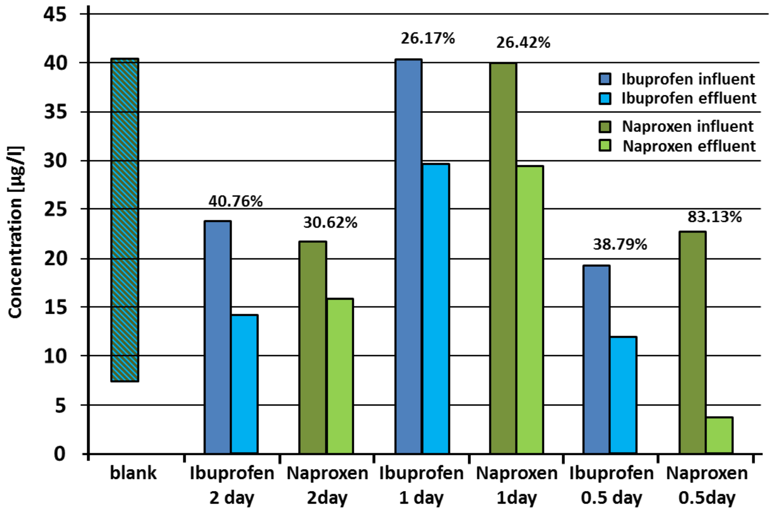


Figure 3: Ibuprofen and Naproxen Removal from Waste Water

Discussion of Results:

Laboratory S2BR as used for this research can be used to evaluate WW removal functionality and pharmaceutical removal efficacy. The established bacteria consortium in the laboratory S2BR will remediate various influent levels of pharmaceutical compounds. At lower pharmaceutical influent levels a higher removal rate can be achieved. Due to a daily change in influent levels it cannot be determined which operation sequence will be best. For pharmaceutical influent levels of up to 25 µg/l a HRR of 0.5 day seems to be sufficient. Whereas for pharmaceutical influent levels of up to 40 µg/l a HRR of 1 day is not sufficient. However, pharmaceutical removal rate seems to be linked to the volume and surface area of the media of the S2BR where better pharmaceutical removal rates can be achieved if the influent level is lower. This leads to the conclusion that a S2BR with greater media surface area will have a higher removal rate due to its larger internal surface area available to host the remediating bacteria consortium.

Acknowledgements:

The author is grateful for the support from Dr. G. Boyer of the SUNY-ESF Chemistry Department and Lacey Kucerak for analyzing the samples.

Next Steps:

- Build a portable 1000 gal S2BR pilot unit and perform initial tests at the Minoa Cleanwater Educational Research Facility and later dispatched the S2BR unit for testing at a golf course site.
- Selection of a suitable Golf Course for installation by USGA.
- Installation and testing of water remediation performance at the selected golf course site.

Nitrous Oxide Emissions and Carbon Sequestration in Turfgrass: Effects of Irrigation and Nitrogen Fertilization

Ross Braun, Dale Bremer, and Jack Fry

Nitrous oxide (N_2O) is important greenhouse gas implicated in global climate change. Turfgrass is typically fertilized with nitrogen (N) and irrigated and has the potential to emit N_2O at similar rates as other agricultural soils and thus, play an important role in atmospheric N_2O budgets. The development of management practices such as slow-release N fertilizer and/or deficit irrigation may mitigate N_2O emissions. The objectives were to quantify the magnitude and patterns of N_2O emissions in turfgrass and determine how irrigation and N fertilization may be managed to reduce N_2O emissions.

The study is being conducted under an automated rainout shelter near Manhattan, Kansas (Fig. 1). By shielding rainfall from turfgrass, researchers can control the amount of water applied to plots. Zoysiagrass was sodded June 4, 2013, and maintained at a 1-inch mowing height. During the summer (June-Aug) of 2014 and 2015, two irrigation treatments were applied including medium (80% evapotranspiration [ET] replacement) and medium-low (60% ET replacement) (Fig. 2). Three N-fertilization treatments included urea and polymer-coated N, both at 2 lb/1000 ft^2, and a control with no N applied. Because little drought stress was observed in the 60% ET treatment in 2014, irrigation amounts in both treatments were reduced, specifically from 80 to 75% ET replacement in the medium and 60 to 50% ET replacement in the medium-low treatment in 2015.

Nitrous oxide emissions were measured of with static chambers placed over the turfgrass surface and analyzed with gas chromatography (Fig. 3). Measurements began on October 29, 2014 (DOY 302) and continued weekly-to-monthly until October 5 2015 (DOY 278), concluding the first year (Fig. 4). Carbon sequestration in the upper soil profile (0 to 12 inches) will be measured by sampling soil C at the end of the 3-year study; initial soil C was measured on Aug. 28, 2013. Ancillary measurements included soil moisture, temperature, nitrate and ammonium, visual quality, and percent green cover using digital image analysis.

Cumulative annual emissions of N_2O were significantly greatest in urea and least in untreated (no N) zoysiagrass among treatments. Annual emissions were 1.82, 2.09, 2.77 kg N_2O-N ha^{-1} yr^{-1} for untreated, polymer-coated urea, and urea, respectively (Fig. 5). Annual emissions were similar to those reported in other turfgrass studies, which ranged from 1 to 3.85 kg N_2O-N ha^{-1} yr^{-1} across various turfgrass species and under different fertilization regimes (Bremer, 2006; Kaye et al., 2004; Lewis and Bremer, 2013). The percentage of applied N fertilizer emitted as N_2O in this study was 2.2% from poly and 2.9% from urea fertilizer. The highest fluxes and majority of emissions occurred in the summer because of the fertilization events and, presumably, higher soil temperatures. There were spikes after applications of urea fertilizer, but increases were much smaller with application of controlled release (poly) N fertilizer. Both urea and controlled release N fertilizer treatments resulted in higher turfgrass quality than the control, but all three treatments maintained acceptable turfgrass quality during deficit irrigation treatments (Fig. 6).

Bullet Points:

- Annual N_2O emissions were greatest in urea and least in untreated (no N) among treatments.
- Differences were negligible due to irrigation treatment. Irrigation levels may be decreased further in the final year to induce slight stress on the low irrigation treatment.
- All fertilizer treatments maintained acceptable quality, however the controlled-release fertilizer resulted in more consistent visual quality ratings compared to urea and untreated
- Urea fertilizer had higher peak fluxes after fertilization and overall annual emissions than polymer-coated N-fertilizer.
- Thus, controlled released N fertilizers such as polymer-coated urea in turfgrass systems could potentially help mitigate N_2O emissions.

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 on July 22, 2015 DOY 174.

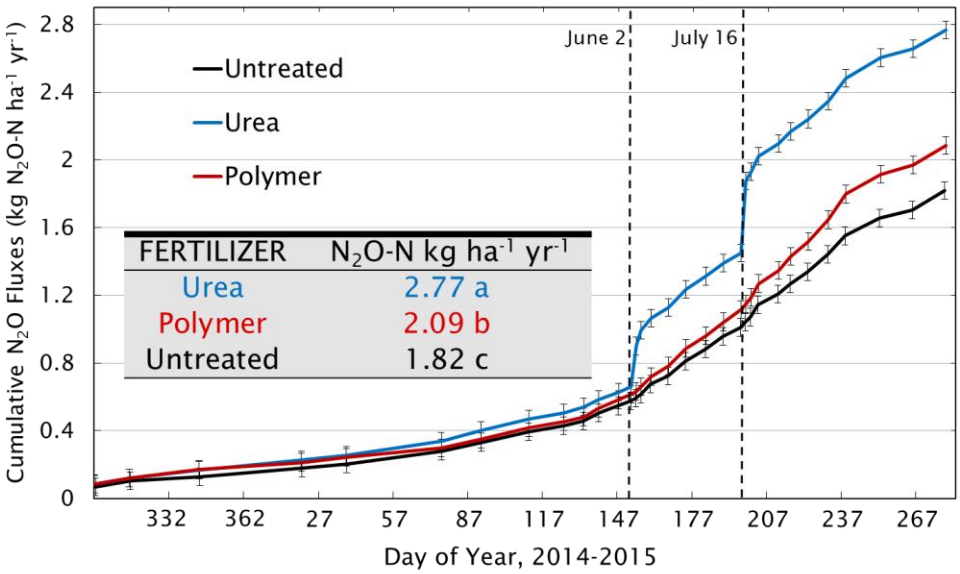


Figure 5. Cumulative fluxes of N_2O-N from plots treated with urea, polymer-coated urea, and untreated. Vertical dashed lines represent fertilization dates.

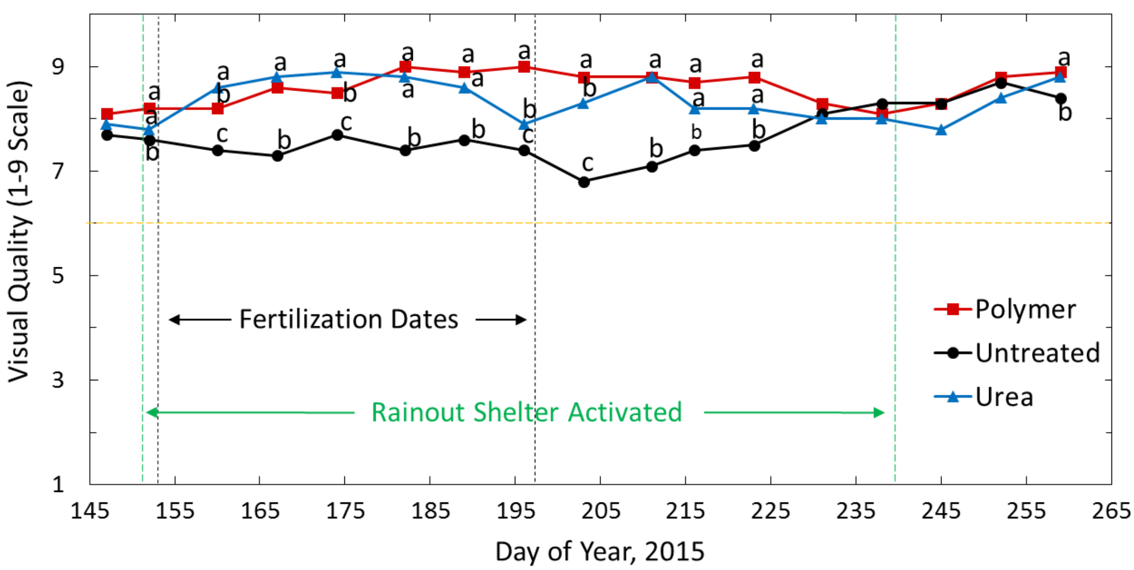


Figure 6. Visual quality ratings (9 = best quality) of Meyer zoysiagrass prior to and following the summer period under the automated rainout shelter. Plots were fertilized with Urea and Poly on DOY 153 and only Urea fertilizer again on DOY 197. Any points below yellow horizontal dashed line at rating of 6 would be below acceptable quality. Means followed by the same letter on a date are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

Green's Brushing: When Does Physiological Stress Occur?

Gail Gu, Matt Williams, David Gardner, and Karl Danneberger
Department of Horticulture and Crop Science
The Ohio State University

The objective of this study is to quantify the fluctuations in physiological benefits or stress due to brushing creeping bentgrass greens throughout the growing season.

Methods & Materials

Our study was initiated on May 19, 2014 on a 'Penncross' creeping bentgrass turf maintained on native soil located at the Ohio Turfgrass Foundation Research and Educational Facility, Columbus, Ohio. The creeping bentgrass turf was maintained at 0.125 inches with 0.25 lbs of Nitrogen per 1000 square feet applied every 14 days. Trinexapac-ethyl (Primo MAXX) was applied weekly at 0.125 fluid ounces per 1000 square feet. A light topdressing (dusting) was done weekly during the study. These practices were continued through 2015.

In 2014 the treatments consisted of 1) brushing once a week, 2) brushing three times a week, and 3) control. On August 18, 2014 the brushing treatment once a week was changed to 5 times a week. In addition, we set the brushing unit to 0.000 inch and ran the brushes in reverse (initially the brushes were set in the forward position at 0.100 inch). The treatments were applied using a Jacobsen Eclipse 2 walk behind mower.

In 2015, the brushing once a week was dropped and replaced with a double cut mowing treatment. The treatments consisted of 1) single cut (untreated), 2) double cut, 3) double cut with brushing 3 times a week, and 4) double cut with brushing 5 times a week. The brushing treatments consisted of brushing in reverse set at 0.000 inch.

Treatments were evaluated visually for color and injury. Malondialdehyde (MDA) levels were measured as an indicator of plant stress. Malondialdehyde forms when reactive oxygen species (ROS) degrade membranes (lipid peroxidation). During periods of environmental stress (ex. heat, light) ROS can increase dramatically resulting in damage to cell structure.

During 2015 we made multiple measurements of photochemical efficiency (chlorophyll fluorescence) through the summer as an indicator of stress.

Results – 2015

Through October 15, 2015 we found improvement in leaf (turf) texture with brushing. No significant differences ($P=0.05$) occurred among the treatments for 6 out of the 7 sampling dates between July 23rd and October 15th.

In 2014 we observed a thinner leaf blade that appeared to have less leaf moisture in the brushed treatment compared to the un-brushed treatment. In 2015 we quantified the amount of cuticle on the leaf blade among the treatments which is shown in Table 1. Double cutting had the greatest effect (P=0.05) on reducing the amount of cuticle wax from the leaf blades. Brushing had no effect.

Treatments	Cuticle Wax (mg/g) October 1, 2015	Cuticle Wax (mg/g) November 17, 2015
Single cut	7.4053	5.6605
Double cut	5.4598	5.1946
Double cut + 3x brushing	5.6072	5.0614
Double cut + 5x brushing	5.2996	5.2614
LSD (P=0.05)	1.7171	NS
LSD (P=0.01)	NS	NS

Conclusion

Our study over the last two years demonstrates the benefits of improving leaf texture through brushing. Under the conditions of the study, native soil green, mowed at 0.125 inches with a brushing unit positioned in front of the cutting unit, we found no detrimental effect either visually or physiologically from brushing.

Cultural and chemical weed management in native fine fescue roughs

Doug Soldat, Bruce Schweiger, and Paul Koch
University of Wisconsin-Madison

- Weed control in native areas composed of fine fescue presents agronomic and economic challenges.
- Three trials have been initiated to evaluate the impact of cultural and chemical practices on grassy and broadleaf weed control in native areas.
- Mowing and herbicide use resulted in the lowest weed populations, but if no herbicide is applied, mowing increases total weed population.
- Preliminary results indicate several products are effective for controlling weeds common to native areas in Wisconsin, including low rates of glyphosate when applied in May.

As native fine fescue rough areas grow, finding effective chemical and cultural management of weeds is becoming a high priority (Figure 1). These areas are intended or are perceived to reduce maintenance costs and environmental impact; however, a solid understanding of how to manage them is lacking which has led to possibly excessive inputs of chemicals and labor to obtain the desired visual effect. The objective of this project is to evaluate various cultural and chemical management strategies in a fine fescue rough.

This project is being conducted at Hawks Landing Golf Club in Madison, WI. At Hawks Landing, we have initiated three separate trials. The first trial investigates the impact of three cultural management strategies (mowing and removing material, mowing and returning material, and not mowing) on weed and desirable grass composition. Each strategy is evaluated either with or without chemical control. A second trial evaluates the performance of five different herbicides on weed composition. Finally, a third trial evaluates the efficacy of various rates and timings of glyphosate on spring weed control. The hypothesis is that glyphosate at low rates can be useful for controlling early season weeds (i.e. quackgrass) without harming desirable grasses such as fine fescue. For all three studies plot size is 6 ft. by 10 ft. with each treatment replicated four times and arrayed in a randomized complete block design. Visual estimates of plant populations are made in spring, summer, and fall. The trials will continue for at least three years after initiation.

For the cultural management trial, we observed that the combination of mowing and herbicide use resulted in the lowest weed populations. However, if no herbicide is applied, mowing increased weed populations (Table 1). The chemical efficacy trial showed good control of broadleaf weeds in the first two years of the study as all treatments resulted in substantially lower weed populations than the non-treated control (Table 2). The third trial (in its first year) has found that May-applied glyphosate (at a low rates) and Barricade resulted in similar weed control and increased playability than fall applied broadleaf herbicides in July (Table 3). However, these differences disappeared by October (Table 4).

Figure 1. Weed control in native areas remains problematic for many golf course superintendents.

Table 1. Grass and weed composition of plots under various mowing and chemical management on October 8, 2015. Mowing treatments and chemical applications were initiated on May 20, 2014.

Mowing	Herbicide* Applied	Desirable Grasses	Bare Soil	Grassy Weeds	Broadleaf Weeds	Total Weeds
Mowed, Returned	Yes	92.5 A	3.8 A	2.5 A	1.3 B	3.8 C
Mowed, Returned	No	49.5 C	1.8 A	11.3 A	37.5 A	48.8 A
Mowed, Removed	Yes	88.8 A	3.8 A	6.3 A	1.3 B	7.5 C
Mowed, Removed	No	62.5 BC	3.8 A	2.5 A	31.2 A	33.8 AB
Not Mowed	Yes	82.5 AB	5.0 A	11.3 A	1.3 B	12.5 BC
Not Mowed	No	82.5 AB	3.8 A	1.3 A	12.5 B	13.8 BC

* Herbicide treatment included Barricade (1 lb/A), SpeedZone (1.5 oz/1000 sq. ft.), and Milestone (4.0 oz/1000 sq. ft.) in sprayed at 2 gallons/1000 sq. ft.

Table 2. Grass and weed composition on October 8, 2015 as affected by herbicide application. Chemical applications were made on May 20, 2014.

Herbicide Treatment	Desirable Grasses	Bare Soil	Grassy Weeds	Broadleaf Weeds	Total Weeds
Exp. Tmt 1 (4 pts/A)	92.3 A	2.5 A	1.8 B	0.5 B	2.3 C
Confront (2 pts/A)	90.8 A	1.8 A	3.8 AB	3.8 B	7.5 BC
Confront (4 pts/A)	82.5 A	1.3 A	15.0 A	1.3 B	16.3 B
Milestone (6 oz/A)	93.8 A	1.3 A	1.3 B	3.8 B	5.0 BC
SpeedZone (2 pts/A)	88.8 A	1.3 A	2.5 B	7.5 B	10.0 BC
Non-treated control	43.3 B	1.8 A	6.3 AB	48.8 A	55.0 A

Table 3. Grass and weed composition on July 1, 2015 as affected by herbicide application. Chemical applications were made in Spring 2015 with the exception of ForeFront and Chapparal which were applied in Fall 2014.

Herbicide Treatment	Desirable Grasses	Bare Soil	Grassy Weeds	Broadleaf Weeds	Total Weeds	Playability**
Non-treated control	65 AB	3 D	10 A	23 BC	32 BC	3 A
ForeFront (fall applied)	82 A	4 CD	11 A	3 D	14 C	2.5 ABC
Chapparal (fall applied)	79 AB	5 BCD	7 A	9 CD	16 C	2.75 AB
Glyphosate 1 lb AI/acre in April*	36 C	4 CD	5 A	55 A	60 A	2.75 AB
Glyphosate 2 lb AI/acre in April*	45 C	6 BCD	9 A	40 AB	49 AB	3.0 A
Glyphosate 1 lb AI/acre in May*	75 AB	10 B	8 A	8 CD	15 C	1.75 C
Glyphosate 2 lb AI/acre in May*	57 ABC	21 A	3 A	19 BCD	22 BC	2.0 BC
Glyphosate 1 lb AI/acre in June*	63 ABC	8 BC	5 A	24 BCD	29 ABC	2.75 AB

* also included Barricade at 1 lb of product/acre

**A subjective assessment of the ability of an average golfer to play a shot out of the treatment and back into play with a reasonable chance of success. Rated on a 1 to 3 scale with 1 being playable, 3 being unplayable, and 2 intermediate.

Table 4. Grass and weed composition on October 8, 2015 as affected by herbicide application. Chemical applications were made in Spring 2015 with the exception of ForeFront and Chapparal which were applied in Fall 2014.

Herbicide Treatment	Desirable Grasses	Bare Soil	Grassy Weeds	Broadleaf Weeds	Total Weeds	Playability**
Non-treated control	75 A	0.0 A	15 A	10 B	25 A	3.0 A
ForeFront (fall applied)	65 A	2.5 AB	20 A	13 AB	33 A	3.0 A
Chapparal (fall applied)	80 A	1.3 AB	6.3 A	13 AB	19 A	3.0 A
Glyphosate 1 lb AI/acre in April*	53 A	2.5 AB	6.3 A	39 A	45 A	3.0 A
Glyphosate 2 lb AI/acre in April*	54 A	10.0 A	8.8 A	28 AB	36 A	3.0 A
Glyphosate 1 lb AI/acre in May*	83 A	1.3 AB	5.0 A	11 AB	16 A	3.0 A
Glyphosate 2 lb AI/acre in May*	74 A	3.8 AB	1.3 A	21 AB	23 A	2.5 B
Glyphosate 1 lb AI/acre in June*	79 A	1.3 AB	5.0 A	15 AB	20 A	3.0 A

* also included Barricade at 1 lb of product/acre

**A subjective assessment of the ability of an average golfer to play a shot out of the treatment and back into play with a reasonable chance of success. Rated on a 1 to 3 scale with 1 being playable, 3 being unplayable, and 2 intermediate.

Adaptability of Bermudagrasses in Northern Climates

Matt Williams, John Street, Dave Gardner and Karl Danneberger

Department of Horticulture and Crop Science

The Ohio State University

The objective of this study is to determine if different cultural practices can provide enhanced cold tolerance to 4 winter hardy bermudagrass cultivars.

Methods & Materials

This study was originally initiated on April 2014 on a sand based area at the Ohio Turfgrass Foundation Research and Education Facility, Columbus, Ohio. Four cold tolerant cultivars ('Latitude 36', 'Riviera', 'Patriot', and 'Northbridge') were sodded while still dormant. 'Latitude 36'and 'Riviera' had been grown at the research facility and were harvested and transplanted. 'Patriot', and 'Northbridge' were provided by Oakwood Sod Farms Delmar, Maryland. Treatments were applied and data collected were during the fall of 2014 and reported to the USGA. In the spring of 2015 the study suffered virtually 100% winterkill. On June 1st it was decided to reestablish the study for fall treatments. It was determined that sprigging would be the best method of establishment. The plots were sprigged on July 14th, and mowing began August 3rd.

The plots were all mowed 6x a week at 0.75" Foramsulfuron (Revolver) was used to control annual grassy weeds and overseeded ryegrass in September at a rate of 0.4 fl oz per 1000 sq ft. During the growing season the bermudagrass received 0.5 lb of nitrogen (Ammonium Sulfate) weekly and were sand topdressed and dethatched every two weeks.

Treatments were replicated three times and the design was a split plot design. The main plot factor was bermudagrass cultivar and the subplot factor was cultural practice. The cultural treatments were initiated on September 10, 2015 and will continued until November 12, 2015. The cultural treatments consisted of:

1) Untreated Control
2) GreenLinks Turf Colorant at a rate of 16 fl oz per 1000 sq ft every 14 days
3) Trinexapac-ethyl (Primo MAXX) at a rate of 0.125 fl oz per 1000 sq ft every 14 days
4) Trinexapac-ethyl (Primo MAXX) at a rate of 0.375 fl oz per 1000 sq ft every 14 days
5) GreenLinks Turf Colorant at a rate of 16 fl oz per 1000 sq ft + Trinexapac-ethyl (Primo MAXX) at a rate of 0.125 fl oz per 1000 sq ft every 14 days.
6) GreenLinks Turf Colorant at a rate of 16 fl oz per 1000 sq ft + Trinexapac-ethyl (Primo MAXX) at a rate of 0.375 fl oz per 1000 sq ft every 14 days.

Treatments have been evaluated for color (1-9 scale) and soil temperatures (K-Type Thermocouple).

There were three major changes from the 2014 protocol:

1) The mowing height was reduced from 1.25" to .75"

2) The rate of plant grow regulator was adjusted to the label rates for the common bermudagrasss ('Riviera') and the hybrid bermudagrasses ('Latitude 36', 'Patriot', and 'Northbridge') in the study.
3) Evergreen Turf Covers were installed on the plots daily when the forecasted overnight low was < 50^{o} F. The covers will be left one for the entire winter.

Results

- Spring data was not collected as the study suffered nearly 100% winterkill. We speculate that the winterkill was caused when the plots were exposed to record low temperatures while the plots were still green between November 14th – 21st.(**Table 1**) We are also concerned that the plots experienced desiccation throughout the winter on the 100% sand based rootzone.
- The hybrid bermudagrasses ('Latitude 36', 'Patriot', and 'Northbridge') in the trial maintained an acceptable color rating through 10/30. Whereas the common bermudagrass ('Riviera') last acceptable color rating was on 10/22. (**Table 2.**)
- It was observed that PGR application weather alone or in combination with pigment had a negative impact on color when applied to the common bermudagrass variety 'Rivera'. (**Table 3**)
- There were no observed differences of soil temperature between treatments or cultivars

Table 1. Temperatures

	11/14/14	11/15/14	11/16/14	11/17/14	11/18/14	11/19/14	11/20/14	11/21/14
Max Air Temp	32.4	33.0	36.5	34.0	19.1	37.0	30.5	31.5
Min Air Temp	20.5	15.9	29.4	16.2	9.9	11.8	20.7	13.0
Avg Air Temp	27.0	23.9	32.9	26.6	14.4	24.2	25.1	21.7

Table 2. Color rating by Variety

Trt	Cultivar	10/08	10/15	10/22	10/30	11/06	11/25	12/01
1	Patriot	6.52	6.77a	6.71a	5.21a	5.02a	4.31a	3.81a
2	Northbridge	6.50	5.94b	6.40ab	5.02a	4.94ab	3.46b	1.98b
3	Riviera	6.42	5.5c	6.06bc	4.85a	4.54b	4.27b	2.17b
4	Latitude 36	6.69	6.29b	5.62c	5.40a	5.46a	3.46b	1.85b
$LSD_{(0.05)}$		NS	0.43	0.53	NS	NS	0.63	0.69

† Color rated on a 1-9 scale where 1 = brown, 5 = lowest acceptable rating, 9 = dark green
‡ Means followed by the same letter are not significantly different (P=0.05) according to Fisher's Protected LSD test
¶ NS means not significantly different (P=0.05) according to Fisher's Protected LSD test

Table 3. Color rating by Cultural Treatment

Trt	Treatment	10/08	10/15	10/22	10/30	11/06	11/25	12/01
1	Untreated	6.58ab	6.25a	6.33ab	5.15b	5.00b	3.71a	2.27b
2	Pigment	6.75a	6.40a	6.48a	5.44a	5.33a	3.77a	2.52a
3	PGR (Hybrid)	6.39bcd	6.11a	6.08b	5.03b	4.92b	3.50ab	2.5ba
4	PGR (Common)	6.17d	5.25b	5.33c	4.58c	4.33c	3.00c	1.83c
5	PGR + Pigment (Hybrid)	6.50bc	6.19a	6.30ab	5.06b	5.05b	3.75a	2.72a
6	PGR + Pigment (Common)	6.3cd	5.25b	5.42c	4.75c	4.25c	3.33b	2.58a
$LSD_{(0.05)}$		.25	0.30	0.28	0.24	0.28	0.28	0.24

† Color rated on a 1-9 scale where 1 = brown, 5 = lowest acceptable rating, 9 = dark green
‡ Means followed by the same letter are not significantly different (P=0.05) according to Fisher's Protected LSD test
¶ NS means not significantly different (P=0.05) according to Fisher's Protected LSD test

Research for 2016

1) Continue to monitor color until there is no evidence of green tissue.
2) Monitor soil moisture and soil temperature throughout the winter.
3) Evaluate how the fall treatments affect spring green up, % winterkill and spring dead spot incidence.

Presentations

1) Tri-State Green Industry Conference; Cincinnati, Ohio, Feb 5th, 2015
2) The Ohio State University/Ohio Turfgrass Foundation Research Field Day, Columbus, Ohio, August 11th, 2015
3) Ohio Turfgrass Foundation Conference and Show, Columbus Ohio, Ohio, December 8, 2015

Title: Evaluation of Cumyluron and Methiozolin Herbicides for Pre- and Postemergence Control of Annual Bluegrass on New Creeping Bentgrass Putting Greens in California

Investigator: Jim Baird
Turfgrass Specialist
Department of Botany & Plant Sciences
University of California, Riverside
900 University Ave.
Riverside, CA 92521
jbaird@ucr.edu; 951-333-9052

Justification:

California's Mediterranean climate is ideal for annual bluegrass (*Poa annua*). However, under intensive management this species is highly susceptible to several biotic and abiotic stresses including heat/drought/cold, disease, and nematodes. As a result, a growing number of golf courses are resorting to conversion to creeping bentgrass, which has better stress tolerance and putting traits (e.g., no seedheads under low mowing). The challenge facing golf course superintendents in California and abroad is keeping annual bluegrass from re-infesting new bentgrass greens. In California especially, the window of Poa germination and infestation is much broader compared to other regions. Currently, paclobutrazol and flurprimidol are used for *Poa* suppression, but these PGRs cannot be used year round due to temperature constraints. Cumyluron (Marubeni Corp., Japan) and methiozolin (Moghu Research Center, South Korea) are currently under development in the U.S. for selective control of annual bluegrass in bentgrass putting greens and other turf areas.

Objectives:

1. Evaluate effective timing and total active ingredient of cumyluron and methiozolin required to provide effective preemergence control of annual bluegrass in new creeping bentgrass putting greens in northern and southern California.
2. Evaluate postemergence activity of these herbicides as *Poa* infests the greens.

Locations:

The study will be conducted on four golf courses with new creeping bentgrass putting greens installed within the last 6 months. Two golf courses are located in southern California in the Los Angeles area: Brentwood Country Club (cultivar Tyee/007) and Bel-Air Country Club (cultivar Pure Distinction). The northern California golf courses include: Tournament Players' Club at Harding Park, San Francisco (cultivar Tyee/007) and Monterey Peninsula Country Club, Pebble Beach (cultivar Pure Distinction). All greens have little to no *Poa* at the start of the experiment.

Treatments:

No.	Treatment	Rate (oz/1,000 ft^2)	Timing	Total (oz/1,000 ft^2)
1	Control	--	--	--
2	Cumyluron	1.0	ABCDEFGHIJ	10
3	Methiozolin	0.6	ABCDEFGHIJ	6.0
4	Cumyluron	1.5	ACEGI	7.5
5	Methiozolin	0.6	ACEGI	3.0
6	Cumyluron	3.0	ADGJ	12
7	Methiozolin	1.2	ADGJ	4.8
8	Cumyluron	3.0	AG	6.0
9	Methiozolin	1.2	AG	2.4
10	Cumyluron	6.0	A	6.0
11	Methiozolin	1.2	A	1.2
12	Cumyluron	6.0	G	6.0
13	Methiozolin	1.2	G	1.2

Timing
A = February
B = March
C = April
D = May
E = June
F = July
G = August
H = September
I = October
J = November

Design:

Randomized block with 4 replications. Plot size will be 4 ft x 6 ft with 2-ft alleys between rows. Total area needed per location is 30 ft x 52 ft. Treatments will be applied using a CO_2-powered backpack boom sprayer with TeeJet 8004 flat fan nozzles calibrated for 2 gal/1,000 ft^2 spray output. Treatments will be irrigated with 0.02 inches (cumyluron) or 0.1 inches (methiozolin) of water immediately following each application.

Ratings:

Visual annual bluegrass cover and bentgrass phytotoxicity (0-100%) will be assessed monthly from February 2016 through December 2017. Rootzone samples will be collected for root mass and/or winRhizo analyses in May and October 2016 and March 2017.

Expected Completion Date:

Final report will be completed by January 2018.

Expected Results:

Prevention is the best strategy for managing annual bluegrass invasion into putting greens. To date, almost all field studies involving these herbicides have focused on postemergence annual bluegrass control. This study will identify which herbicide, rates, and frequency of application provide optimum preemergence control of annual bluegrass in new creeping bentgrass putting greens. The study will also examine postemergence control of these herbicides. The study will be repeated in very different climates in northern and southern California and results will be adaptable to the remainder of the U.S.

Other Funding Sources:

This study will be funded in part by the chemical companies, the California Turfgrass & Landscape Foundation (CTLF), and HATCH funds.

Accuracy of FieldScout TDR 300 Soil Moisture Meter in Saline Soils

Bernd Leinauer, Matteo Serena, Dawn VanLeeuwen, and Elena Sevostianova
New Mexico State University

Objectives:

1. To evaluate the accuracy of a FieldScout TDR 300 hand held soil moisture sensor in a USGA sand at salinity levels ranging from 0.46 to 20 dS m^{-1}
2. To compare the accuracy of a TDR 300 to a permanently installed Decagon 5TE soil sensor

Start Date: 2015
Project Duration: 2 years
Total funding: $6,000

Measuring soil moisture with Time Domain Reflectometry (TDR) sensors can aid in turfgrass water conservation efforts, help improve playing conditions, green speed, and irrigation efficiency, and can assist in rootzone salinity management. However, information is lacking on the accuracy and reliability of newly introduced hand-held electromagnetic moisture sensors in saline soils. A laboratory study was conducted at New Mexico State University during 2015 to investigate the accuracy and reliability of a FieldScout TDR soil moisture sensor and a Decagon 5TE soil sensor at different salinity levels (expressed as electrical conductivity of the saturated soil paste extract ECe).

Columns measuring 14 cm in height and 20 cm in diameter were filled with a sand meeting USGA specifications for particle size distribution. Columns were subsequently saturated for 24 hours with either distilled (ECw = 0 dS m^{-1}), tap (ECw = 0.7 dS m^{-1}), or saline water (ECw = 2, 4, 6, 8, 10, and 15.5 dS m^{-1}) which resulted in ECe of 0.46 (distilled water), 1.08 (tap water), and 3.68, 5.40, 5.78, 7.68, 9.38, and 19.84 dS m^{-1}, respectively. Two FieldScout TDR 100 (Spectrum Technologies, Inc. Aurora, IL) (rod length 7.6 cm) and two Decagon 5TE (Decagon Devices Inc., Pullman, WA) (rod length 5 cm) sensors were used in this study. The soil sensors were inserted into the columns and subsequently placed onto a pressure plate inside a pressure chamber to record sensor readings at different soil moisture levels. For the purpose of this study we used the Spectrum Technologies' TDR 100 sensor instead of the TDR 300 as it uses the same measurement technology as the TDR 300 (Spectrum Technologies, pers. communication) but does not have a long handle attached to the body that holds the rods. Columns and sensors were then exposed to increasing air pressures which initiated soil drying by removing water from the soil. At the end of the dry-down period, columns were dried at 105 °C. Volumetric soil moisture was subsequently determined for each moisture level and data comparisons were based on either fitting linear regressions or quadratic polynomials to all salinities. Results are presented for the TDR 300 only.

There were no differences between values from the two sensor replicates therefore data were pooled over both sensors. Overall, sensor values increased with increasing soil moisture as slopes differ significantly from 0 for every soil salinity. Slopes for ECe ≥ 5 dS m^{-1} were greater than for salinities of ECe < 4 dS m^{-1}. The slope at ECe = 19.8 dS m^{-1} was 4 times higher than the slope at ECe = 0.5 dS m^{-1}. These results suggest that different salinity levels need separate calibration if the absolute soil moisture value is of interest. When separate quadratic polynomials were fit for each salinity the models differed significantly from 0 for salinities of ECe =3.7 and greater. Only for the salinities of ECe = 0.5 and 1.1 dS m^{-1} data did not suggest to fit a quadratic term. However, caution needs to be used when fitting a quadratic polynomial as some of the moisture ranges included only 4 data points.

Table: Intercept and slope for the linear regression models to measure soil moisture with a Spectrum TDR 300 at different soil salinities compared to moisture determined gravimetrically (SE = Standard Error).

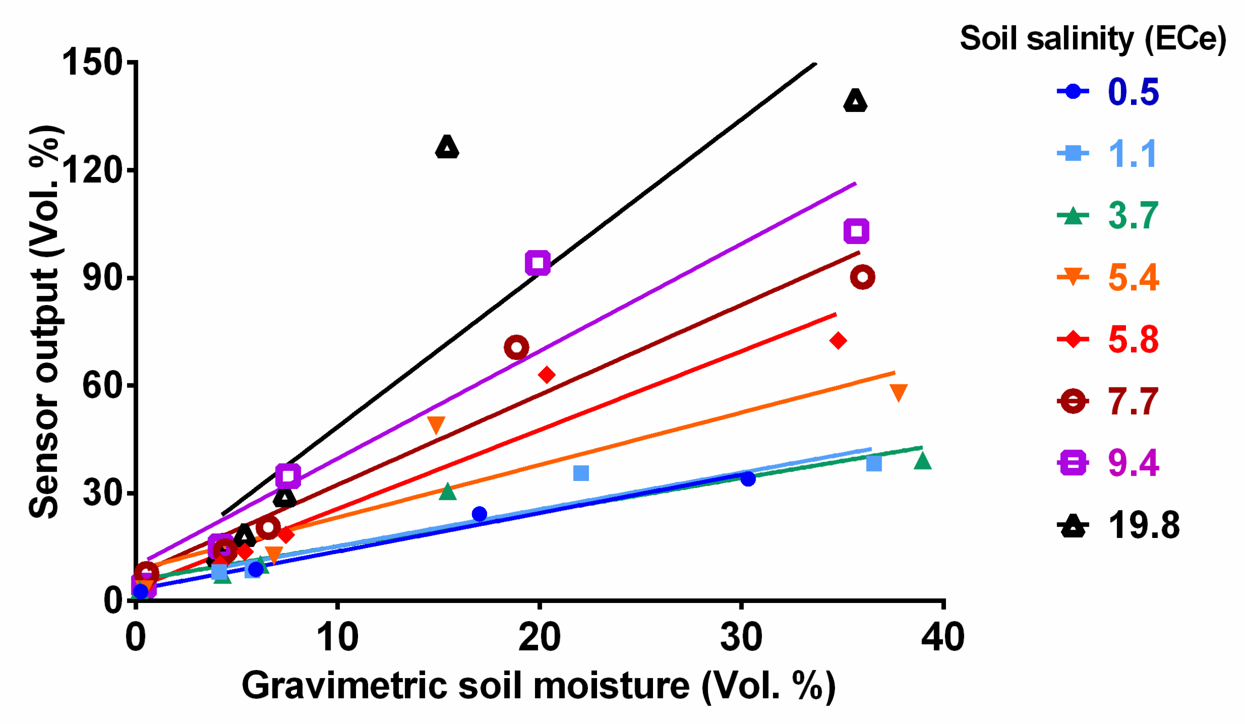
Soil salinity (ECe)	Intercept	SE	Slope	SE
0.5	3.13	7.61	1.07d*	0.43
1.1	5.06	8.11	1.02d	0.37
3.7	5.76	6.07	0.95d	0.32
5.4	8.67	7.22	1.46cd	0.35
5.8	3.74	5.77	2.20bc	0.34
7.7	7.32	6.36	2.51b	0.34
9.4	9.79	6.44	2.99b	0.34
19.8	5.67	5.93	4.28a	0.36

* Values followed by the same letter are not significantly different from one another (Fisher's protected LSD, $\alpha = 0.05$)

Summary Points

- Hand held TDR sensors can help in turfgrass water conservation efforts and in improving playing conditions
- Soil moisture readings between two replicate TDR 300 sensors with a rod length of 7.5 cm (3") did not differ from one another across a wide range of soil salinities.
- Soil sensors estimated moisture in a USGA sand accurately at salinity levels of ECe < 5 dS m^{-1}
- Different salinity levels need separate calibration for ECe > 5 dS m^{-1} if the absolute soil moisture value is of interest rather than the relative difference.


FIELDSCOUT
TDR 100
ON
MODE
Delete Clr Avg
READ
Spectrum
FIELDSCOUT
TDR 100
ON
MODE
Delete Clr Avg
READ
Spectrum


Soil salinity (ECe)
0.5
1.1
3.7
5.4
5.8
7.7
9.4
19.8
Sensor output (Vol. %)
Gravimetric soil moisture (Vol. %)
0
30
60
90
120
150
0
10
20
30
40

Effects of Winter Foot Traffic on an Annual Bluegrass Putting Green in Corvallis, OR
USGA ID#: 2014-22-511

A. Kowalewski, B. McDonald, C. Mattox, B. Daviscourt, C. Olsen and M. Gould
Oregon State University

RESEARCH SUMMARY (YEAR 2)

- As traffic rates (golf rounds per day) increased turf quality and color decreased.
- The higher traffic rates (220 and 330 rounds per day) caused the greatest reduction in turf quality and color observed in February.
- Traffic at the high rate (330 rounds per day) reduced turf quality and color to unacceptable levels in February and March.
- When temperatures are less than 50° F and solar radiation is less than 300 golf rounds should be restricted to 220 rounds per day.

Objective:

- Evaluate the effects of winter foot traffic rates on an annual bluegrass putting green in Corvallis, OR.

Material and Methods:

Field research was initiated Feb 14, 2014 on an annual bluegrass putting green established in 2009 with sod from Bos Sod, Canada on 12 inches of 100 % USGA sand specified green at the Lewis-Brown Turf Farm, Corvallis, OR.

Experimental design was a randomized complete block with four replications. Treatments were foot traffic applied at rates equivalent to 110, 220 and 330 rounds of golf per day, compared to a control which did not receive foot traffic. Foot traffic rates and timing were derived using methodology defined by Hathaway and Nikolai (2005). Traffic was applied 5 days per week, with one day simulating heavy traffic around the hole. To simulate 330 rounds per day, the traffic times applied from highest to lowest to the 6 foot by 4 foot plots were 8 minutes 40 seconds, 2 minutes, 56 seconds, 32 seconds, and 28 seconds, respectively for the 5 days.

The putting green was maintained at 0.135 inch height with clippings removed. Fertilizer was applied at 1.63 lbs. N per 1,000 ft^2 from Oct 28, 2014 to Mar 26, 2015. Because of the heavy precipitation rates in Corvallis, OR no irrigation was applied from Oct 28, 2014 to Apr 12, 2015.

Response Variables:

Turf color and quality data were collected throughout the 79 day experimental period, Jan 7 to Mar 26, 2015. Turf color was assessed using a 1 to 9 visual rating scale, with 1 equaling straw brown or no color retention, and 9 equaling dark green (Morris, 2104). The color assessments evaluated overall plot color and not genetic color. Turf quality was assessed on a 1-9 scale, with 9 being outstanding or ideal turf and 1 being poorest or dead (Morris, 2014). A rating of 6 or above is generally considered acceptable. A quality rating value of 9 is reserved for a perfect or ideal grass, but it also can reflect an absolutely outstanding treatment plot.

Preliminary Findings:

Turf Quality:

Foot traffic had a significantly negative effect on turf quality throughout the 79 day traffic period January 7 to March 26, 2015 (Figure 1). Foot traffic applied at the high rate (330 rounds per day) produced the greatest reduction in turf quality. The control produced the highest turf quality ratings throughout the study. Traffic at the high rate reduced turf quality to unacceptable values (< 6) in February and March. Reduction in turf quality were the greatest in February, when atmospheric temperatures were the lowest. Regression analysis of the effects of foot traffic on turf quality in the month of February were strongly, negatively correlated (R-square = 0.85; Figure 2).

The average temperature in February was 49° F and the average solar radiation was 183.6, while the average temperature in March was 50.7°F and the average solar radiation was 293. Considering these results, putting greens should be restricted to 220 rounds per day to prevent significant reductions in turf quality when temperatures are less than 50° F and solar radiation is less than 300.

Turf Color:

Foot traffic had a significantly negative effect on turf color throughout the 79 day traffic period January 7 to March 26, 2015 (Figure 3). Foot traffic applied at the high rate (330 rounds per day) produced the greatest reduction in turf color. The control produced the highest turf color ratings throughout the study. Traffic at the high rate reduced turf color to unacceptable values (< 6) in February and March. Traffic at the 220 rounds per day decreased turf color to an unacceptable level in early March. Reduction in turf color was the greatest in February, when atmospheric temperatures were the lowest. Regression analysis of the effects of foot traffic on turf color in the month of February were strongly, negatively correlated (R-square = 0.79; Figure 4).

Future Research:

In 2016, traffic will be initiated again at 0, 110, 220 and 330 rounds per day in January to replicate the results observed in 2015.

References:

Hathaway, A.D., and T.A. Nikolai. 2005. A putting green traffic methodology for research applications established by in situ modeling. International Turfgrass Society. 10:69-70.

Morris, K.N. 2014. A Guide to NTEP Turfgrass Ratings. National Turfgrass Evaluation Testing Program. Beltsville, Maryland. p. 1-5.

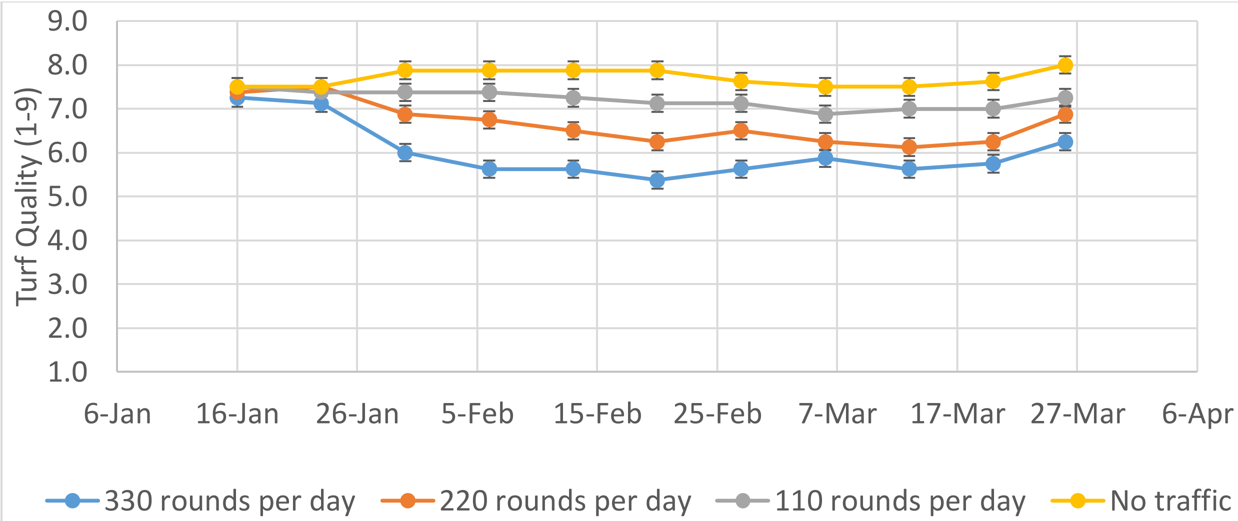


Figure 1: Effects of foot traffic on turf quality (1-9 scale, 6 or greater acceptable) on an annual bluegrass putting green from January to March 2015 in Corvallis, OR. Points with overlapping error bars are not significantly different at a 0.05 level of probability.

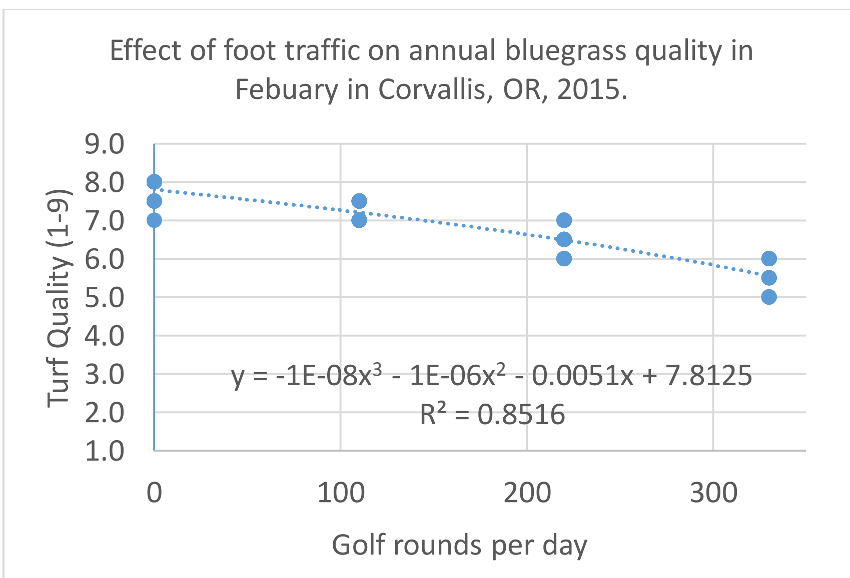


Figure 2: Trends in turf quality (1-9, 6 or greater acceptable) across golf rounds per day (0, 110, 220 and 330) on an annual bluegrass putting green in Corvallis, OR in February 2015. 64 data points collected across 4 replications, 4 traffic levels and 4 data collection dates (Feb 6, 13, 20 and 27).

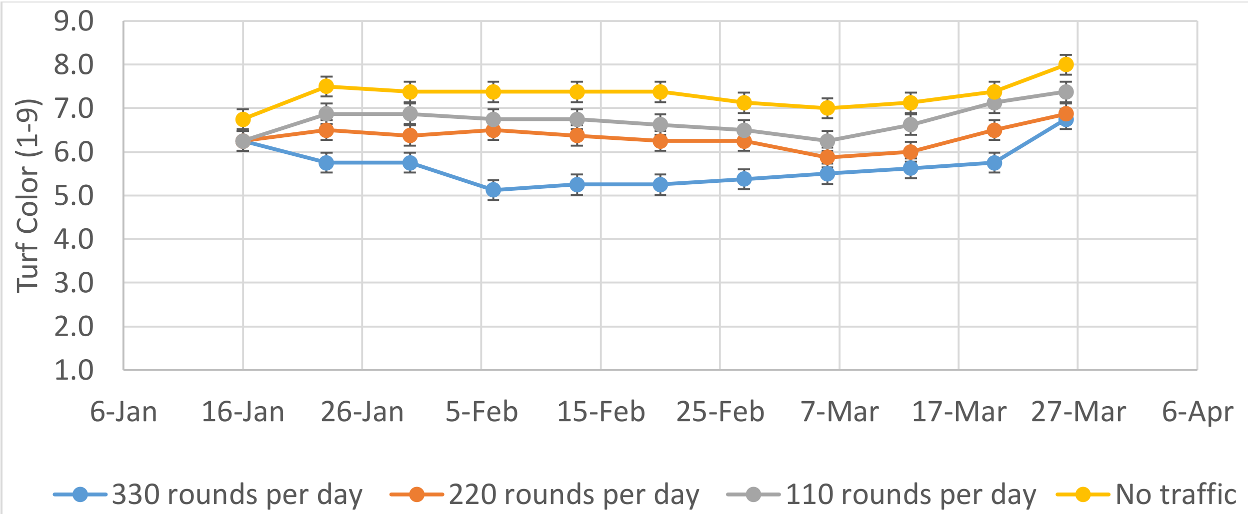


Figure 3: Effects of foot traffic on turf color (1-9 scale, 6 or greater acceptable) on an annual bluegrass putting green from January to March 2015 in Corvallis, OR. Points with overlapping error bars are not significantly different at a 0.05 level of probability.

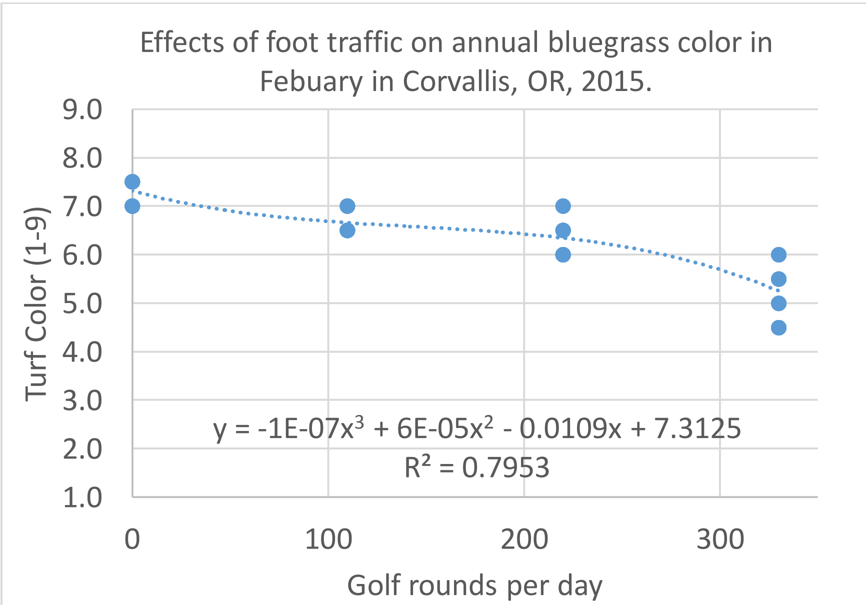


Figure 4: Trends in turf color (1-9, 6 or greater acceptable) across golf rounds per day (0, 110, 220 and 330) on an annual bluegrass putting green in Corvallis, OR in February 2015. 64 data points collected across 4 replications, 4 traffic levels and 4 data collection dates (Feb 6, 13, 20 and 27).

Fall Potassium Fertilization and Winter Traffic Effects on 'Crenshaw' Creeping Bentgrass Putting Green Playability and Performance
Study Duration: October 2014-May 2016
USGA Support: $6,000

Principle Investigator:

Dr. Haibo Liu, Professor, Clemson University
Dr. Bert McCarty, Professor, Clemson University
Mr. Nickles Mirmow, MS Student, Clemson University

Questions exist over the winter traffic tolerance of creeping bentgrass (Agrostis stolonifera) putting greens, and additional enquiries exist concerning the potential benefit in winter traffic tolerance from supplemental fall potassium (K) fertilization in the transition zone. Traffic on morning frost can be detrimental to turf health, and afternoon traffic has the potential to negatively affect turf health when growth rate is decreased in the winter. Additionally, previous studies have shown the effects of traffic on frost covered turf both before and after the prescribed traffic treatment time implemented in this study (8:00 AM), so there is a gap in the data that, if filled, may prove to be largely beneficial for golf course managers. A modified roller was used for the study (Fig. 1). This study was also conducted to evaluate fall-applied potassium fertilizer's effects on turf playability and performance on 'Crenshaw' creeping bentgrass putting greens when subjected to varying amounts of traffic.

After one season of data collection, several trends emerged from the analysis. In terms of chlorophyll content, there were statistical differences in readings based on the interaction between potassium levels and morning rolling levels (Fig. 2). For potassium levels of 0 and 3.66 g K m^{-2}, there was no indication of a significant difference in chlorophyll contents for the number of morning rolls. However, for the potassium level of 7.32 g K m^{-2}, the chlorophyll contents for 0 morning rolls were significantly higher than the chlorophyll contents for 4 and 8 morning rolls.

Additionally, there were statistical differences in chlorophyll contents based on morning rolling levels . During weeks 9-13, the chlorophyll contents for plots receiving 0 morning rolls were higher than the chlorophyll contents for plots receiving 4 or 8 morning rolls, but there was not an indication of a significant difference between chlorophyll contents for plots that received 4 and 8 morning rolls. For all other weeks, there was not an indication of any significant differences in the chlorophyll contents for plots that received 0, 4, and 8 rolls.

There were also statistical differences in chlorophyll contents based on afternoon rolling levels. Comparisons of the chlorophyll contents for plots that received 0 and 6 afternoon rolls did not indicate any significant differences except for weeks 15 and 17. Plots that received 6 afternoon rolls had statistically higher chlorophyll contents than plots that received 0 afternoon rolls.

When analyzing NDVI readings, there were statistical differences based on morning rolling levels. For weeks 5 through 13, the NDVI readings for plots that received 0 morning rolls were significantly higher than the NDVI readings for plots that received 4 and 8 morning rolls. There were no other indications of a significant difference for the different morning rolling levels during the other weeks.

Ball roll speed also showed a statistical difference in measurements based on morning rolling levels. For month 3 (February), the ball roll speed for plots that received 0 morning rolls was significantly lower than the ball roll speed for the plots that received for 4 and 8 morning rolls. There were no other indications of a significant difference for the different morning rolling levels during the other months. (Fig. 3)

Figure. 1. The Roller Used for the Study

Figure 2. Profile plot of chlorophyll contents for potassium levels by morning rolling levels interaction

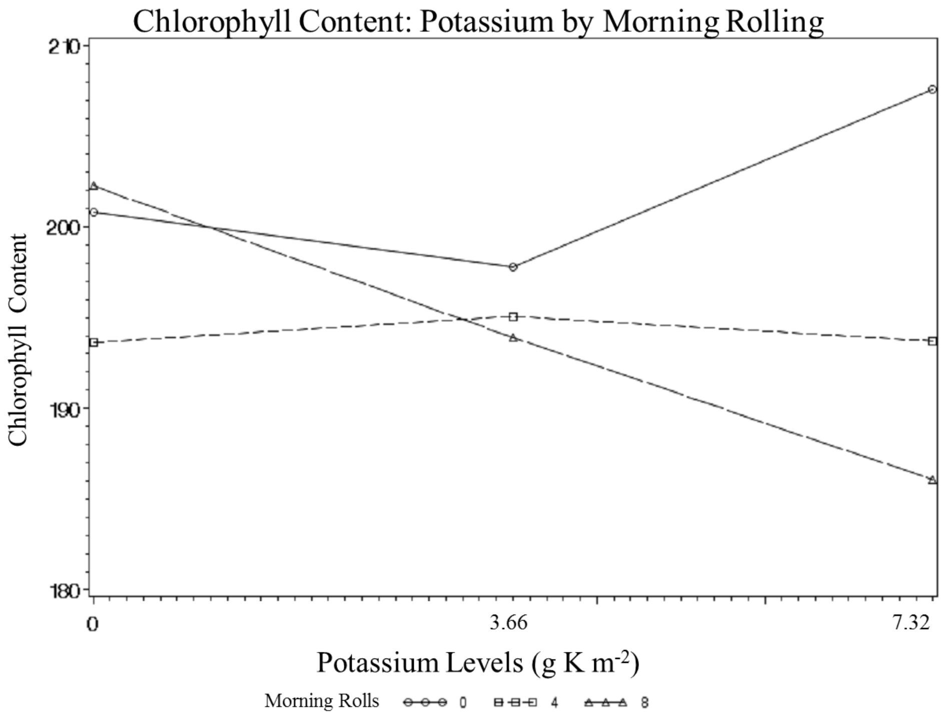


Figure 3. March 7 2015 of the treatments of plots with 0, 4, and 8 rolling times at 8 am on the last frost event of the winter

Characterization of Pathogenicity and Fungicide Sensitivity of *Gaeumannomyces graminis* var. *graminis* Causing Bermudagrass Decline in Golf Course Turf

USGA ID#: 2015-22-537

Research Summary

There is a lack of epidemiological information of *Gaeumannomyces graminis* var. *graminis* (Ggg) causing a devastating root disease of bermudagrass in golf courses (Fig. 1) and take-all root rot in residential turf (Fig. 2). Consequently, cultural and chemical control practices are not well studied for bermudagrass decline. Systemic and site-specific fungicides labeled for turfgrass applications have proven effective for many fungal diseases. However, their field efficacy data for Ggg are limited and no long-term control of bermudagrass decline has been achieved by these fungicides. Characterization of Ggg populations is critical for improving our current bermudagrass decline management in golf courses. Knowing fungicide sensitivities of Ggg populations can provide rapid and reliable data to suggest if acceptable control of bermudagrass decline can be achieved by given fungicides. First, we performed fungicide sensitivity assays (Fig. 3) of Ggg isolates collected from Texas turfgrass-growing regions where previous usage of the fungicides has been limited. We determined baseline sensitivities (EC_{50} = the effective concentration of a particular fungicide that inhibits mycelial growth by 50%) to three major chemical classes: benzimidazole fungicide thiophanate-methyl (< 500 μg a.i. ml^{-1}), demethylation inhibitor fungicide tebuconazole ($\leq$ 0.3 μg a.i. ml^{-1}), and quinone outside inhibitor fungicide azoxystrobin ($\leq$ 0.4 μg a.i. ml^{-1}). We also determined variation of pathogenicity within our Ggg isolate collection. Since innate difficulty to produce signs or symptoms of Ggg on turfgrass by artificial inoculation, we use rice plants instead because both turfgrass and rice provide susceptible hosts for Ggg (Fig. 4). Certain isolates were much aggressive and virulent causing significantly stunted shoot and root growth of rice seedlings (Fig. 5). Golf course superintendents can design a proper fungicide program based on fungicide sensitivity data, which will save money on costly fungicides that otherwise would be ineffective in the event of infection by resistant Ggg. Our pathogenicity assays will also be helpful to decision making processes of turfgrass managers, which will allow them to respond differently to bermudagrass decline based on virulence of causal Ggg isolates.

- Baseline fungicide sensitivities of *Gaeumannomyces graminis* var. *graminis* (Ggg) to three major fungicides were determined
- Ggg pathogenicity assay can be performed in rice plants
- A wide variability in the infection aggressiveness was found in Ggg isolates

Fig. 1. Bermudagrass decline in a Texas golf course

Fig. 2. Take-all root rot caused by Gaeumannomyces graminis var. graminis in St. Augustinegrass

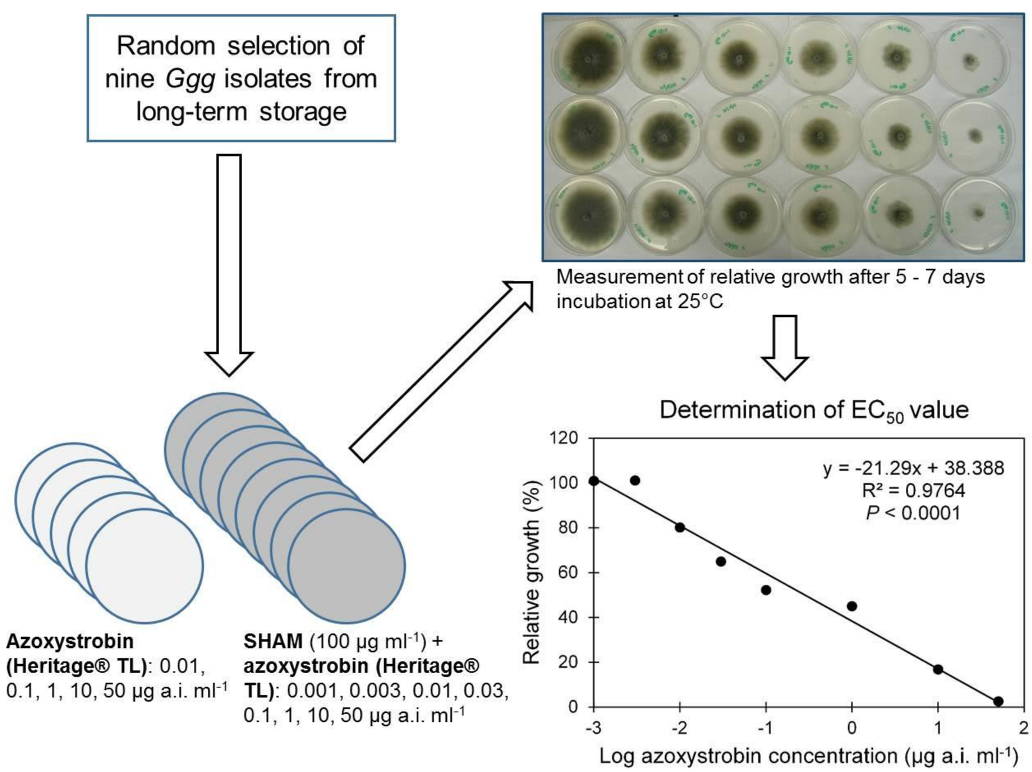


Fig. 3. Procedure of fungicide sensitivity assay

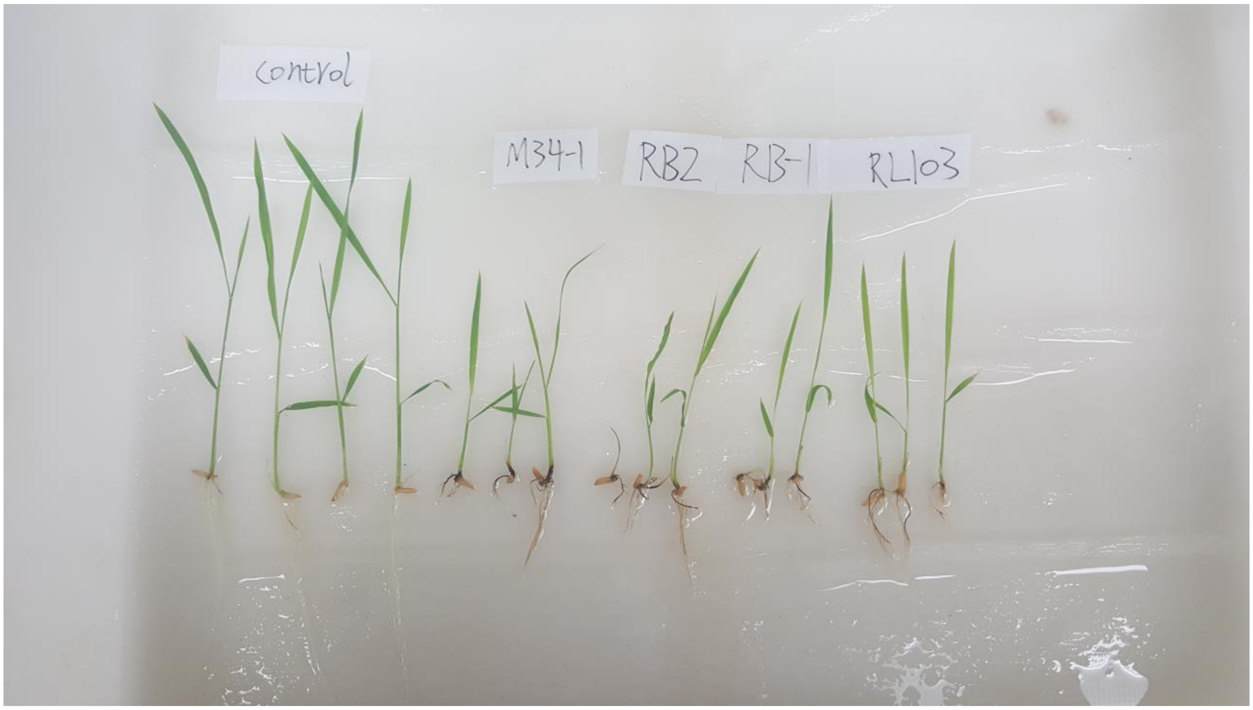


Fig. 4. Infection of Gaeumannomyces graminis var. graminis isolates in rice seedlings

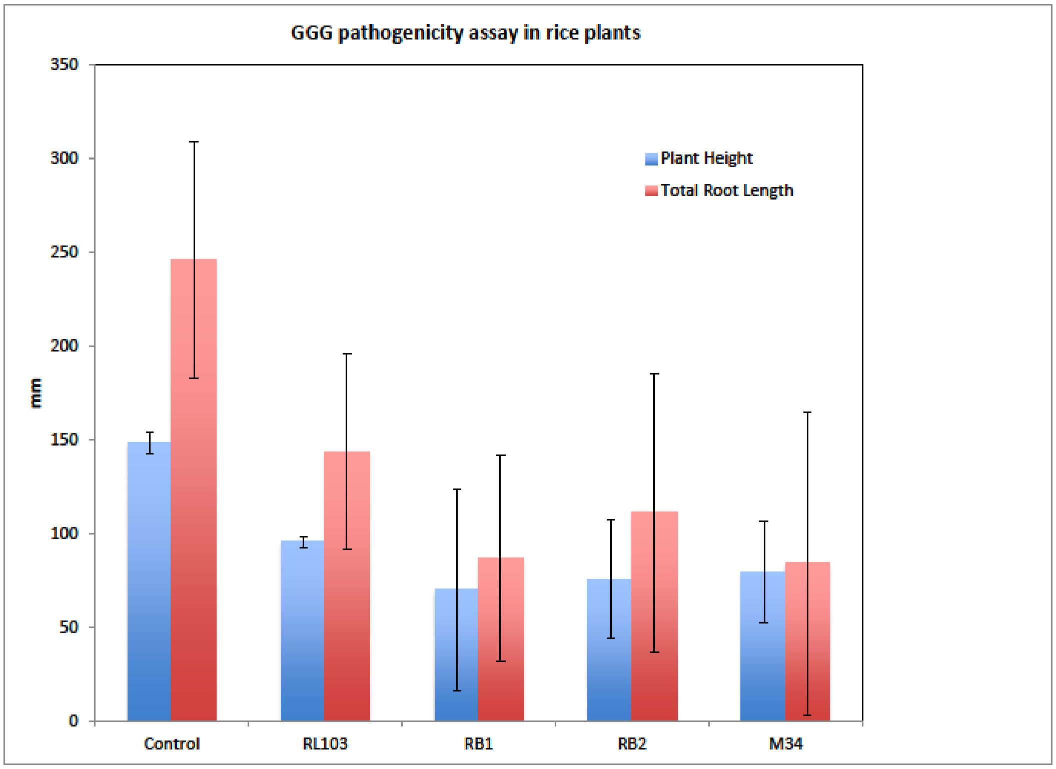


Fig. 5. Reduced growth of rice roots and shoots by Gaeumannomyces graminis var. graminis isolates

Assessing the Effects of Winter Overseeding on Newer Bermudagrasses

Cale Bigelow[1], Gregg Munshaw[2], Mike Richardson[3], Xunzhong Zhang[4] and Mike Goatley[4]
Purdue University[1], University of Kentucky[2], University of Arkansas[3] and Virginia Tech[4]

The overall goal of these field studies was to fill important knowledge gaps regarding the effects of winter overseeding on bermudagrass. Specific research questions were: (1.) What is the physiological impact of winter overseeding on bermudagrass carbohydrate reserves/winter survival? (2.) What are the optimal strategies/techniques for overseeding the newest group of cold-hardy bermudagrassess (e.g. Latitude 36)?

<u>STUDY I:</u> This study was conducted at four locations (Fayetteville, AR; West Lafayette, IN; Lexington, KY and Blacksburg, VA) representing a wide geographic spectrum of where bermudagrass is overseeded for golf and athletic turf. Mature stands of bermudagrass (Riviera, Patriot, Tifway) were overseeded at three seeding rates; 0, 15 and 30 pounds of seed/1000 ft^2 using a high quality perennial ryegrass blend (Futura 2000: Pickseed USA-Halsey, OR). Carbohydrate status of bermudagrass stolon/rhizome was determined by harvesting plugs as the turf acclimated to winter (e.g. mid-Dec.) and broke dormancy (e.g. March/April). Ground tissue was analyzed for total non-structural carbohydrates (TNC) and other sugars by the turf physiology laboratory at Virginia Tech. In addition, soil temperature at the crown level was measured using data logging temperature probes (e.g. Hobo Sensor/Temperature probes; Onset Corp.).

<u>STUDY II</u>. In a separate companion study in West Lafayette, IN, questions related to overseeding practices for the newest group of cold-hardy bermudagrasses (e.g. Latitude 36 and Northbridge) will be evaluated. Evaluations will include a range of overseeding treatments (e.g. seeding rates ranging from 15-60 pounds of seed per 1000 ft^2) starting in late-summer. Additionally, seeding variations like multiple dates (e.g. 20+20+20, 14 days apart) and strategies to facilitate seed soil contact (e.g. brushing, incorporating sand topdressing with seed, etc.) will be studied. Latitude 36 and Northbridge were planted from stolons in mid-Summer, 2015. Due to the very mild summer conditions full coverage of bermudagrass did not occur. This phase has been delayed until late-summer 2016 when a fully mature bermudagrass is available. The following will be measured: Visual estimates of perennial ryegrass establishment as well as

periodic digital image analysis for green cover. Spring appearance/density, and occurrence of winter diseases (e.g. *Microdochium* patch, etc.) will also be monitored.

Results: Winter overseeding had positive effects on the general appearance of the overseeded plots (e.g. green turf present), but also clear negative effects on bermudagrass spring green-up and stand density (Figure 1). Stolon tissue samples across all four locations are still being analyzed for carbohydrate status but some early trends from the West Lafayette site have emerged (Table 1). As expected total carbohydrate status declined with time and values ranged from 73 to 34 mg g^{-1} tissue. The starch portion of the carbohydrates followed a similar pattern of decline with time and values ranged from 36 to 28 mg g^{-1} tissue. The overall effect of overseeding was less clear and consistent, but there was a significant decrease in starch for the Dec. sampling in turf oveseeded with 30 pounds of seed 1000 ft^2 compared to the 0 and 15 pounds of seed. This study will continue into the 2015-2016 growing season.

Table 1. Carbohydrate status of Patriot bermudagrass stolons on three sampling dates as affected by three perennial ryegrass winter overseeding rates, West Lafayette, IN.

	Bermudagrass stolon carbohydrates ‡					
	Total non-structural carbohydrates			Starch		
Overseeding rate†	Dec 2014	Mar 2015	Apr 2015	Dec 2014	Mar 2015	Apr 2015
# seed/1000 ft^2	(mg g^{-1} tissue)					
0	79.5 a	48.6 a	36.0 a	37.9 a	37.3 a	30.0 a
15	79.2 a	48.6 a	36.5 a	38.5 a	39.7 a	29.4 a
30	59.9 a	51.7 a	29.4 a	31.8 b	32.4 a	25.4 a
Overall mean	72.9 A	49.6 B	34.0 C	36.1 A	36.5 A	28.3 B

†Winter overseeding occurred on 15 Sept., 2014 where the seed was applied with 0.5 ft^3 of sand topdressing and immediately brushed into the turf canopy with a stiff bristle broom.
Means in the same column followed by the same lowercase letter and means in the same row within each carbohydrate category followed by the same uppercase letter are not significantly different according to Fisher's protected LSD (p=0.05).

Summary:

- Winter overseeding of bermudagrass improves the visual appearance and potentially playability at four locations across the South and transition zone climates.
- Winter overseeding at either 15 or 30 pounds of seed/1000 ft^2 resulted in less dense bermudagrass the following spring after a selective transitioning herbicide was applied.
- The effect of winter overseeding on bermudagrass stolon carbohydrate status is still being determined, but there was a decline in December starch concentrations for turf overseeded at 30 pounds of seed/1000 ft^2 compared to 0 or 15 pounds of seed/1000 ft^2 at the West Lafayette study site.

Figures 1. Logging soil temperature probes were installed at the turf crown/soil interface to monitor soil temperatures during the study.

Figure 2. Winter appearance of a bermudagrass turf overseeded with three rates of perennial ryegrass (0, 15, 30 pounds of seed/1000 ft2).

Figure 3. Turf plugs were harvested during bermudagrass acclimation to winter dormancy (e.g. Dec.) and breaking dormancy (e.g. April) and analyzed for stolon carbohydrate status.

Figure 4. Spring green-up and density of bermudagrass turf in Lexington, KY (June 2015) showing the negative effects of overseeding on spring turf density following an application of a transitioning herbicide.

1. Project Title.
   Development of management programs for root decline of warm-season grasses and root-knot nematodes in ultradwarf bermudagrass greens

2. Nathan R. Walker
   Oklahoma State University, Department of Entomology and Plant Pathology
   Address: 127 Noble Research Center, Stillwater, OK 74078-3033
   Phone: 450-744-6830
   E-mail: Nathan.walker@okstate.edu

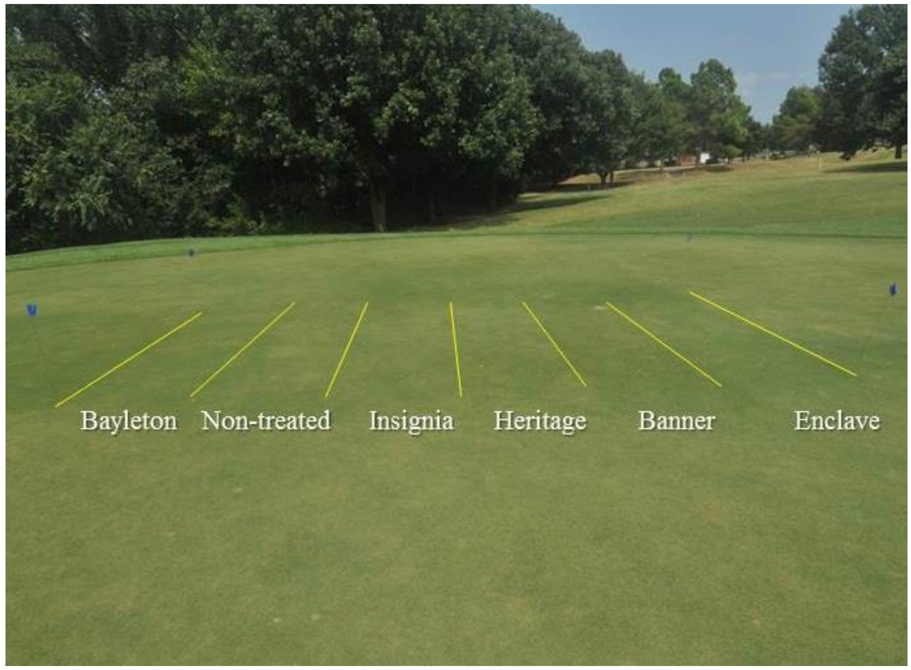
In recent years due to high summer temperatures and the challenges associate with maintaining bentgrass putting greens, some golf courses in the transition zone have converted to ultradwarf bermudagrass greens (UDB). Recently, UDB greens in Oklahoma that experienced damage from cold temperatures were characterized as having poor rates of growth and recovery. Root-knot nematodes, root decline of warm-season grasses, or both often were present. The objective of the research was to identify effective management programs for both root-knot nematode and root decline for ultradwarf bermudagrass greens. An UDB green located in central, OK was be used for this study. This location had established root-knot nematode (*Meloidogyne marylandi*) and root decline (*Gaeumannomyces graminis* var. *graminis*) (Fig 1) pathogens. Fungicide applications were made in the spring when soil temperature at a 2-inch depth averaged over five days was greater than 55°F. The fungicides: Heritage 50WG (azoxystrobin, Syngenta Professional products), Banner Maxx 1.3 MEC (propiconazole, Syngenta Professional products), Insignia 20 WG (pyraclostrobin, BASF Specialty Products), Bayleton 50 WG (triadimefon, Bayer Environmental Science), and Enclave 5.3 SC (chlorothalonil, iprodione, thiophanate-methyl + tebuconazole, Nufarm Americas) were all applied at the highest label rate to 3 ft by 9 ft plots on April 8, 29, & May 20, 2015 using a CO_2 pressurized wheeled sprayer equipped with TX8008 flat fan nozzles and calibrated to deliver 87 GPA or 2 gal/1,000 sq ft. Non-fungicide treated plots served as a control. Perpendicular to the fungicide treated plots two experimental nematicides were applied to 3 ft by 18 ft plots. One nematicide was applied on the same dates as the fungicides using the same equipment. The second granular nematicide was applied on May 26 and June 23 using a Gandy drop spreader. Immediately following all treatments plots were overhead irrigated with approximately 1/4 inch of water. Non-nematicide treated plots served as a control. The plots were arranged in a randomized complete block strip plot design with four replications. On 18 August, plots were evaluated using a FieldScout TCM 500 NDVI Turf Color Meter (Spectrum Technologies, Plainfield, IL) to determine turfgrass quality. Five, 1 inch diam. by 2 inch in depth soil cores were taken from each nematicide treated plot both at the start of the study and on 18 August. Soil samples were processed using bucket-decanting, centrifugal floatation to determine the populations of nematodes present. Additional soil cores were taken from each sub-plot and root systems were evaluated for color and rooting depth.

No differences in root-knot or lance nematodes populations were present at the start of the trial (Table 1). Across the four replications there were considerable differences in both fungicide and nematicide treatment effects. This may be due to the patchiness of nematode populations. A reduction in root-knot nematodes was present for the liquid applied nematicide but it was not significant. Plots treated with this product had statistically higher lance nematodes possibly suggesting reduce root-knot nematode competition permitted greater lance numbers. No differences were observed for root length and color and both nematicides significantly increased turfgrass quality; however, the increases were not large. Despite plots in some replication having better visual quality there was no consistant effect of the fungicides. The results of this study suggest more research should be conducted on application timing, rates, and the number of applications of the fungicides and nematicides evaluated.

Table 1. Effects of two experimental nematicides on nematode populations and ultradwarf bermudagrass quality.

	April 8, 2015		August 18, 2015		
Treatment	Root-knot	Lance	Root-knot	Lance	Turfgrass quality
Non-treated	64	23	96	9 b*	7.93 b
Liquid Nematicide	60	21	31	36 a	8.06 a
Granular Nematicide	66	13	94	6 b	8.11 a

*Means followed by the same letter in each column are not significantly different based on Fisher's protected least significant difference test at $P \leq 0.05$.


Bayleton
Non-treated
Insignia
Heritage
Banner
Enclave


Granualar nematicide
Liguid nematicde
Non-treated

Impact of post-application irrigation and pigment on the efficacy of spring fungicide applications targeted for large patch control

Principal Investigator(s):
G.L. Miller, and D.T. Earlywine
University of Missouri, Division of Plant Sciences, Turfgrass Pathology

Large patch, caused by *Rhizoctonia solani* AG2-2 LP, is a perennial disease that causes severe damage on zoysiagrass fairways in the United States transition zone. Control of this disease primarily relies on 2-3 fungicide applications per year, timed in the fall and spring in accordance with the disease infection period. Little research has been conducted to investigate fungicide application strategies aimed specifically at extending residual control and reducing the number of applications necessary.

Large patch, a foliar disease, infects the zoysiagrass towards the base of the leaf sheath. Utilizing less water carrier (1 instead of 2 gal H_20/1000 ft^2) is a common practice when applying fungicides aimed at large patch control to reduce the labor and time involved with more frequent trips to spray larger fairway acreages. When applying xylem mobile systemic fungicides, however, it may be critical to deliver the fungicide lower in the turfgrass canopy, and lower carrier volumes may be leading to a reduction in efficacy. Post-application irrigation may be an appropriate fungicide delivery method on zoysiagrass fairways, and provide more effective, long-lasting control.

In the last four years since being introduced to the turfgrass market, tebuconazole, a DMI fungicide, has increasingly been utilized for large patch control on zoysiagrass fairways due its effectiveness and low cost. More recently, Bayer CropScience released a tebuconazole formulation that includes its proprietary pigment branded Stressgard®, which may provide benefits in plant health and stress tolerance. Evaluation of the impact of this pigment vs. a non-pigmented fungicide on zoysiagrass greenup and large patch severity is an additional focus of this proposed research. The specific objectives of this research are to 1) investigate the impact of post-application irrigation on residual efficacy of single spring preventive fungicide applications targeted for large patch control on zoysiagrass fairways and 2) examine the effect of a pigmented tebuconazole formulation on zoysiagrass greenup and large patch severity, and determine if post-application irrigation has any influence on this effect.

A field research trial at Belk Park Golf Course in Wood River, IL was conducted in spring 2015. The site is an established 'Meyer' zoysiagrass fairway that had considerable large patch incidence in fall 2014, and was left untreated. Azoxystrobin (Heritage TL: 1.5 fl oz/1000 ft^2) and tebuconazole (Torque: 0.6 oz/1000 ft^2 and Mirage: 1.08 fl oz/1000 ft^2) were applied on April 6 – prior to greenup and April 27 – after 2 mowings. Fungicides were unirrigated for 24 hours or watered-in immediately with 0.1" or 0.25" of post-application irrigation (3.1 or 7.8 gallons H_20/50 ft^2 plot respectively). Irrigation was implemented with a simulator designed with a shut-off and flow valve, 8 Hunter irrigation heads, and a flow meter to measure water output.

Heavy rainfall from May 8 – 12 (4 inches), followed by sustained precipitation events at the site rendered the trial area saturated and under water until May 30 (**Fig. 2**). Results were presumably confounded by the persistent rain events, as ratings taken on 30 May through mid June showed no statistical differences among treatments (**Fig. 3**). This field trial will be repeated in 2016 at the MU Turfgrass Research Farm in Columbia, MO on plots inoculated in fall 2015.

- Fungicides applied in low volumes of water carrier may be less effective for pathogens that infect the lower leaf sheath.
- The effects of pigment containing fungicides on large patch severity and zoysiagrass greenup need to be investigated further.
- Heavy rainfall events confounded the results of this trial, as no treatment resulted in satisfactory control, and no differences were observed between treatments.

Table 1: Study Treatments
Fungicide
Heritage TL (1.5 fl oz/1000 ft^2)
Torque (0.6 fl oz/1000 ft^2)
Mirage (1.08 fl oz/1000 ft^2)
Timing
Early Spring (April 6)
Late Spring (April 27)
Post Application Irrigation
None
1/10” = 3.1 gallons/50 ft^2 plot
1/4” = 7.8 gallons/50 ft^2 plot

Figure 1: A. Photo of post-application irrigation being applied after fungicide treatment on April 6.
B. Severe rainfall in early May inundated the research site and confounded trial results.

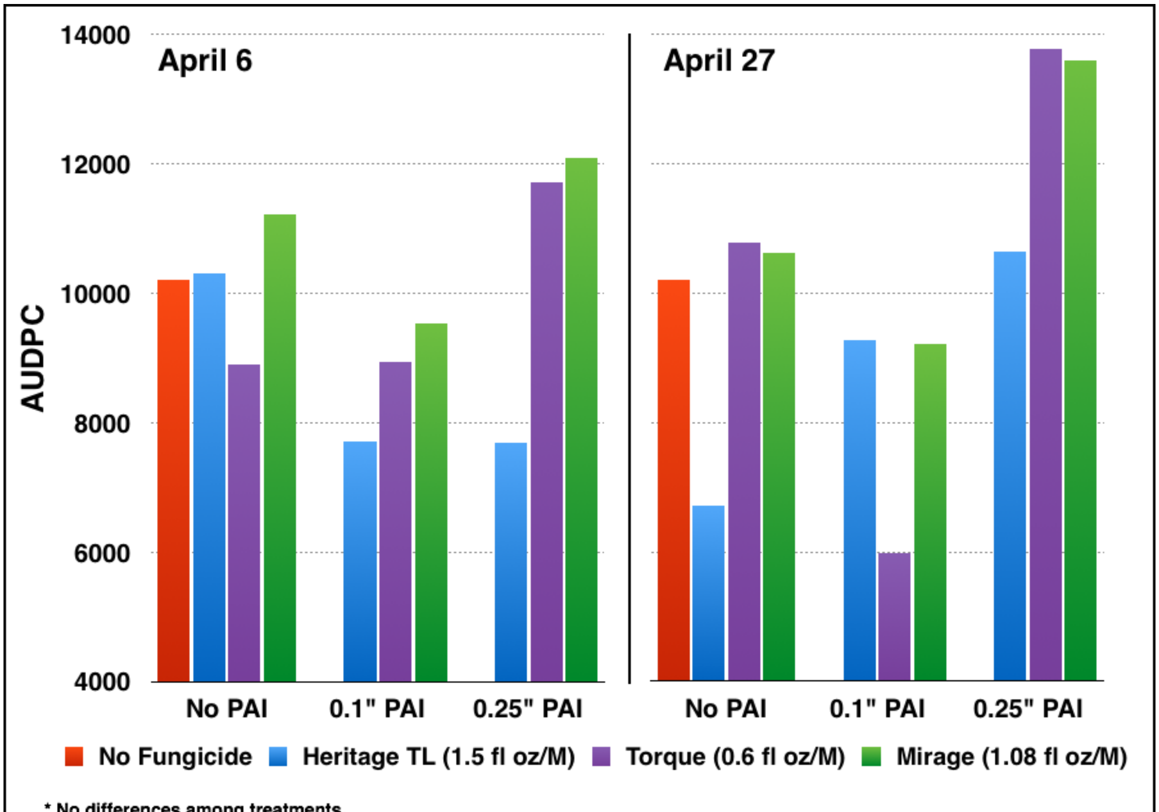


Figure 2: Effect of fungicide and post-application irrigation on performance of spring applied fungicides for large patch control. Fungicide treatments were applied either on April 6 (left panel) or April 27 (right panel) in 1 gallon H_20/1000 ft^2. Results were variable due to significant rainfall events during the spring season, and no statistical differences were noted among treatments.

Title: Off-Type Grasses of Ultradwarf Bermudagrass Putting Greens: A New Weed Management Problem?

USGA ID#: 2015-30-545

Project Leaders: Eric Reasor, M.S. and James Brosnan, Ph.D

Affiliations: The University of Tennessee

Objective: Determine the response of off-type grasses and commercially available ultradwarf bermudagrass cultivars to increasing rates of trinexapac-ethyl and nitrogen

Summary Text: Use of ultradwarf bermudagrass on putting greens in the transition zone is rapidly increasing. As use has increased, the presence of off-type grasses in ultradwarf bermudagrass putting greens has become an issue for golf course superintendents.

These weedy, off-type grasses vary in color and texture from commercial ultradwarf cultivars such as ‘TifEagle’, ‘Champion’, and ‘MiniVerde’. Moreover, anecdotal observations by golf course superintendents suggest that these off-type grasses respond differently to nitrogen applications and are less tolerant of commonly used plant growth regulators. The objective of this research was to determine the response of off-type grasses and commercially available ultradwarf bermudagrass cultivars to increasing rates of trinexapac-ethyl and nitrogen.

Research was initiated during summer 2015 at the University of Tennessee. Bermudagrass cultivars TifEagle, Champion, and MiniVerde were compared to three off-type selections from golf course putting greens. Plants were established and maintained in greenhouse culture at a mowing height of ~0.4 in. Plants were treated with increasing rates of the plant growth regulator trinexapac-ethyl (e.g. Primo Maxx) at rates of 0, 0.1875, 0.375, 0.75, 1.5, 3, 6, or 12 fl oz/acre using a spray chamber calibrated to deliver 23 gal/acre at 40 PSI using an 8002EVS nozzle. These rates represent 0, 0.0625, 0.125, 0.250, 0.50, 1, 2, or 4 times the highest labeled rate of Primo Maxx for use on ultradwarf bermudagrass putting greens (3 fl oz/acre). A separate set of plants was subjected to 0.125, 0.25, 0.375, 0.5, or 1 lb N/1000ft^2/week from urea. Nitrogen was dissolved in distilled water and applied to the soil surface of each pot using a pipette.

Clipping was suspended after initial trinexapac-ethyl and nitrogen application for seven days. Growth above 0.4 in was harvested every seven days after treatment (DAT), oven dried at 100 °C for 4 d, and weighed.

When treated with the maximum labeled rate of trinexapac-ethyl, clipping production of MiniVerde was reduced more than TifEagle with Champion ranking intermediate (Figure 1). Clipping production of the off-types tended to be greater than MiniVerde or Champion but was only statistically significant in one case (off-type #7). Few differences were observed between commercial cultivars and off-types with trinexapac-ethyl at 12 fl oz/acre; however, off-type 48 did yield more clippings than Champion (Figure 1).

Few statistically significant differences were detected among ultradwarf cultivars and off-types with treated with either 0.25 or 0.5 lb N/1000ft^2/week (Figure 2). However, when treated with 0.5 lb N/1000 ft^2/week there was a trend for off-type grasses to produce greater clipping yields than commercial cultivars.

Additional research is needed to better understand responses of commercial ultradwarf and off-type bermudagrass to rate titrations of trinexapac-ethyl and nitrogen. *Data presented herein are preliminary*. This research will be repeated several times during 2016 to reduce the variability within treatment means.

Summary Points

- Select differences were observed between commercial ultradwarf bermudagrass cultivars and off-type grasses in response to increasing rates of trinexapac-ethyl. However, more research is needed in 2016 to better understand these differences.

- There was a trend for off-type grasses to produce greater clipping yields than commercial ultradwarf bermudagrass cultivars when treated with 0.5 lb N/1000 ft^2/week. At lower nitrogen rates these differences were less pronounced. However, more research is needed in 2016 to better understand these responses.

- Additional data to be collected in 2016 will help golf course superintendents better understand how to manage off-type infestations in ultradwarf bermudagrass putting greens.

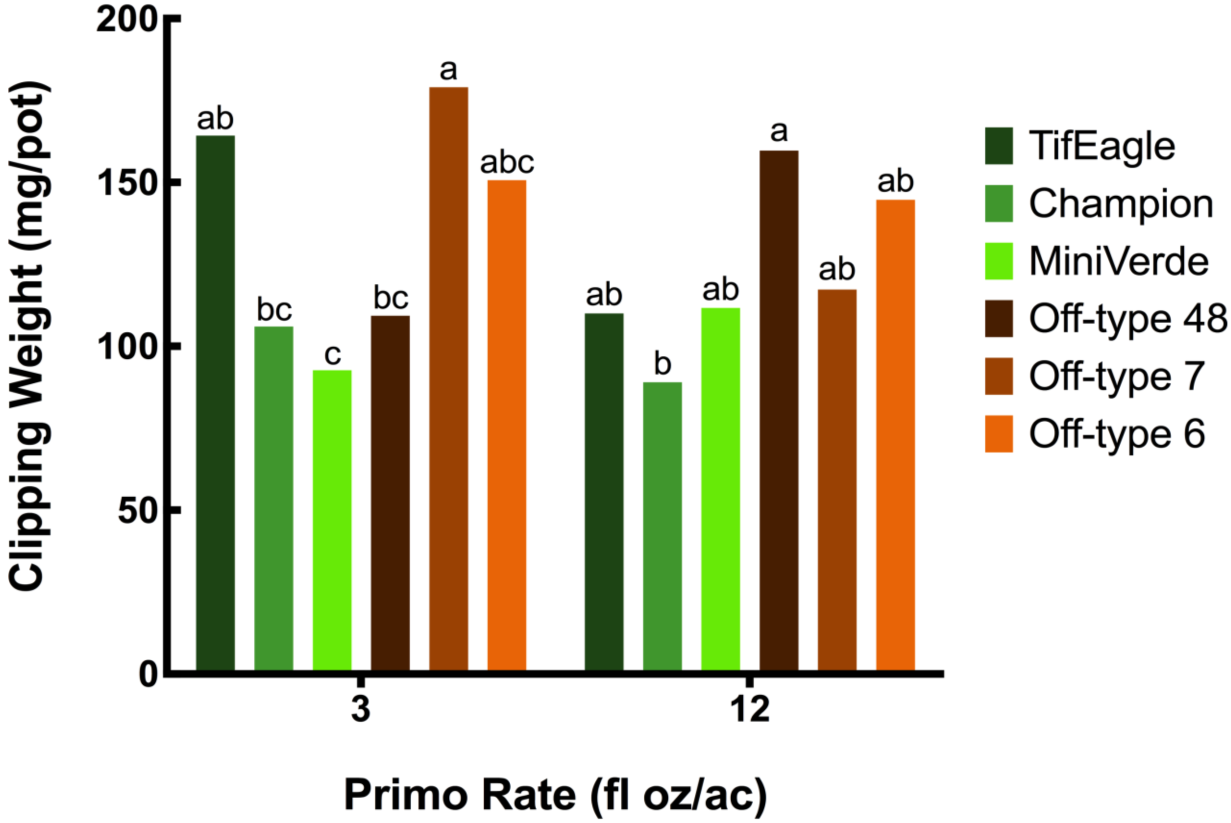


Figure 1. Response of ultradwarf bermudagrass cultivars and off-type grasses to 3 and 12 fl oz/acre of trinexapac-ethyl (Primo Maxx) 28 days after treatment. Ultradwarf bermudagrass cultivars TifEagle, Champion, and MiniVerde (green bars) were compared with three off-type selections (brown bars) from golf course putting greens in the southeastern United States. Response to trinexapac-ethyl treatment was quantified by measuring clipping weights (mg/pot). Means were separated using Fisher's Protected Least Significant Difference at $\alpha = 0.05$. Grasses labeled with the same letter for each rate are not significantly different.

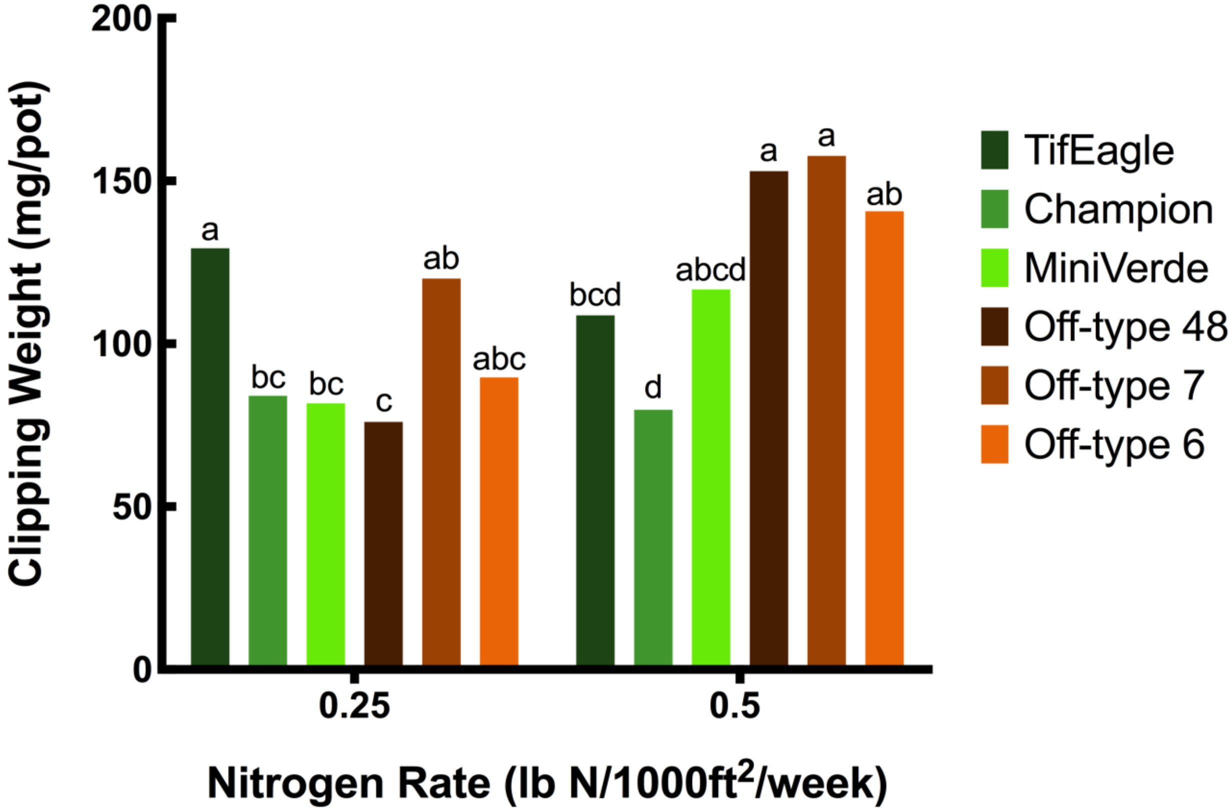


Figure 2. Response of ultradwarf bermudagrass cultivars and off-type grasses to 0.25 and 0.5 lb N/1000ft^2/week 28 days after initial nitrogen treatment. Ultradwarf bermudagrass cultivars TifEagle, Champion, and MiniVerde (green bars) were compared with three off-type selections (brown bars) from golf course putting greens in the southeastern United States. Response to nitrogen treatment was quantified by measuring clipping weights (mg/pot). Means were separated using Fisher's Protected Least Significant Difference at $\alpha = 0.05$. Grasses labeled with the same letter for each rate are not significantly different.

Figure 3. Response of ultradwarf bermudagrass cultivars TifEagle, MiniVerde, and Champion and an off-type selection 48 to 12 fl oz/acre of Primo Maxx 28 days after treatment.

Confirmation and Management of Herbicide Resistance in Annual bluegrass (*Poa annua* L.) Populations on Texas Golf Courses

Dr. Casey Reynolds, Dr. Matt Elmore, Dr. Muthu Bagavathiannan, Dr. Vijay Singh

Annual bluegrass (*Poa annua* L.) is one of the most problematic weeds for golf course superintendents throughout the country and Texas is no different. While there are approximately 25-30 herbicides and 10 modes of action (MOA) registered for Annual bluegrass control in turf, resistance to these products has become an extensive problem in recent history (Figure 1). The size and scope of this issue has yet to be documented in Texas despite the widespread prevalence of resistant populations in other southern states including Alabama, Tennessee, South Carolina, Georgia, and others. As a result of this, the USGA funded a survey for researchers at Texas A&M University to investigate and document herbicide resistance on Texas golf courses.

In spring 2015, a notice was sent out to Texas golf course superintendents to notify Texas A&M University turfgrass faculty if they have Annual bluegrass populations with suspected herbicide resistance. Respondents included 28 golf courses (Table 1) from which samples were collected and placed in growth chambers in College Station, TX. Plants from each golf course were allowed to mature at which point seeds were harvested for herbicide resistance screening.

Dormant seeds were exposed to cold treatment (-20°C) for 2 months before being moved to 4°C for 2 weeks and then placed at room temperature for one week to break dormancy. Seeds were sterilized in 10% sodium hypochlorite supplemented with 0.1% enzyme grade Tween surfactant for 5 minutes followed by washing with water before setting for germination. Seeds were placed into 9-cm-diameter Petri-dishes containing moistened filter paper (Figure 2) and incubated in a growth chamber at day/night temperatures of 27/22°C. Incubated seed samples germinated in approximately 2-3 days, at which point 2cm seedlings were transplanted into 6-cell trays filled with commercial potting-mix in a greenhouse with day/night temperatures of 27°C/23°C until they reach maturity (Figure 3).

Each of these plant populations are being screened for herbicide resistance to various products based on discussions with each golf course superintendent regarding their history of product use, turf type, location, etc. (Table 1). Current results of the survey indicate that most golf course superintendents suspect resistance to Acetolactate synthase inhibitors (Revolver, Monument, others) and Photosystem-II inhibitors (Simazine, Atrazine, others), but we are screening for resistance to other herbicides and modes of action as well. If herbicide resistance is confirmed, future studies will be conducted to investigate the presence of cross- and multiple-resistances in these biotypes and also to understand the mechanisms behind resistance so that appropriate management tactics can be developed and delivered.

Summary

- Annual bluegrass populations with suspected herbicide resistance were collected from 28 Texas golf courses during the spring of 2015 based on survey responses from golf course superintendents.
- Seed from resistant populations were harvested, exposed to cold treatments in the lab to ensure germination, and planted in petri dishes before being moved to the greenhouse for herbicide resistance screening.
- Plant populations are currently being screened for resistance to various products and modes of action commonly used for Annual bluegrass management
- Results from this research are expected to be available in early 2016 and any findings will be reported to the USGA, Weed Science Society of America (WSSA), Herbicide Resistance Action Committee (HRAC) and Texas golf course superintendents through various research and extension publications

Figure 1. Annual bluegrass biotypes that have survived an application of Revolver (foramsulfuron) herbicide adjacent to those that were successfully controlled.

Figure 2. Seeds from Annual bluegrass plants with suspected herbicide resistance germinating in a petri dish for screening using various products and modes of action (MOA).

Figure 3. Germinated seedlings in the greenhouse to be used for herbicide resistance screening with various products and modes of action (MOA).

Table 1. 2015 USGA Herbicide Resistance Screening on Texas Golf Courses

Location	Site Description	Suspected Resistance	Mode of Action (HRAC, WSSA Classification*)
Georgetown, TX	Fairway	Revolver	Acetolactate synthase inhibition (B,2)
Georgetown, TX	Fairway	Revolver	Acetolactate synthase inhibition (B,2)
Houston, TX	Nursery Green (Collar)	Revolver	Acetolactate synthase inhibition (B,2)
Pearland, TX	Putting Green	Revolver	Acetolactate synthase inhibition (B,2)
Humble, TX	Collar	Revolver	Acetolactate synthase inhibition (B,2)
Humble, TX	Collar	Revolver	Acetolactate synthase inhibition (B,2)
Humble, TX	Putting Green	Revolver	Acetolactate synthase inhibition (B,2)
Bryan, TX	Chipping Green (Rough)	Revolver	Acetolactate synthase inhibition (B,2)
Waco, TX	Putting Green	Revolver	Acetolactate synthase inhibition (B,2)
Houston, TX	Practice Green (Collar)	Revolver	Acetolactate synthase inhibition (B,2)
Houston, TX	Putting Green	Revolver/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
Houston, TX	Putting Green	Revolver/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
Houston, TX	Approach	Revolver/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
Woodlands, TX	Rough	Revolver/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
Woodlands, TX	Fairway	Revolver/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
Spring, TX	Chipping Green (Approach)	Revolver	Acetolactate synthase inhibition (B,2)
Houston, TX	General Use area	Revolver	Acetolactate synthase inhibition (B,2)
Dallas, TX	Collar	Glyphosate	Enolpyruvyl shikimate-3 phosphate inhibition (G,9)
Dallas, TX	Collar	Glyphosate	Enolpyruvyl shikimate-3 phosphate inhibition (G,9)
Houston, TX	Putting Green	Simazine	Photosystem-II Inhibition (C1,5)
Houston, TX	Putting Green	Simazine	Photosystem-II Inhibition (C1,5)
Houston, TX	Putting Green	Simazine	Photosystem-II Inhibition (C1,5)

Houston, TX	Putting Green	Monument/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
Houston, TX	Putting Green	Monument/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
Houston, TX	Putting Green	Monument/Simazine	Acetolactate synthase inhibition (B,2)/ Photosystem-II inhibition (C1,5)
McKinney, TX	Rough	Ronstar	Protoporphyrinogen oxidase inhibition (E,14)
Overton, TX	Putting Green	Monument	Acetolactate synthase inhibition (B,2)
Benbrook, TX	Putting Green	Revolver	Acetolactate synthase inhibition (B,2)

* Herbicide Resistance Action Committee (HRAC) & Weed Science Society of America (WSSA)

Utilizing protective covers to reduce winter injury on ultradwarf bermudagrass

Eric De Boer, Mike Richardson, and Doug Karcher, University of Arkansas

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

Research currently being conducted at the University of Arkansas in Fayetteville aims to examine predicted low temperature thresholds that can be used to determine when to cover ultradwarf greens. The ultimate goal is to provide superintendents with firm numbers they can use to assure covers are being utilized in the most efficient manor. Consistent winter injury to ultradwarf bermudagrass putting greens in northwest Arkansas make this an ideal location for this type of study.

A protective cover trial is being performed on a USGA-constructed green with replicated plots of Champion, Mini-Verde, and Tifeagle ultradwarf bermudagrass. The custom covers from Xton (Xton, Inc. Florence, Alabama) are designed specifically for this study and are composed of permeable, black woven polypropelene. Covers are placed based on predicted low temperatures for Fayetteville, Arkansas from the National Oceanic and Atmospheric Administration (www.noaa.gov). The predicted low temperature thresholds include 25, 22, 18, and 15 °F and an uncovered control. The covers remain in place until the temperature for the following day is predicted to exceed 45 °F. This is designed to mimic a golf course that would remove covers to allow play on warmer winter days. Temperature probes are installed in each cover treatment to continuously monitor the soil temperature at a depth of 1.0 inch. Soil volumetric water content is being recorded monthly for all plots using a Spectrum TDR 300 with 1.5 inch probes. During the greenup period, winter injury will be assessed on all plots using digital image analysis and visual ratings of % turfgrass coverage. Spring greenup and quality will be monitored bi-weekly until all plots are fully green and recovered.

Since this research was just initiated in the fall of 2015, there are no data to report on actual winter survival at this time. However, some interesting trends from soil temperature data have been observed (Figure 2). The soil temperature for the uncovered controls has dropped below the freezing mark for a number of days during the winter while the 25 °F cover treatment has resulted in the warmest soil temperature over the winter. However, it is noteworthy that the other cover treatments have also sustained soil temperatures above freezing for most of winter while reducing the number of coverings and the number of days that greens were covered. There have also been some interesting observations of surface thermal conditions using the FLIR-One camera, with as much as 6 degree differences between covered and uncovered plots (Figure 2).

Figure 1. Average weekly minimum soil temperature at a depth of 1 inch for each of the cover treatments (Control, 15, 18, 22, and 25 °F). The embedded table summarizes the number of covering events for each treatment as well as the number of days plots were covered.

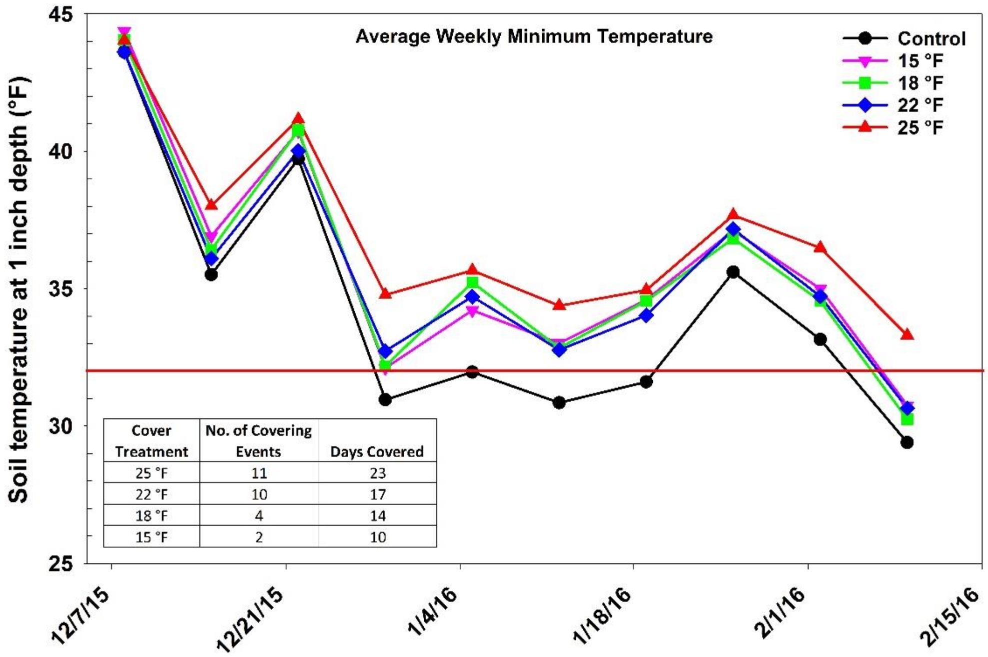
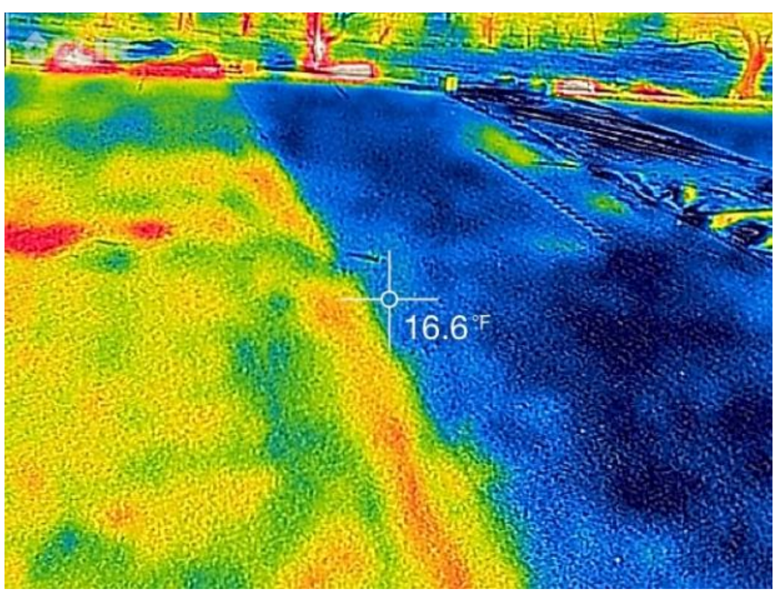


Figure 2. Thermal imagery of covered (yellow/red on left) and uncovered (blue on right) bermudagrass greens in Fayetteville AR.



Dormant sprigging of ultradwarf bermudagrass putting greens. 2015 Update

Michael D. Richardson and Douglas E. Karcher, University of Arkansas, Department of Horticulture

Background

Ultradwarf bermudagrasses such as Champion, Mini-Verde, and Tifeagle are hybrid cultivars that must be planted vegetatively as either sod or sprigs, as they do not produce viable seed. Most conversions to ultradwarf greens involve the planting of sprigs into an existing putting green or into a new rootzone. Most golf courses that are converting from an older bermudagrass or from bentgrass use some form of conversion that causes minimal disruption to the existing surface so that costs associated with tillage or regrading of the surface are avoided. These conversion methods are commonly called “no-till” and include eradication of the existing turf with a non-selective herbicide, followed by either aggressive aerification of the remaining organic matter or removal of the organic matter with a deep sod cut. Once these steps are followed, sprigs are planted directly on the surface, topdressed heavily with sand, and established using appropriate cultural practices (Hartwiger, 2007).

Sprig establishment of hybrid bermudagrasses has been studied extensively and numerous papers are available that describe the effects of sprig planting rates (Johnson, 1973), optimal fertilization programs (Rowland et al., 2010), and the effectiveness and safety of various herbicides (Johnson, 1973; Brosnan et al., 2014). One factor that has not been studied as extensively in relation to sprig planting is the optimum time of the year to establish sprigs. Most researchers and practitioners generally seek to plant sprigs when soil and air temperatures (18 °C and 30 °C, respectively) are ideal for rooting and vegetative growth of the desired species. However, several studies with hybrid bermudagrasses have demonstrated that successful establishment can occur when sprigs are planted at non-optimal planting periods such as late winter or early spring (Beaty, 1966; Chamblee et al., 1989; Ruemmele et al., 1993).

A recent project at the University of Arkansas began investigating the idea of dormant sprigging of warm-season grasses to promote early-season establishment of hybrid grasses. In that study, ‘Tifway’ bermudagrass and ‘Meyer’ zoysiagrass (*Zoysia japonica*) were sprigged at three rates in early March, May and July in a prepared seedbed of the native silt loam soil. Although the site had a very cool and wet spring, sprig survival in the dormant-planted plots was very high and the bermudagrass plots were at 100% coverage by 1 May. Similarly, positive results were observed with dormant-sprigged zoysiagrass, where dormant-sprigged plots reached 100% coverage by August, whereas other planting dates in late spring or summer failed to reach full coverage by the end of the growing season.

Although the early results from this trial are promising and suggest that dormant sprigging could benefit sod production or large-scale plantings such as fairways or athletic fields, it also suggests that dormant sprigging might also be beneficial for establishing ultradwarf bermudagrass greens. In the conversion from creeping bentgrass to bermudagrass, early establishment of bermudagrass during the late winter and spring might reduce the number of days of lost revenue that would occur during the optimum golfing season. Our hypothesis is that dormant sprigging can lead to faster establishment of ultradwarf bermudagrass greens compared to traditional sprigging dates in late spring or early summer. As such, the overall objective of this study is to determine the effects of dormant sprigging on the establishment of an ultradwarf bermudagrass in both a new putting green as well as in a no-till conversion from a creeping bentgrass green.

Methods

Simultaneous trials were established at the University of Arkansas Research and Extension Center in Fayetteville AR in late winter/early spring of 2015. The trials were planted either in a new, sand-based putting green built to USGA specifications or in an existing creeping bentgrass green that is also built to USGA specifications. The existing creeping bentgrass green was eradicated using 2 applications of the non-selective herbicide, glyphosate, prior to planting, with the first application made approximately 3 weeks prior to each planting date and the second application made within 1 week of planting. After eradication of the bentgrass, the plots were aggressively aerified using a 25 x 25 mm tine spacing and 12.5 mm hollow tines. Following removal of the cores, plots were topdressed to backfill aerification holes and to an overall depth of 0.25 inches.

Out initial intent was to utilize Tifeagle bermudagrass sprigs from a grower in North Louisiana, harvested using typical methods. Unfortunately, the weather patterns in N. Louisiana prevented the grower from getting into the field during the entire month of March, so sprigs were harvested from our research green in Fayetteville by cutting sod from the green and shredding the sod to create sprigs. Sprigs were broadcast applied to all plots at a rate of 35 m^3 ha^{-1}. Two planting dates were compared in this study, including a mid-March planting (dormant) and an early May planting (spring). Sprigs were top-dressed with sand to an appropriate depth to cover approximately 75% of the plant material and rolled to enhance sprig to soil contact. An application of a starter fertilizer was made at planting and oxadiazon was applied at planting to prevent emergence of grassy weeds. Plots were irrigated after sprigging to maintain adequate moisture for growth and prevent desiccation of the sprigs, although a very wet spring season minimized the need for significant irrigation. Once temeratures were conducive for growth, plots were fertilized with a soluble nitrogen source at a rate of 2.5 g N m^{-2} wk^{-1} to promote rapid grow-in (Rowland et al., 2010).

Turfgrass coverage was monitored frequently throughout the grow-in periods using digital image analysis (Richardson et al., 2001). Mowing was initiated on plots once green leaves were being produced. Mowing height was started at 7.5 mm and lowered by 1.0 mm per week until a final mowing height of 3.0 mm was obtained. Plots were lightly topdressed with sand every 14 days during the grow-in and rolled with a lightweight roller 2 times per week.

Results

Results from this study were very inconsistent and it is difficult to draw any significant positive or negative conclusions from the first year of this trial. Weather patterns in the spring were very cool and wet and sprigs that were dormant-planted in late winter struggled to get established. However, in the fresh sand (Figure 1), establishment rates were similar for both the dormant and spring-planted sprigs. In the bentgrass conversion trial, the spring-planted sprigs performed better than the dormant-planted sprigs (Figure 2).

Another potential problem that existed with this trial is the use of sprigs from our research green in Fayetteville. When the research green from which the sprigs were harvested began to green-up, there was considerable winter injury on the green and the injury was not uniform across the green. It is possible that sprigs that were harvested from the green may have already been damaged by winter injury and were further exposed to harsh conditions, especially those that were planted in March.

Plans for 2016

We are planning to repeat this trial in the spring of 2016, with again the plan to use sprigs from a grower in North Louisiana to minimize the potential for damaged plant material. Planting dates will again be in mid-March, early May, and mid-June. The mid-June date was also planned for 2015, but once we saw the very poor results we were getting with the earlier dates, we decided to forgo that planting date.

Figure 1. Turfgrass coverage of Tifeagle bermudagrass planted either in March (dormant) or May (spring) in a new sand-based putting green

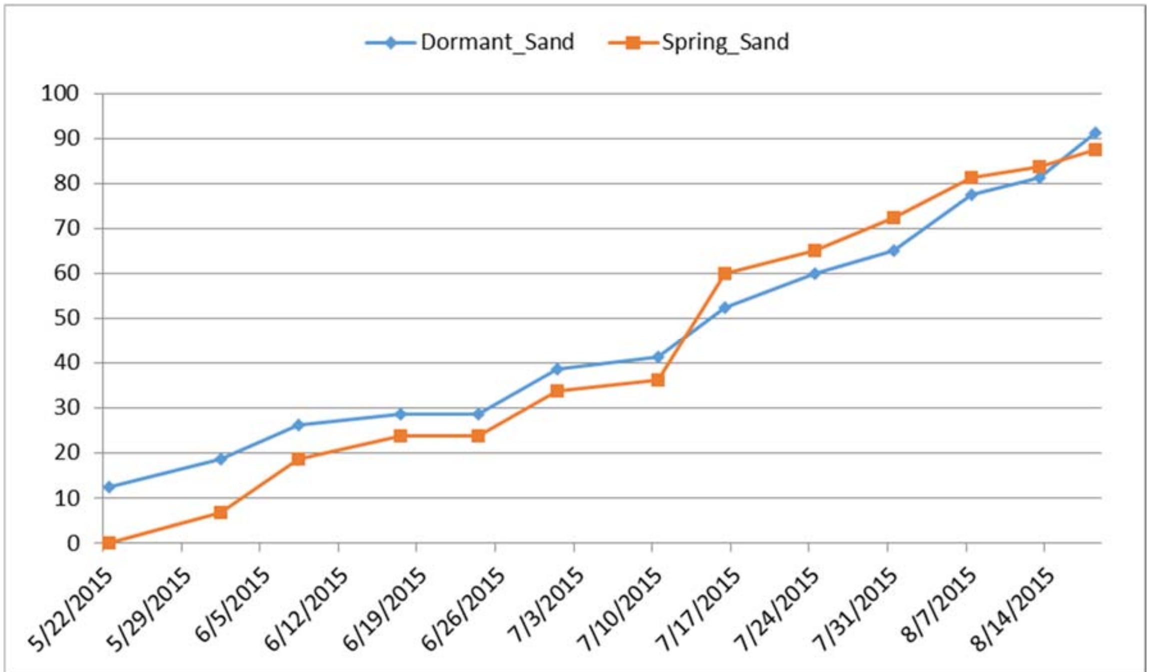
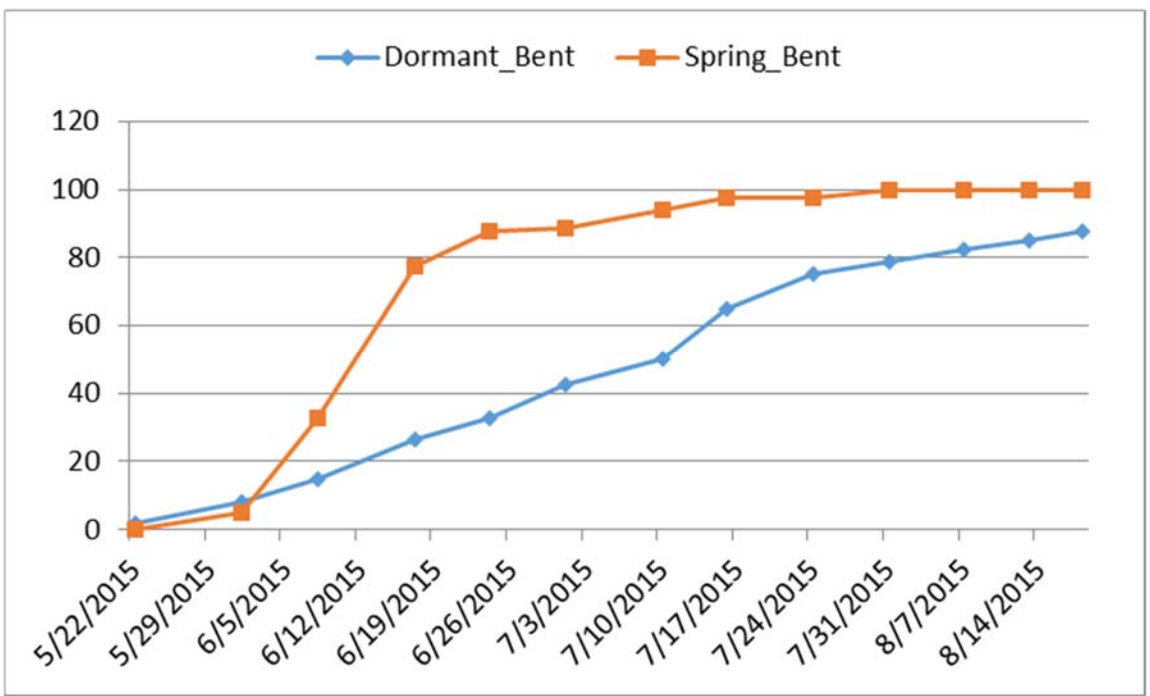


Figure 2. Turfgrass coverage of Tifeagle bermudagrass planted either in March (dormant) or May (spring) in a bentgrass putting green using no-till conversion methods



Literature Cited

Beaty, E. R. 1966. Sprouting of Coastal bermudagrass stolons. Agron. J. 58:555-556.

Brosnan, J. T., G. K. Breeden, A. W. Thoms, and J. C. Sorochan. 2014. Effects of preemergence herbicides on the establishment rate and tensile strength of hybrid bermudagrass sod. Weed Technol. 28:206-212.

Chamblee, D. S., J. P. Mueller, and D. H. Timothy. 1989. Vegetative establishment of three warm-season perennial grasses in late fall and late winter. Agron. J. 81:687-691.

Hartwiger, C. 2007. No till in no time: The advantages of ultradwarf bermudagrass putting greens are unlocked with minimally invasive and effective conversion method. USGA Green Sec. Rec. 45(6):22-26.

Johnson, B. J. 1973. Herbicides, sprigging rates, and nitrogen treatments for establishment of Tifway bermudagrass. Agron. J. 65:969-972.

O'Brien, P., and C. Hartwiger. 2011. A time to change: The ultradwarf bermudagrass putting green golf model is solid in the southern USA. USGA Green Sec. Rec. 49(8):1-5.

Richardson, M. D., D. E. Karcher, and L. C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884-1888.

Rowland, J. H., J. L. Cisar, G. H. Snyder, J. B. Sartain, A. L. Wright, and J. E. Erickson. 2010. Optimal nitrogen and potassium fertilization rates for establishment of warm-season putting greens. Agron. J. 102:1601-1605.

Ruemmele, B. A., M. C. Engelke, S. J. Morton, and R. H. White. 1993. Evaluating methods of establishment for warm-season turfgrasses. Int. Turfgrass Soc. Res. J. 7:910-916.