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Proceedings of the Twenty-Fifth Anniversary Rutgers Turfgrass Symposium

Josh Honig and Barbara Fitzgerald, Editors

Associate Director's Remarks

Welcome to the 25th Turfgrass Symposium at the School of Environmental and Biological Science and the New Jersey Agricultural Experiment Station. The symposium was established in 1991 to provide Rutgers faculty, students, and staff with an annual forum for the exchange of ideas to include presentations by colleagues at other institutions.

This is a special anniversary year for it represents 25 years since the Turf Center was established, as well as the 250th anniversary of Rutgers University. We want to thank the organizing committee of Drs. Bruce Clarke, Stacy Bonos, Jim Murphy, Bingru Huang, Ning Zhang, Albrecht Koppenhöfer and Barbara Fitzgerald. Thanks are also owed to the editors of this year's symposium proceedings Dr. Josh Honig and Barbara Fitzgerald.

This year, we invited many Rutgers graduates who are now enjoying productive careers at other institutions, in industry and government, and at Rutgers. We would like to thank the following speakers, who are former students of the Rutgers Turfgrass Program: Dr. Ben McGraw from Pennsylvania State University, Dr. JoAnne Crouch from the USDA-ARS in Beltsville, MD, Dr. Eric Watkins from the University of Minnesota, Dr. Jonathan Bokmeyer from the Monsanto Corporation, Mr. John Zimmers, Jr., superintendent at Oakmount Country Club, Dr. Al Turgeon from Pennsylvania State University, and Dr. Joseph DiPaola from the Syngenta Corporation.

The faculty and students in the Turfgrass Center continue to be recognized for their excellence in research, teaching, and outreach. Dr. Jim Murphy was named a Fellow of the American Society of Agronomy, Dr. Bruce Clarke was awarded the USGA Green Section Award, Ning Zhang received Rutgers Board of Trustees Research Fellowship for Scholarly Excellence, and Dr. Bingru Huang was the recipient of the Tengtou Agricultural Science Award from the American Society of Agronomy. The following PhD students received national awards: Chas Schmid, the Gerald O. Mott award; Phillip Vines, David Jespersen and Chas Schmid, the James Watson Fellowship; and Dr. Lisa Beirn, the Musser Award. In addition, Dr. David Jespersen won 1st place and Eric Chen placed 3rd in the graduate student oral competition at the Crop Science Society national meetings in Minnesota.

Over the past 25 years, the Turf Center faculty have continued to conduct outstanding research, teaching, and outreach in support of the turfgrass industry. The turfgrass industry has provided over $5 million in research grants and gifts and $95,000 per year in student scholarships. Throughout this time, the Turfgrass Center has had a great and very productive relationship with the turfgrass industry.

We are very pleased to celebrate this year's anniversary symposium with all of the attendees including members of the Rutgers community and our stakeholders. We hope that it will be a very enjoyable and rewarding experience.

Sincerely,

W. A. Meyer

William A. Meyer, Associate Director

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TWENTY-FIFTH ANNIVERSARY RUTGERS TURFGRASS SYMPOSIUM

School of Environmental and Biological Sciences, Rutgers University
Neilson Dining Hall, Cook Campus

March 18, 2016

Friday, March 18, 2016

8:15 - 8:45 am **Registration, Coffee and Donuts**

8:45 – 9:00 am **Welcome and Opening Remarks** –Dr. Bradley Hillman (Director of Cooperative Research, New Jersey Agricultural Experiment Station)

9:00 - 10:00 am **SESSION I: Improving Our Understanding of Plant Pests**
(Moderator: Dr. Albrecht Koppenhöfer, Dept. of Entomology, Rutgers University)

9:00 – 9:30 **Dr. Benjamin McGraw** (Department of Plant Science, Penn State University)
The Rutgers Model: A Cultural Approach to Minimizing Annual Bluegrass Weevil Insecticide Applications on Putting Greens

9:30 – 10:00 **Dr. JoAnne Crouch** (Research Molecular Biologist, USDA-ARS, Beltsville, MD)
Deciphering Genome Diversity of Seven Diverse Fungal Strains Causing Dollar Spot Disease on Four Turfgrass Hosts

10:00 – 10:30 am **Discussion and Poster Session**

10:30 – 12:15 pm **SESSION II: Advances in Plant Breeding**
(Moderator: Dr. Josh Honig, Department of Plant Biology, Rutgers University)

10:30 – 11:00 **Dr. Eric Watkins** (Dept. of Horticultural Science, University of Minnesota)
New Approaches for Breeding Low-Input Turfgrasses

11:00 – 11:30 **Dr. Jonathan Bokmeyer** (Monsanto Co., Saint Peters, MO)
Finding the Green Grass – Looking Beyond Your Field of Study for Career Opportunities

11:30 – 12:15 **Drs. William Meyer and Stacy Bonos** (Dept. of Plant Biology, Rutgers Univ.)
Major Advances from the Rutgers Turf Breeding Program

12:15 - 1:15 pm **Lunch and Poster Session**

1:15 – 2:45 pm **SESSION III: Exploring the Boundaries of Turfgrass Management**
(Moderator: Dr. James Murphy, Dept. of Plant Biology, Rutgers University)

1:15 – 1:45 **Charles Schmid** (Department of Plant Biology, Rutgers University)
Anthracnose of Annual Bluegrass: How Our Understanding of Soil Fertility Requirements Has Changed Over the Past Five Years

1:45 – 2:15 **Dr. David Jespersen** (Department of Plant Science, University of Georgia)
Characterization and Validation of Molecular Markers Linked to Heat and Drought Tolerance for Marker Assisted Selection of Stress-tolerant Creeping Bentgrass

2:15 – 2:45 **John Zimmers, Jr.** (Superintendent at Oakmont Country Club, Oakmont, PA)
Preparing for the U.S. Open and Other Major Golf Tournaments

2:45 – 3:15 PM **Discussion and Poster Session**

3:15 – 4:15 PM **SESSION IV: Advances in Turf Science Education and the Private Industry**
(Moderator: Mr. Brad Park, Department of Plant Biology, Rutgers University)

3:15 – 3:45 **Dr. Al Turgeon** (Professor Emeritus, Dept. of Plant Science, Penn. State Univ.)
A Compelling Case for Online Education

3:45 – 4:15 **Dr. Joseph DiPaola** (Head, Integrated Solutions, Global Lawn/Garden R&D, Syngenta, Greensboro, NC)
A Rutgers Enabled Career: From Lawn Care Maintenance to Global Lawn and Garden R&D

4:15 – 4:30 PM **Discussion and Summary of Symposium**

4:30 – 5:30 PM **Cocktail reception**

5:30 – 8:00 PM **Dinner MC – Dr. William Meyer**
(Associate Director, Center for Turfgrass Science, Rutgers University)

Dr. Bruce Clarke
(Director, Center for Turfgrass Science, Rutgers University)
The History of the Rutgers Turfgrass Program

Chris Carson
(Echo Lake Country Club, Westfield, NJ)
Leadership and the Industry/Rutgers University Partnership

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PLENARY PRESENTATIONS

The Rutgers Model: A Cultural Approach to Minimizing Annual Bluegrass Weevil Insecticide Applications on Putting Greens

Benjamin McGraw

Department of Plant Science, Penn State, College of Agricultural Sciences

The annual bluegrass weevil, *Listronotus maculicollis* Dietz. (Coleoptera:Curculionidae) (ABW) is the single most destructive insect pest of golf course turf in the mid-Atlantic and northeastern United States and eastern Canadian provinces. However, it remains unknown what impact cultural practices (e.g. mowing, fertilization, and irrigation) have on weevil development, abundance, and turfgrass damage. This void hinders the ability to manage the pest culturally or without intense reliance on chemical insecticides. Larval feeding damage is most severe in short-mown (< 1.25 cm) turf. Damage is common on golf course tees, fairways, and collars, but is rarely observed on golf course putting greens (< 0.38 cm). We sought to determine if ABW are capable of surviving, ovipositing, and developing to damaging stages in a range of putting green heights-of-cut (HOC) and early-season N regimes. A reel mower mounted on a greenhouse bench was used to assess the ability of adults to survive mowing, and to determine a low-end threshold for adult survival. These studies were coupled with observations of adult behavior in the lab and field using time lapse photography to determine periods when adults were present on top of the turf canopy and therefore could be removed by mowers. Finally, male and female weevils were seeded into *Poa annua* L. research plots and caged cores to determine the likelihood of oviposition, development, and damage expression under different putting green management programs.

The results from laboratory and field studies demonstrate that *L. maculicollis* has the ability to accept and oviposit into host plants maintained at putting green heights. This suggests that *L. maculicollis* may pose a threat to golf course putting greens, despite the lack of damage observed in these areas. However, significantly more adults were removed from the lowest HOC (30% of infested adults removed at 0.25 cm) than the medium HOC (7% at 0.32 cm) and high HOC (3% at 0.38 cm) mowing treatments. Although *L. maculicollis* was capable of laying eggs in all three mowing height treatments, we observed more eggs being laid outside the turfgrass stem, than were inside at lower putting green heights. This ovipositing behavior has not been previously documented, and is not known to occur at higher HOC. The consequences of ovipositing outside of the plant remain unknown, though may prove costly to the weevil if they are likely to be exposed to predation or desiccation. Time-lapse video also indicated a clear trend to the diel activity of the weevil. An increase in weevil activity on top of the turf canopy was greatest in the early morning hours (0600 to 0900 hr) or prior to and following the period when lights were activated in the incubator. Our findings and their implications on ABW cultural and chemical management will be discussed.

Deciphering Genome Diversity of Seven Diverse Fungal Strains Causing Dollar Spot Disease on Four Turfgrass Hosts

Jo Anne Crouch[1], Lisa A. Beirn[2,3], Michael J. Boehm[4], Ignazio Carbone[5], Bruce B. Clarke[2], Martha Malapi-Wight[1,] Angela Orshinsky[6], Lane P. Tredway[3] and Daniel Veltri[1]

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Outbreaks of dollar spot disease, caused by the fungus *Sclerotinia homoeocarpa* F.T. Bennett, are a constant threat to warm- and cool-season turfgrasses worldwide. The disease is widespread and persistent, with more money spent on its control than any other disease affecting golf course turf. Surprisingly little is known about the diversity of *S. homoeocarpa* in natural populations and the pathogenicity factors that influence host infection and the course of disease. We identified seven distinct molecular groups of *S. homoeocarpa* using phylogenetic analysis of nucleotide sequence data drawn from eight standard molecular markers and 16 novel next-generation-sequenced markers. To learn more about the basis of diversification of these seven unique groups of *S. homoeocarpa*, draft whole genome assemblies were generated from a representative isolate drawn from each molecular group. Sequenced fungal strains were originally isolated from four turfgrass hosts: *Agrostis stolonifera* L., *Cynodon dactylon* (L.) Pers., *Festuca rubra* L. and *Paspalum vaginatum* Sw. For comparison, draft whole genome sequences were generated from two additional members of the Rutstroemiaceae family, *Rutstroemia echinophila* (Bull.) Höhn. and *R. sydowiana* (Rehm) W.L. White. In this presentation, the genomes of these seven unique strains of *S. homoeocarpa* will be introduced and discussed. Whole genome scale comparisons were performed between (a) the genomes of the seven *S. homoeocarpa* strains; (b) the *S. homoeocarpa* genomes and other related fungi in the Rutstroemiaceae/Sclerotineaceae families; and (c) the *S. homoeocarpa* genomes and other fungal pathogens of turfgrass. Together these data provide a comprehensive profile of the genomic characteristics unique to the fungi responsible for turfgrass dollar spot disease, and provide insight into the unique genome profiles that differentiate these organisms on the molecular level.

New Approaches for Breeding Low-Input Turfgrasses

Eric Watkins

Department of Horticultural Science, University of Minnesota

The turfgrass breeding program at the University of Minnesota aims to develop low-input winter hardy turfgrasses for cold climates. Turfgrass performance in cold climates is the result of a number of factors, some of which are difficult to exploit in a breeding program. Technological advances have helped open up new ways to study the microbes that surround turfgrass roots, endophytes that live within the plants, and the multitude of metabolites that are produced by the plant. We are beginning to use these technologies to better understand how certain turfgrasses succeed in low-input environments. We hope to utilize this knowledge to more efficiently select elite genotypes in a turfgrass breeding program.

An overlooked aspect of turfgrass breeding is the need to understand the preferences of the non-professional consumer of grass seed. For several decades, turfgrass breeders have made assumptions about the traits that are important to these consumers. High turfgrass quality and darker green color, for instance, have been assumed to be the primary desires of the consumer, and therefore these traits have driven turfgrass germplasm development efforts. As the public begins to become more aware of the potential environmental effects of yard and lawn care practices, we anticipate that other characteristics may become more important. We are collaborating with a horticultural marketing researcher to identify what consumers desire in a lawn grass, and also how much of a premium they are willing to pay for improved cultivars with those traits. Our data has indicated that consumers value turfgrasses that withstand traffic, require less mowing, and have reduced irrigation needs.

Finding the Green Grass - Looking Beyond Your Field of Study for Career Opportunities

Jonathan Bokmeyer

Monsanto Co., Saint Peters, MO

For many graduate students, thesis projects are selected in the field of study in which they would like to eventually establish a career. Even with this careful preparation there are still situations where this does not go as planned. Looking beyond your field of study for career opportunities can be a challenging experience but one that is also very rewarding. It is important to remember the skills you acquire through your research project are transferable across many career disciplines. From a personal perspective, the skill set I acquired at Rutgers from my time in the Turfgrass Breeding Program enabled me to transition into a career with Monsanto conducting corn and soybean research. My career has progressed from conducting on-farm research focusing on corn and soybean commercial advancements for Illinois to managing a soybean product portfolio that is part of the largest biotech launch in the history of Monsanto. I have found, regardless of the career path you choose, you can always find the “green grass”.

Major Advances from the Rutgers Turfgrass Breeding Program

William A. Meyer and Stacy A. Bonos

Department of Plant Biology and Pathology, Rutgers University

Rutgers University and the New Jersey Agricultural Experiment Station have a worldwide reputation as the leading developers of cool-season turfgrasses. In 1962, Dr. C. Reed Funk started a germplasm collection effort that has led to the development of many improved turfgrass cultivars. Since 1996, a large scale collection program has been conducted from old turfgrass areas throughout Europe and the eastern United States to broaden the germplasm base of cool-season turfgrass species. All seed from the European collections have been produced from vegetative material by den Haan Zaden (Peter den Haan) at his farm in Steenbergen, Holland.

Since 1996, over 20,000 grasses have been collected in Europe and then rogued before anthesis to produce seed. Over 10,000 of these new sources were put into the Rutgers turfgrass breeding pool after evaluation in New Jersey. Over 2000 bentgrasses (*Agrostis* spp.) were collected from old golf courses in the eastern United States. A small percentage of these have been identified as sources of dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) resistance and released as the first cultivars with improved resistance to this economically important disease.

Tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), and Kentucky bluegrass (*Poa pratensis* L.) are the most important cool-season species used in the United States and Europe. Beginning in the 1980's, the National Turfgrass Evaluation Program (NTEP) has conducted national coordinated turf trials in the United States, where a new test for each species is initiated every 4 or 5 years. Data on turf performance and other characteristics are collected, analyzed, and published each year. The cool-season turfgrass cultivars developed through the Rutgers breeding program have dominated these trials for the last four decades.

Endophytes

Many of the perennial ryegrasses, fine fescues (*Festuca* spp.), and tall fescues collected from old turf areas in the US and Europe contain fungal endophytes. These endophytes are maternally transmitted and enhance turf performance and resistance to above ground feeding insects. In fine fescues, the presence of endophytes provides resistance to dollar spot, and one line of endophyte provides red thread (*Laetisaria fuciformis* (McAlpine) Burds.) resistance in strong creeping red fescue (*Festuca rubra* L. ssp. *rubra*). All of the top performing tall fescues, fine fescues, and perennial ryegrasses contain a high level of endophyte in the better performing cultivars.

Tall Fescues

The NTEP results (NTEP.org) from the 2012 trial for 2014, showed that the top 30 cultivars of tall fescue in the northeast and Midwestern states were from Rutgers and their cooperators. When comparing tall fescue cultivars for overall performance, 20 Rutgers cultivars were in the top 25% for all of the trials 47% of the time or more. Eighteen out of 20 Rutgers sourced cultivars had the highest rating for brown patch (*Rhizoctonia solani* Kuhn), which is the most serious disease of tall fescue.

The seed yields of tall fescue have continued to improve since the release of 'Rebel' in 1980. In fact, in 30 years seed yield has increased by 283%. The turf quality and disease resistance of tall fescue has also continued to improve with higher seed yields.

Some notable recent tall fescues cultivars from the Rutgers turfgrass breeding program include Regenerate, Rebounder, Rowdy, 4th Millennium, Amity, Traverse 2, Firewall, Titanium 2L5, Hot Rod, Reflection, Avenger II, Screamer LS and Maestro.

Perennial Ryegrasses

The turf-type perennial ryegrass industry started in the US in 1967 with the Rutgers release of 'Manhattan'. Perennial ryegrass has become the second largest market for cool-season turfgrass species. Since the start of the breeding program in 1962, perennial ryegrass has continued to improve with cycles of genotypic and phenotypic selection each year.

In the late 1990's, gray leaf spot (*Magnaporthe grisea* (T. T. Hebert) M.E. Barr) became a very important disease of perennial ryegrass. Since the early 2000's, new sources of genetic resistance were found to control this disease in improved cultivars. There are now over 35 cultivars developed from Rutgers sources that have excellent resistance. In the 2011-2014 NTEP for perennial ryegrasses, the overall turf quality of 11 new Rutgers cultivars were in the top 25% in each trial in 50-85% of the trials throughout the US.

The perennial ryegrass cultivars from Rutgers with the top performance and gray leaf spot resistance in 2010-2014 NTEP trials were Apple SGL, Benchmark, Evolution, Pangea GLR, Karma, and Wicked. Many additional Rutgers cultivars were ranked in a second group, slightly below these elite cultivars.

Kentucky Bluegrasses

Rutgers has had a leading position in releasing new hybrid apomictic Kentucky bluegrass cultivars since the release of Midnight and America in the 1980's. These are landmark hybrids that have performed well for over 35 years. Shamrock is a landmark cultivar developed in the 1990's that has average turf quality along with excellent seed yield. The development of Shamrock and Shamrock type cultivars have dramatically affected the turfgrass seed production industry since these types of cultivars can be produced with or without irrigation.

Some of the top performing new Kentucky bluegrass cultivars are Midnight II, P105, Skye, Bewitched, Blue Note, Langara, Wild Horse, Bedazzled, Shiraz, Moonlight, Brooklawn, Volt, Bolt, Ridgeline, Mallard, Avid, Rhapsody, Katie, Fielder, Dauntless, Aries, Aura, Shannon, Fargo, Bluebank, Mazama, Fullback, Gaelic and Zinger. Some new hybrids have also been derived from crosses between Kentucky and Texas bluegrass (*Poa arachnifera* Torr.). Examples of these hybrid cultivars include Longhorn, Bandara, and Fahrenheit 90.

Fine Fescues

The primary fine fescues include Chewings fescue (*Festuca rubra* L. ssp. *commutata* Gaud.), hard fescue (*Festuca brevipila* Tracy), strong creeping red fescue, and slender creeping red fescue (*Festuca rubra* L. ssp. *trichophylla* Gaud.). These grasses have the ability to grow in poor soils and at low fertility, yet maintain good turf quality and density. Although the fine fescue seed industry is limited in size, turfgrass breeders at Rutgers are committed to improving these important low maintenance species.

Seed production has historically been a limiting factor in fine fescues. However, the Rutgers breeding program has helped to increase yields by more than 200% in the last 30 years. The strong creeping red fescue cultivars from Rutgers such as Wendy Jean, Kent, Lustrous, Fortitude, Miser and Shademaster III have improved seed yields. Some notable Chewings fescue cultivars from Rutgers are Shadow II, Treasuer II, Longfellow III, Intrigue II, Ambrose, Seven Seas, Radar, SR 3150 and Zodiac. The hard fescues, Oxford, Nordic, Reliant I, Reliant IV, Predator, Firefly, Beacon, Sword, Gladiator, and Blueray are also top performing cultivars.

Bentgrasses

Dr. C. Reed Funk and Dr. Ralph Engel developed a number of creeping bentgrass (*Agrostis stolonifera* L.) cultivars in the late 1980’s and early 1990’s, including Viper, Cobra and L93 (the first cultivar with significant improved dollar spot resistance); however, bentgrass cultivar development was not a significant part of the Rutgers turfgrass breeding program at that time. Since 1996, the Rutgers turfgrass breeding program has significantly increased efforts to develop new bentgrass cultivars. There are three main species currently being developed in the breeding program, including creeping bentgrass, colonial bentgrass (*Agrostis capillaris* L.) and velvet bentgrass (*Agrostis canina* L.).

Disease resistance has been a significant breeding objective within the bentgrass program. Dollar spot is the biggest disease problem in creeping bentgrass; since 2003, more than 10 cultivars have been developed with improved resistance to this important pathogen. Brown patch is the biggest disease problem in colonial bentgrass. Currently, there are several cultivars with improved brown patch resistance including Capri, Puritan and Muskett.

In the 2008-2013 NTEP putting green trial, 9 out of the top 10 cultivars originated in the Rutgers breeding program. In the 2008-2013 NTEP fairway trial, 7 out of the top 10 cultivars were developed at Rutgers. In fact, Rutgers cultivars always ranked #1 in these two trials.

Conclusions

The Rutgers turfgrass breeding program is committed to improving cultivars with reduced environmental impacts. Improving disease resistance results in reduced pesticide use, while the development of drought, salinity and heat tolerant cultivars can limit water use and increase water conservation efforts. Many of the breeding efforts are focused on cultivar improvements for low input, sustainable turfgrass management. These improved cultivars, in concert with best management practices, can help to reduce the environmental impact of turfgrass while providing safe enjoyable turf for lawns, landscapes and playing surfaces.

Anthracnose of Annual Bluegrass: How Our Understanding of Soil Fertility Requirements Has Changed Over the Past Five Years

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Anthracnose (caused by *Colletotrichum cereale* Manns sensu lato Crouch, Clarke & Hillman) of annual bluegrass [*Poa annua* L. f. reptans (Hausskn) T. Koyama; ABG] turf is a destructive disease that is strongly influenced by cultural management practices. Optimizing the management of N fertility has proven to be one of the most effective cultural practices to reduce the severity of this disease. Field studies conducted over a period of six years on ABG turf maintained at 2.8 – 3.2 mm have enabled us to better understand the response of anthracnose disease to N fertility practices, as well as the influence of soil potassium and soil pH on disease development. Initial research investigating the role of N fertility found that both slow release (IBDU) and soluble N (ammonium nitrate) influenced the disease, with slow release N applied in the spring at 146 or 219 kg ha^{-1} and soluble N applied at 4.6 kg ha^{-1} wk^{-1} in the summer resulting in the greatest reduction in anthracnose severity. Further study of soluble N applied from late-May through mid-August found that weekly applications at 10 kg ha^{-1} provided the greatest reduction in anthracnose severity compared to higher and lower rates of the same N source. A third field study investigated the effect of N source on anthracnose. Results from this trial indicated that potassium nitrate applied at 4.9 kg N ha^{-1} wk^{-1} provided the greatest reduction in anthracnose severity, whereas, ammonium sulfate applied at the same rate resulted in the least reduction in disease severity. However, because these N sources were also altering soil pH or potassium (K) levels, it was unclear whether these factors were contributing to the N source response. Thus, two additional field trials were conducted to evaluate the impact of soil pH and soil K on anthracnose development. A study investigating the effect of K source and rate on anthracnose found that deficient levels of K in soil increased disease severity. Analysis of soil and leaf tissue data indicated that critical K values were 50 mg kg^{-1} and 20 g kg^{-1}, respectively, with lower levels resulting in greater disease severity. A fifth field study investigating the influence of soil pH on anthracnose and turf quality found that disease severity decreased and turf quality was better at a soil pH > 6.0. These studies have clearly demonstrated that the proper management of N and K nutrition and soil pH can greatly reduce anthracnose severity on ABG putting green turf.

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

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Creeping bentgrass (*Agrostis stolonifera* L.) is a cool-season turfgrass valued for its dense, fine canopy and ability to withstand low mowing heights. Due to these desirable characteristics creeping bentgrass is frequently used for high value turf areas such as golf course greens and fairways. Unfortunately creeping bentgrass has low to moderate stress tolerance which can limit its performance and use during periods of abiotic stress. Two major abiotic stresses affecting creeping bentgrasses are drought and heat which lead to reductions in growth, premature leaf senescence and eventual plant death. The development of elite cultivars with improved stress tolerance would allow plants to maintain greater turf quality during stress periods with fewer inputs, as well as potentially allowing turf managers in southern latitudes to take advantage of creeping bentgrass's superior turf characteristics. One way to develop improved cultivars is through the use of marker assisted selection (MAS) which utilizes molecular markers linked to important traits resulting in improved selection speed and efficiency. Potential molecular markers have been identified using quantitative trait loci (QTL) analysis on existing creeping bentgrass linkage maps developed at Rutgers University. Additionally several candidate gene markers have also been developed which correspond to genes previously implicated to play important roles in stress tolerance, such as stress defense genes coding for heat shock proteins, or genes involved with photosynthesis and energy production. These markers include microsatellite or simple sequence repeat (SSR) markers as well as gene specific markers using cleaved amplified polymorphic sequences (CAPS) and Ecotilling methodologies. Using these previously identified markers, a diverse population of creeping bentgrass germplasm consisting of 127 individuals was screened during 2014 and 2015 at both the University of Georgia and Rutgers University for important physiological traits associated with drought and heat tolerance. These traits include leaf membrane stability, chlorophyll content, green leaf biomass as estimated by normalized difference vegetation index (NDVI), as well as visual ratings of turf quality. In addition to identifying individuals with improved levels of stress tolerance, association analysis was performed to determine if the previously identified molecular markers were associated with important physiological traits for drought or heat tolerance in this new population. Markers significantly associated with important physiological traits for stress tolerance may be linked with important mechanisms for abiotic stress tolerance and be used in MAS to develop improved cultivars. The confirmation of these markers will not only support their utility for use in MAS protocols, but may also be useful for identifying key mechanisms for abiotic stress tolerance.

Preparing for the U.S. Open and Other Major Golf Tournaments

John F. Zimmers, Jr.

Grounds Superintendent, Oakmont Country Club, Oakmont, PA

Oakmont Country Club, located fifteen miles east of Pittsburgh, Pennsylvania is a Club steeped in championship history and tradition. Founded in 1903 by local steel magnate Henry Fownes, Oakmont has developed a venerable reputation for its penal features and fast, undulating greens. Oakmont has hosted eight U.S. Opens, five U.S. Amateurs, two U.S. Women's Opens, and three PGA Championships. Some 113 years following its inception, Oakmont Country Club continues to place an enormous emphasis on maintaining the character and philosophies Henry Fownes initiated. The Club has done this by placing a premium on maintaining conditions and infrastructure necessary to host championship golf events.

John Zimmers graduated from Rutgers in 1993 and joined Oakmont Country Club as the Grounds Superintendent in 1999. Throughout his tenure at Oakmont he has been directly involved in upholding the Clubs championship legacy. After the 1994 U.S. Open, the United States Golf Association returned to Oakmont to host the 2003 U.S. Amateur. Prior to, and following this Championship, the Club underwent extensive restoration initiatives to reestablish and maintain the features and character in which the Club was founded. Following the restoration process, the Club hosted the 2007 U.S. Open and 2010 U.S. Women's Open.

After hosting three national championships in less than a decade, Oakmont continues to execute a vast array of restoration projects to ensure the Clubs golf course and related infrastructure continues to attract national championships. Oakmont is currently preparing to host its record ninth U.S. Open in June 2016. As the scope and size of hosting major golf events has continued to evolve, Oakmont's commitment to preparing for and hosting such events is evident in the poignant work completed throughout the history of the Club.

A Compelling Case for Online Education

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Online education is a process by which students learn from online resources created by an instructor in cooperation with instructional designers and others knowledgeable in relevant computer operations. This was created to provide location-bound students with opportunities for achieving their educational goals. The benefits of online education also include combining on-the-job experience with formal instruction, and reducing educational costs for both students and educational institutions.

Historically, there were two learning environments: resident and extension. In the resident learning environment, students must travel to where the instructors are resident, typically a college or university. In the extension learning environment, the instructors travel to where specific groups of students reside in a particular town or city. In recent years, the creation of the worldwide web led to the development of a new "online" learning environment in which instructors and students remain at their respective locations and employ computer-based technologies to bridge the geographic distance between them (Figure 1).

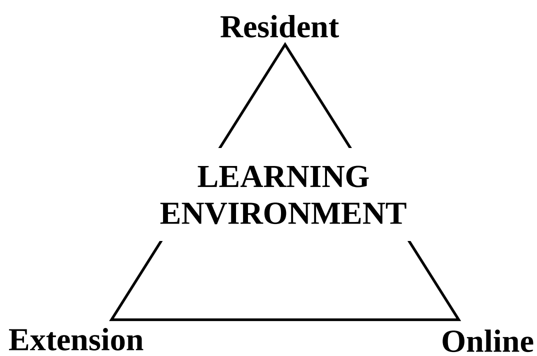

Figure 1. Illustration of the three learning environments: resident, extension, and online.

A comparison of the new online learning environment with two traditional learning environments—resident and extension—reveals several important differences. Resident/extension learning is face-to-face, synchronous, and, since it involves groups, is often a social experience. In contrast, online learning is both remote (i.e., not face-to-face) and isolated (i.e., not social, as students operate for the most part by themselves in front of a computer screen). Furthermore, it is asynchronous in that a posting by the instructor or another student almost always occurs at a different time from when students access these postings. The "a" in asynchronous stands for any time, any place, and any pace, as the student can access the learning resources at a time and place of his choosing but usually within the time frame established by the instructor (e.g., by next Sunday or within the next two weeks). Furthermore, the student proceeds through the lesson at a pace with which she is most comfortable. In fact, a student can go back to a site in the lesson to review it before proceeding further if the need to do so exists. Thus, asynchronous learning resources are characterized as "student-centered." In contrast, as the time, place, and pace of resident/extension learning are controlled by the instructor, synchronous learning is characterized as "instructor-centered," and by some as "the tyranny of the instructor."

Before getting into the development and use of asynchronous learning resources for online teaching, it's important to establish what our learning objectives are. Based on Bloom's Taxonomy (Figure 2), learning can occur at different levels (1956). The lowest level achieves factual or recall knowledge; this is essentially the memorization of facts about a subject. Next is *comprehension* or concept knowledge, which refers to how specific facts fit together to form concepts by which one acquires understanding about a subject. The next level within the taxonomy is *application*; this refers to one's ability to apply what one has learned in the performance of specific tasks.

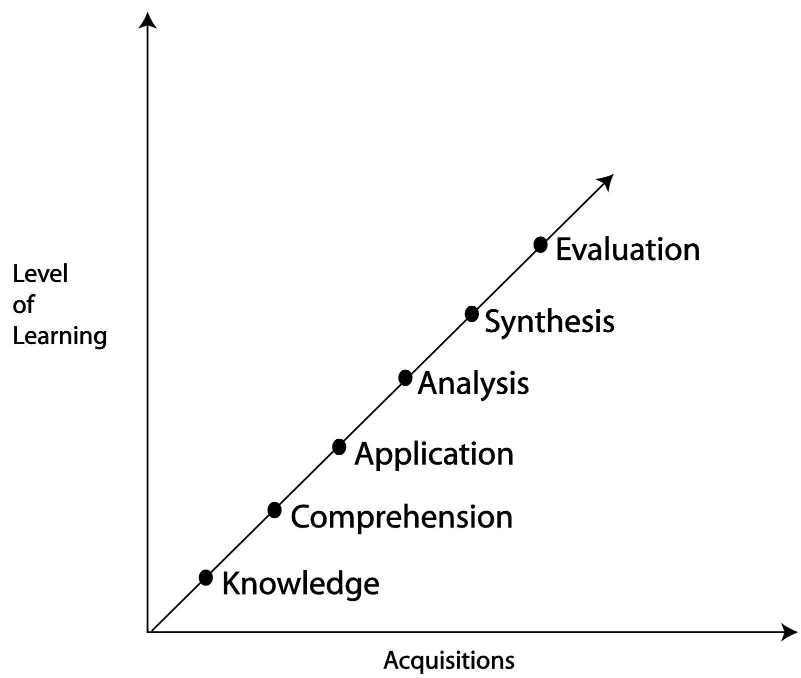

Figure 2. Bloom's Taxonomy in which the different levels of learning are shown.

The next three levels in the taxonomy are sometimes referred to as the problem-solving or critical-thinking skills; they include: analysis, synthesis, and evaluation. *Analysis* requires cognitive skills to interpret information obtained by some means—perhaps from direct field observations or the results of tests performed on samples taken from the site—using one's relevant knowledge. This process enhances descriptive information and forms what is sometimes called a "rich picture" of the problem or problematic situation. For example, if you discovered that the surface two inches of the soil beneath a lawn was composed of silt loam, and that underlying this layer was a relatively coarse sand, you would know—if you had any understanding of soil physics—that the lawn would be poorly drained. This is because infiltrating water would percolate through the silt loam at a rate reflective of its hydraulic conductivity—relatively slowly—and that, when it reached the sand, further downward movement would stop, forming a perched water table (Figure 3). No further downward movement would occur until and unless a hydraulic head sufficient for the water to overcome the attractive forces holding it within the pores of the silt loam soil developed so that it could move into the sand. Then, it would percolate at a rate reflective of the sand's hydraulic conductivity—in this case, relatively rapidly, due to the larger pores permeating this medium. Thus, the description of a situation—a fine-textured medium situated atop a coarse-textured one, and some comprehension of water movement in texturally diverse soil profiles, provides an enhanced understanding of the basis for poor drainage in the lawn. The ability to perform an analysis reflects a higher level of learning than merely understanding soil water movement, as one has to bridge between subject-matter comprehension and its application to developing an understanding of a situation encountered in the real world.

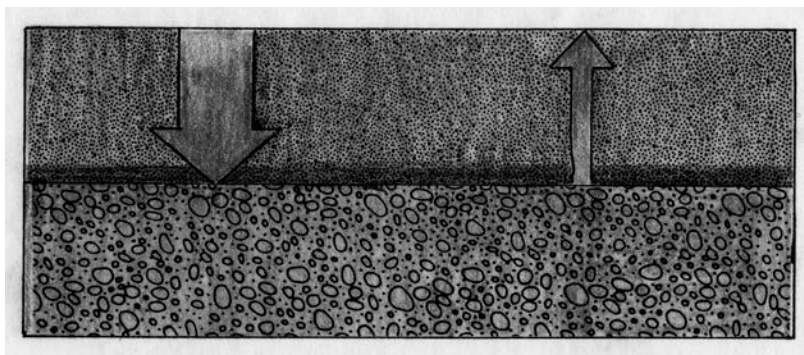

Figure 3. Illustration of water movement through a finer-textured medium resulting in the formation of a perched water table above the interface between this medium and the underlying coarse-textured medium.

Synthesis builds upon the results of an analytical process by also drawing on one's relevant knowledge, in this case to explore ways of solving a problem or ameliorating a problematic situation. In the example just cited, the problem might be solved by removing the troublesome layer of silt loam soil and reestablishing the lawn in the sand medium, or by incorporating the soil into the sand to create a uniform medium in which the two constituents have been blended together. A third alternative would be to core cultivate the site, removing the soil cores extracted from the lawn, and filling in the holes with sand to create bypass drainage channels through the silt loam soil layer to the underlying sand medium. While this approach would not completely solve the drainage problem, it would reduce its severity and, thus, ameliorate the problematic situation. Subsequent operations involving coring and backfilling the holes with sand would further reduce the severity of the problem by removing more soil and creating more bypass drainage channels.

Finally, *evaluation* is the process by which various decision options are assessed and the most appropriate one chosen. This is the highest level of learning in Bloom's Taxonomy because it often requires the greatest skill. One must carefully develop a comprehensive list of all decision options within the context of the problematic situation, explore the advantages and disadvantages of each in order to judge which option would be the most desirable or, in some cases, the least undesirable. For example, in the situation described in the previous paragraph, external factors would probably determine which option would be best. If sufficient time and resources were available, removal or incorporation of the silt loam soil layer might be better choices; if not, coring would probably be the best option. With respect to the choice between removal and incorporation of the silt loam soil into the sand, an important determining factor would be the availability of the proper equipment and expertise to ensure uniform blending of the two soils; otherwise removal might be the best option.

Problem solving usually begins with a critical analysis of the problem to be solved, then the development of solution strategies, and, finally, the choice of a particular strategy for implementation. Likewise, critical thinking can involve all of these activities, but focuses on analysis in evaluating sources of information, looking for inconsistencies, and drawing logical conclusions based on a convincing body of evidence. In evaluating decision options, critical thinking is directed at determining which option is the most defensible.

Instruction versus Education

The terms *instruction* and *education* are often used interchangeably; however, they actually have very different meanings. Instruction comes from the Latin word: *instruere*, meaning "to build in." The intent of instruction is to inform and enlighten, and it is generally intended to mean teaching to achieve the lower levels of learning—knowledge, comprehension, and application—in Bloom's Taxonomy. Education comes from the Latin word: *educare*, meaning "to draw out." The intent of education is to empower, and its focus is on helping students develop their problem-solving skills—analysis, synthesis, and evaluation. Instructional objectives can be achieved by delivering classroom lectures, providing students with access to online learning resources, and involving students in other activities through which they are exposed to new knowledge and, perhaps, some associated skills. In contrast to instructional objectives, educational objectives are primarily—if not exclusively—achieved by exposing students to problem-based learning (PBL) resources and activities. And, as the desired outcomes are primarily cognitive *skills*, their development comes from *some* instruction and *lots* of practice analyzing and solving problems, usually under the supervision of a competent teacher.

The complaint often heard from some teachers is that, while they would like to involve their students in activities that promote the development of problem-solving skills, they are limited in the extent to which they can do so because they have to cover so much material, that is, they are so overwhelmed with attempting to achieve important—even critical—*instructional* objectives, that there is little time available in which to focus on also achieving *educational* objectives. This is actually a fallacious argument for several reasons: first, the ability of most students to understand and retain—beyond the final exam—is usually limited to a small percentage of the material actually covered in class, and second, if students were given a compelling reason to do so, they could learn—mostly on their own—the material from various sources, including online learning resources created specifically for this purpose. And the compelling reason could very well be the need to learn the material in order to participate in PBL exercises.

Furthermore, this type of learning is likely to be understood better and retained longer than that resulting from classroom lectures.

Problem-Based Learning

Problem types range from simple to very complex, and thus can be used at any level of instruction. They also vary with the nature of the subject being taught. For example, in teaching basic science, the instructor may employ scientific problems, often in the form of puzzles, to provide students with opportunities for applying the concepts or techniques they have just learned (Figure 4).

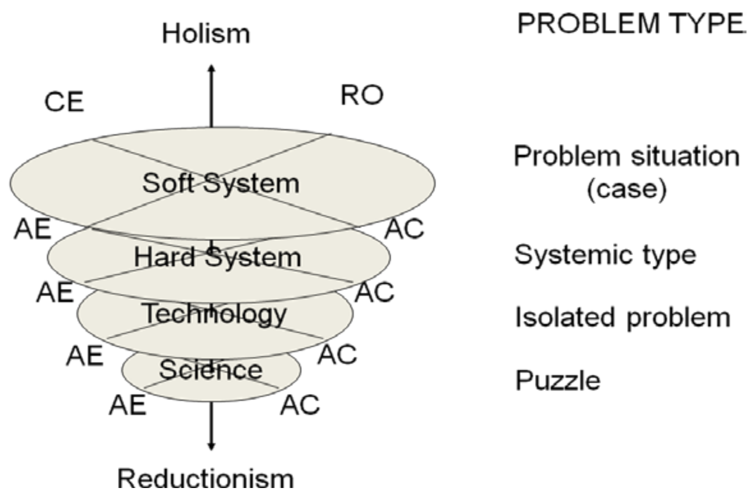

Figure 4. Illustration of problem types, including puzzles for teaching science, isolated problems for teaching technology, hard systems for teaching how to deal with complex problems with interrelated parts, and soft systems for teaching complex problematic situations dominated by people—called cases.

In puzzle-solving activities, the instructor may ask such questions as: What is this? What does it mean? How does it work? In applied-science (i.e., technology) instruction, the questions might include: If this is not working, how can it be fixed? How can this be made to work better? In addressing more complex problems, students may become aware that something done to influence one component of a system may also influence another, interrelated component. Thus, the questions that could be asked when operating at the "systems" level might include: If I do this to influence the operation of component A, what might the effect be on component B? For example, if a plant population growing in a silt-loam soil is subjected to a prolonged drought and exhibits symptoms of moisture stress, the problem may be solved by providing irrigation water. In addressing moisture stress, however, one might induce another problem—an oxygen deficient root-zone—if too much water is provided too quickly, resulting in a water-logged soil. Thus, soil moisture and soil aeration can be viewed as two interrelated subsystems within the soil environment supporting a population of plants

There are two general types of systems: hard and soft. *Hard systems* have components with quantifiable or measurable characteristics. Examples of hard systems include:

machines, tractors, buildings, irrigation systems, drainage systems, golf greens, and whole farms. Each has a boundary separating it from its external environment and interrelated components, which could also be systems or subsystems of the larger system. Problem-based learning employed for engineers working on heating-system designs, physicians studying endocrinology, or agronomists exploring options for improving field drainage is at the hard systems level.

Soft systems are systems dominated by human activity. For example, if a farm is studied as an integrated system of land resources, buildings, equipment, nutrient reservoirs and flows, and energy transformations, it is a hard system. However, if the farmer, his family, neighbors, creditors, suppliers, and others with whom he interacts are included, the farm becomes a soft system. Its operation cannot be characterized just in terms of quantifiable operations. Of critical importance to the functioning of the farm are the non-quantifiable elements, such as the farmer's goals, beliefs, cultural background, and personal priorities. Businesses and institutions are all soft systems because they are dominated by human activity. Problems or problematic situations encountered in the operation of human-dominated systems are called *cases*, and problem-based teaching using cases is sometimes called case-based teaching or the Case Teaching Method.

Case Teaching Method

Story telling precedes recorded history. Stories may be in many forms, including parables, legends, and fables, as well as contemporary literature. Their purpose often extends beyond entertainment, as they can embody important lessons the listener or reader learns vicariously through the experiences of the principals in the story. Stories may be embodied in historical or retroflexive cases, which are complete narratives of situations including a statement of the problem, the actions taken to solve it, and the outcomes resulting from these actions. However, the kinds of cases typically used when employing the case-teaching method are called decision cases, which are incomplete narratives that take the student only to the point at which a decision has to be made; then, the student must decide on the future course of action.

Making an informed, intelligent decision requires several important steps. First, one must obtain and organize all of the essential facts from the case to generate a detailed description. It is important to be thorough in ferreting out all of the significant details; otherwise, subsequent stages in the process will reflect the omissions or errors made during this stage. If crucial information is unavailable, assumptions may be required in their place that could have a dramatic influence on the decision-making process.

Second, one should conduct a thorough analysis of the facts to deduce their essential meaning and generate an interpretation. To do this well, one must possess a specific body of knowledge sufficient to properly interpret the important facts in the case. If the student does not possess such knowledge, the case should provide a powerful motivation for acquiring it. The analytical process should produce an enriched understanding—sometimes called a "rich picture"—of the situation which, in turn, serves as the foundation upon which subsequent stages of the decision-making process are built.

Third, the issues emerging from the analysis are identified. Issues may be of a descriptive or prescriptive nature; *descriptive* issues deal with what is, while *prescriptive* issues deal with what ought to be. Issues are sometimes seen as the problem to be solved. While seemingly straightforward, it is surprising how many times the wrong problem is the focus of decision making. This is not only wasteful of resources, but is usually ineffective and suggests incompetence on the part of the decision-maker.

Fourth, strategies for addressing the issues are developed and evaluated. Besides the knowledge required for conducting an analysis, a broader body of knowledge is usually required for developing solution strategies. This must include the realization that a more favorable situation is possible; then, strategies must be devised for transforming the current situation into the more favorable one. Once all of the strategies have been depicted, the advantages and disadvantages of each are thoroughly explored. This then serves as the basis for deciding upon the most suitable strategy from among those assessed.

Once a decision has been made through the selection of a particular strategy, a detailed action plan is developed for its implementation. The action plan should encompass the traditional management functions: planning, organizing, staffing, leading, and controlling. The *planning* function simply establishes the objectives of the plan; these are statements on what should be accomplished as the outcome or outcomes of the tasks performed. The *organizing* function establishes the sequence of tasks for accomplishing the objectives. While some tasks may be sequentially dependent, others may be performed simultaneously, providing sufficient resources are available. The *staffing* function lists the numbers and capabilities of the personnel needed to perform all of the tasks called for in the plan. If all of the required capabilities do not exist, a detailed staff-development program is provided as part of this function. The *leading* function deals with those actions necessary for motivating the staff to perform in accordance with the standards set for each task. These may include the incentives for favorable performance, as well as the disincentives established for unfavorable performance. Finally, the *controlling* function includes all anticipated actions for monitoring progress and possible adjustments for ensuring satisfactory completion of the project.

The steps described above are consistent with Kolb’s Learning Cycle Model describing four phases of learning: divergence, assimilation, convergence and accommodation (Kolb, 1986). *Divergence* is exploring and describing a situation. *Assimilation* is analyzing the situation. *Convergence* is identifying issues emerging from the analysis, and proposing and evaluating strategies for addressing those issues. Finally, *accommodation* is implementing a strategy for changing the situation, presumably for the better. These steps are in response to four simple questions: What is the situation? What does it mean? What can be done to change it? How can this be done? Together, they constitute a disciplined process of inquiry by which one develops and implements insightful solutions to difficult problems. An adaptation of Kolb’s Learning Cycle Model by Turgeon (1993) is shown in Figure 5.

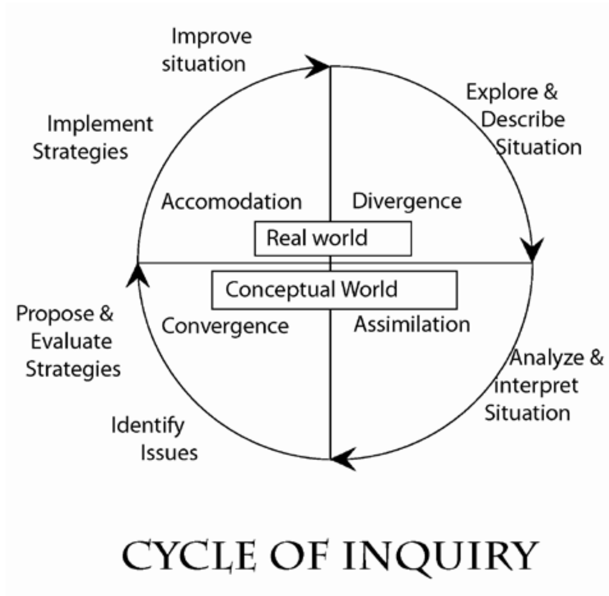

Figure 5. Illustration of the four phases of inquiry, including: divergence—exploring and describing the situation, assimilation—analyzing and interpreting the situation, convergence—identifying issues, and proposing and evaluating strategies, and accommodation—implementing strategies and improving the situation.

LEARNING RESOURCES

Learning resources include any resource from which students can learn on their own. Since the invention of the printing press in Germany by Johann Gutenberg in 1436, textbooks have been an important learning resource. When suitable textbooks are not available, many teachers employ a variety of handout materials—including those they developed, as well as handouts developed by others—in their place. I vividly recall a colleague at another institution informing me he liked the first (1980) edition of my Turfgrass Management book so much that he photocopied several chapters for distribution to his students!

Today, an enormous array of learning resources is available online. These occur in a variety of forms, including advertisements, technical articles, case studies, instructional modules, and PowerPoint slide sets. Online learning resources have one very important advantage over other types; they can be hyperlinked to a course Web site for easy access. And even if one does not provide a link to these resources, students can often locate them by themselves when searching the Web. One type of online learning resource that offers tremendous potential for enhanced learning of information and concepts, including very complex ones, is the instructional module.

Instructional Modules

Web-based instructional modules are composed of hyperlinked Web pages—that is, HTML documents—that are typically organized in a linear series (Figure 6). The individual pages or documents may be text, text with inserted illustrations and/or photographs, or primarily illustrations or photographs with accompanying narrative text. Additionally, they will have navigation icons, usually at the bottom of the document, that the viewer can mouse click in order to move to the next document, or back to the previous document, in the series. Instructional modules are the Web equivalent of a PowerPoint slide set (although PowerPoint slides can also be uploaded to the Web), except that the viewer reads the narration in place of a teacher providing it, and the viewer also controls the pace, as well as the direction, of movement between documents. But the movement from one document to another is not limited to the forward and backward directions, as hyperlinks can be made to enable the viewer to move in many directions, that is, between many different documents. For example, specific words within the narrative text can be made to serve as anchors for direct linkage to another document. These links can be made by inserting the appropriate HTML language within the document, usually by using a Web editor (e.g., Adobe's Dreamweaver). Thus, a module can be simple if its linkages are limited to those between the documents in a linear series (Figure 1.6), or complex if it employs linkages among many documents, enabling the viewer to move in a variety of directions (Figure 7).

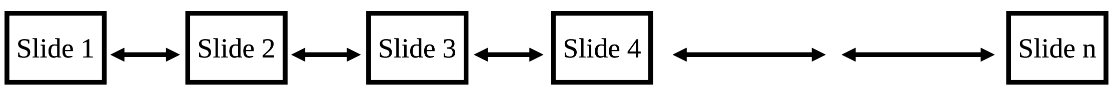

Figure 6. Simple modules: all documents are organized in a linear series, beginning with Slide 1 and ending with Slide n.

Some complex modules employ loops, which are separate sets of documents that can be accessed from the documents within the main path of the module (i.e., a 1^0 loop), or from another loop (i.e., 2^0, 3^0, 4^0, etc. loops). Functionally, there are three types of loops: clarification, preparation, and elaboration. An example of a complex loop-imbedded module is "Annual bluegrass physiology and culture," which can be accessed at the following URL: http://turfgrass.cas.psu.edu/education/turgeon/Modules/10_AnnualBluegrass/Annual_Bluegrass_Module/1.1%20Intro.html

Clarification loops are designed to provide simplified coverage of complex concepts for students requiring it. They provide the means by which a complex concept can be broken down into simpler components, covered in a stepwise, systematic fashion, and reassembled, showing how all the components fit together. For example, the decline in shoot and root growth that typically occurs in the summer months in cool-season grasses can be adequately covered for some students with a brief discussion of net photosynthesis and how it is influenced by high rates of photorespiration under high summertime temperatures. Other students may require more detailed and stepwise instruction to understand the processes involved.

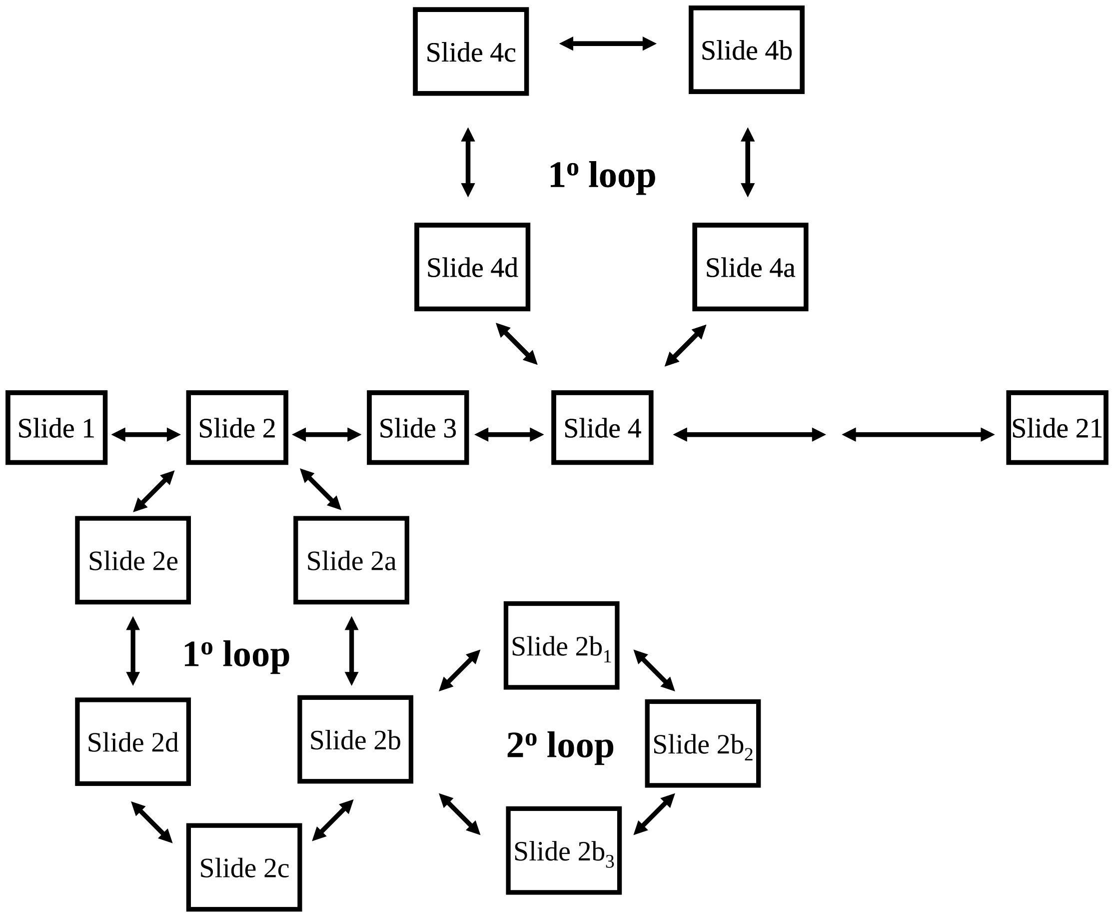

Figure 7. Complex modules: documents are organized in a diverse arrangement with some in the main path of the module and others in loops connected to the main path (1^0 loop) or another loop (2^0 loop).

Preparation loops serve as mini lessons on prerequisite knowledge for students lacking it. Often the material covered in a course of instruction requires knowledge acquired from other courses. For example, a cultural systems course may have several prerequisites listed, including specific biochemistry, genetics, and plant physiology courses. Similarly, an instructional module may cover concepts and processes that require some background knowledge in another subject. In such cases, preparation loops can be developed to enable students to learn the particular piece of physiology, genetics, or biochemistry required to understand the material presented in the module. Such loops not only introduce some students to this material for the first time, but refresh other students who have been exposed to it before but may not have a thorough understanding of it.

Elaboration loops extend the scope of knowledge covered in the linear pathway for students desiring it. They can expand the coverage of a specific topic or approach a qualitative topic in a more quantitative way. For example, certain plant diseases such as dollar spot are mentioned at the late spring recuperative growth development stage in the linear pathway of the annual bluegrass module, some students may wish to pursue dollar spot disease in greater depth than that provided in the linear pathway simply because they find it particularly interesting. In such cases, an elaboration loop can be launched to provide more detailed coverage of this disease, where students can find the name of the pathogenic fungus, favorable conditions, chemical and cultural control, and some pictures to help identify the disease. Also, some students may wish to have a more quantitative treatment of a subject, despite the fact that the instructor is primarily interested in presenting the subject in a largely qualitative fashion. For example, nitrogen fertilization is mentioned briefly at several development stages in the linear pathway. An elaboration loop is developed to provide information on the specific amounts of nitrogen that should be applied at different development stages of annual bluegrass in a putting green.

With the creation and availability of such a multi-looped instructional module, students with none of the prerequisites can understand the concepts and comprehend the topics, providing they take the time necessary to work through the loops and assimilate the material. Meanwhile, students with superior knowledge and industry experiences can skim through the material, focusing only on concepts and topics with which they are not particularly familiar. The shortened linear pathway and the addition of various loops thus provide the means by which students can control the learning pace and the level of instruction, and therefore help individualize students' learning experiences.

Online Teaching

The essence of an online learning experience is interaction. The student interacts with the learning resources, called courseware. Then, he interacts with other students in group exercises. Finally, he interacts with the instructor. The goal in online teaching is to create an appropriate balance among these three forms of interaction.

The courseware includes both instructional modules and problem-based learning exercises. One usually begins with an instructional module in order to acquire some background in a particular subject in preparation for participating in a problem-based exercise; however, the reverse can also happen, i.e., one begins with the problem, then accesses one or more instructional modules in order to be better prepared to solve the problem or case.

Student-to-student interaction occurs in a series of problem-solving exercises. In introductory courses, the problems can be scientific puzzles or technological problems, as shown in Figure 4. In intermediate-level courses, the problems become more complex, and simple cases may be introduced. In advanced and capstone courses, more complex cases are used.

An ideal group for interactive problem-solving exercises has six members. Each group member is assigned a different problem and is asked to post the answer/solution to the group's discussion forum (bulletin board) by a specific date. During the following week or so, each student reads the posts of the other members and posts two questions: challenging the proposed solution, requesting clarification of something in the posting, or requesting a group mate to elaborate on her proposed solution. All students within the group must respond fully to all questions posed them. Finally, based on this exchange, each student revises his original posting in time for the instructor's critique. Thus, every group member is involved—directly or indirectly—in every problem employed in the course.

If the questions are not of sufficient quality or rigor, this presents opportunities for the instructor to step in and "model" proper questioning. This type of intervention invariably leads to better questions and contributes to the students' learning experiences.

While the instructor should be as active as necessary to promote effective learning, his participation in student-instructor interaction should be relatively modest; otherwise, instruction becomes tutoring, requiring more time than is appropriate or productive. Usually, the emphasis on student-courseware interaction and student-student interaction helps to maintain a proper balance among all three types of interaction in an online course. Also, one of the best ways to respond to a student's questions is to respond with another question, encouraging the student to think for herself and find suitable answers independently.

In the online learning environment, the instructor is unable to see his students and read their body language the way this is done in a face-to-face classroom. With a suitable course-management system, however, there is much the instructor can see regarding the activities of his students, the quality of their work, and how well they are learning. This comes from five distinct activities by the instructor; they are: monitoring, motivating, critiquing, intervening, and responding. With respect to *monitoring*, the instructor can observe how often the student logs in, how long he is active, the scores obtained from the quizzes completed with each lesson and on the exams, and the nature and quality of interaction among the students in each of the groups. Where a specific student or group is not performing adequately, the instructor can attempt to *motivate* them to participate more or work more productively. As covered previously, the instructor *critiques* each student's final posting—and *intervenes* as needed to improve the quality of questions—in each of the problem-based exercises. And, the instructor should always respond promptly to students' questions, perhaps by posing another question.

Online students face unique problems. With full-time jobs, family responsibilities, and other demands, satisfactory and timely participation in an online course can be especially challenging for some students. It is the instructor who helps them overcome barriers, motivates them to try their best, and teaches them to properly manage their time through scheduling and rigorously adhering to the schedule. Online teaching is an enormously rewarding experience, especially when an instructor can be effective in helping students satisfactorily complete an online course and make progress in achieving their career goals.

In summary, a compelling case can be made for online education, as it: enables us to *extend our reach* to more students, enhances our *sustainability* as an academic institution as we attempt to reconceptualize and redefine our evolving role in society, and recognizes the *emerging realities* of the 21st century and the opportunities to respond.

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A Rutgers Enabled Career: From Lawn Care Maintenance to Global Lawn and Garden R&D

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My turf career began as a direct result of my father's love of plants. Flowers, lawns, and the whole of the landscape inspired him to start a commercial grounds maintenance business. At that point in time, the weed-eater had just entered the market, but the simple calculator had not. It was, if you can imagine, life before computers, cell phones and much of the technology that we take for granted in 2016. And even the EPA was not in existence yet! While my personal history does not go back as far as that of Dr. George Hammell Cook (1818-1889), it is long enough to have allowed me to collect a few experiences worth sharing. Now closer to the end of my career than the beginning, I have made many friends, experienced more than my share of good memories, and suffered through some hard lessons along the way. Those lessons would have been nice to avoid, but that is unrealistic. Bumps in the road are part of life and the lessons they teach might well be the most valuable. As I look back, I believe I can offer a few career incites for your consideration. Five are offered below.

1) **<u>Self-realization</u>:** ***Do you know how you want your personal and professional life to go in the long term?*** Position yourself with purpose or you will find other forces positioning you. You might get lucky just blowing around in the wind but, more than likely, it will take decision making, diligent application of your skills and a continuous assessment of your progress toward your goals. I knew Cook College would be a great fit for me to learn agronomics and began working toward that goal. Preparation and self – discipline are critical. Ben Franklin said ***"luck is where preparation meets opportunity."*** When prepared, you will recognize good opportunities and have the capability to make the most of them. I recognized I wanted to be an agronomist during my sophomore year in high school. My first opportunity started in a ditch – a *very long ditch* which needed to be cleared of vegetation. My mission was to cut and collect the clippings, and *then* to go back and pick up the trash. After many sweaty hours working harder than I had ever done, I could see my efforts were productive. The result was a safer and vastly improved landscape. What looked like an impossible task at the start, pleased both the commercial account as well as my Dad. My Dad believed in me and I was able to reinforce his trust in my work and capabilities. Still today, I often think about that ditch when a project seems to have no end in sight. **Lesson: You need a plan. End Results Matter, but the means to the end do too!**

2) **<u>People are Important</u>:** **Care** about others and support them whenever possible. See everyone as a person more than an employee, work colleague, stranger, guest, or boss. **Listen** to family, friends, colleagues, and strangers. Pay attention to how others might feel about you, your words, approach, and actions. Your best message will be lost if you bulldoze your way through life. In business circles, one might hear something like "he/she sure got the job done; unfortunately they left a lot of dead bodies behind them in

the process." Listening is a skill that took me a long time to learn and I am still mindful of it every day.

During my junior year at Cook College, my advisor, Dr. Ralph Engel, offered me an opportunity to complete a senior research project. Having never conducted a formal research project before, I knew I needed help. I went to talk with Dr. William Swallow, Professor of Statistics, who willingly took the time to discuss my research project and then enthusiastically offered ongoing advice and computer access. To this day, I have never forgotten how helpful his mentoring was to me. It has led to a life-long appreciation of the utility and necessity of continually practicing the use of statistics. That year, ***Dr. Swallow*** was named the ***Cook College Professor of the Year***. He has since earned many accolades during his career. Amazingly, several years later, we were both faculty members at North Carolina State University. It is a small world as they say. It is even smaller in all things turf! **Lesson: Respect people and be as good to them as you can. Some will be with you for your entire career.**

3) **Community:** Routinely **work professionally with others** on projects, committees, associations, clubs, and in your communities. More can be done shoulder to shoulder with others than you can ever do alone. Today, you have the Rutgers Turf Club. In my day, it was the Horticulture Club. We built paths and completed landscape beautification work across the campus. Two of my club members from those days have worked with me for years at Syngenta. One, Steve Cosky, has an office across the hall from mine today. Avoid the trap of convincing yourself that you don't have time for such things or that you can't see a personal advantage. That is faulty thinking and once the opportunity has passed, another may not come again. **Lesson: Service to others is worthy of your time and it will help to keep you grounded on your blessings and the needs of others.**

4) **Reinvention:** Be prepared to reinvent yourself during the course of your career. The world's pace will only get faster. The expectation of immediate response to text messages and emails is only one measure of the speed required for communications and judgments today. In my journey, there have been at least 8 major career reinventions. Each took a good deal of courage, was not a simple decision, and certainly carried a degree of risk. It has been my good fortune to have worked in R&D, L&G Technical Support, Turf, Flowers, Agriculture, Teaching, Administration, Marketing, and Landscape Maintenance. Rutgers provided me a foundation upon which I could build each time I needed to reinvent myself through the course of my career. I am grateful. Recognize that there are many turf and "turf-related" career possibilities. Be open to opportunities that may not neatly line up in the plan you now have. They can lead to a broader array of knowledge and networking opportunities. **Lesson: You must change with the world and continuously improve your skill set. A change in jobs/roles usually means you have to be a bit different too. Old strengths and work styles are often weaknesses (less appropriate or ineffective) in a new role.**

Turf and Turf Related Career Options

5) **Be a Leader:** Bring others along with you, share the glory generously, but accept responsibility and get the job done. A training that has stuck with me is the task triangle. Be clear when assigning a **task**, listen, and ask questions. **Tend** the task appropriate to its importance and the skills of your employee/team member. Recognize the **trust** being achieved during and through the completion of each task. Celebrate clear accomplishments along the way and in hind-sight. **Lesson: Success builds upon itself. Create a winning team and atmosphere and they will repeatedly perform.**

Marc Luber, Founder, JD Careers Out There, tells us that "success is when you don't know whether you are working or playing." Your path and formula for success will be unique. Take control of your plan each day. I wish you all the Best of Luck, in the sense meant by Ben Franklin!

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The History of the Rutgers Turfgrass Program

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The New Jersey Agricultural Experiment Station (NJAES) has a long and distinguished history of providing turfgrass research, education and service programs in support of the turfgrass industry in the state, region and nation. The first turfgrass evaluation plots were established at the NJAES in 1923 under the leadership of G. W. Musgrave to determine the adaptability of Virginia, Metropolitan, and Washington bentgrass cultivars for golf courses in New Jersey (2, 6). In 1925, additional studies were established by Musgrave and doctoral student H. B. Sprague with financial support from the Green Section of the United States Golf Association (2, 4, 6). Dr. Sprague pioneered the establishment of the turfgrass research and extension program at Rutgers University and served as its first full-time turf faculty member from 1927-1942 (1, 2). He was an incredibly productive researcher who released the first turfgrass cultivar from the NJAES (Raritan velvet bentgrass) in 1940 (2, 3). Sprague was president of the Crop Science Society of America (1960) and the Agronomy Society of America (1964), and published five turf management books over a career that spanned more than 55 years.

After an unusually hot, wet summer in 1928 resulted in extensive turf loss on poorly drained annual bluegrass greens throughout the state, the State of New Jersey appropriated funds to increase the size of the turf research facility at the NJAES. This allowed the emerging turf team of Sprague, Musgrave, E. E. Evaul, T.C. Longnecker, H. R. Cox, and other well-known names on today's Cook Campus such as J.C. Lipman (Lipman Hall), R.L.Starkey (Starkey Apartments), and F.G. Helyar (Helyar House) to greatly expand their research and outreach efforts.

The Rutgers Turfgrass Program has the distinction of having hosted the Nation's first turf field day and first turfgrass conference in 1928 (1). The following year it also initiated a five-day Turf Short Course that educated hundreds of turf managers from throughout the Tri-State Region between 1929 and 1957. After World War II, the turfgrass program at Rutgers was re-established under the leadership of Dr. R.E. Engel, who was hired as a full-time turf faculty member (with a 50% research and 50% extension appointment) to replace H. B. Sprague in 1946. Dr. Engel was a superb researcher whose career at Rutgers spanned more than 40 years and who contributed to many of the basic principles on which turfgrass management is based today. He was instrumental in establishing the 10-week Winter Turf Course in 1946, as well as the two-year Professional Golf Turf Management School in 1962, which over the past 54 years has educated over 5,000 young men and women from throughout the United States and abroad. Dr. Engel also established the golf course visitation service for the metropolitan area, a progenitor of the current USGA Green Section Turf Advisory Service.

In the 1950s, the Rutgers Turfgrass Program really started to expand. Dr. Richard Skogley was hired in 1956 as a full-time turfgrass extension specialist thus freeing up Ralph Engel to concentrate more on research and teaching. The following year Dr. Richard Ilnicki was hired as a research professor in weed science, followed by Dr. John

Meade as the extension weed scientist in turf and ornamentals. Dr. Louis Vasvary soon joined the turf team as the extension turf and ornamentals entomologist, as did Dr. Robert Duell who worked extensively on the management of low maintenance turf for roadsides in the state. In 1960, Dr. Henry Indyk was hired as the extension specialist in turfgrass management when Dr. Skogley left Rutgers to lead the turf program at the University of Rhode Island. Dr. Indyk helped form the Cultivated Sod Association of New Jersey in 1962, the New Jersey Turfgrass Association in 1970, and was the driving force behind the development of the annual New Jersey Turfgrass Expo educational conference and trade show in 1974. He was also a strong advocate for the certification of seeded turfgrass varieties, and initiated a sod certification program in New Jersey, the first of its kind in the United States.

The turfgrass breeding program took a giant step forward when Dr. C. Reed Funk joined the faculty in 1962. At the same time, the University purchased a 200 acre dairy farm in Freehold, NJ to support the new breeding program as well as applied research in cereal crops, forages, and field crops. The first field day was held at the new Plant Science Research and Extension Farm (known as the Adelphia Farm) in 1965. Dr. Funk was a pioneer in turfgrass breeding and was the first full-time cool-season turfgrass breeder in the United States. He helped shape the turfgrass team that is in place today and had an incredibly productive career that spanned more than four decades. Funk is credited with the development of hundreds of cool-season turfgrass cultivars with dramatic improvements in pest and stress tolerance. Many of his germplasm releases, such as 'Manhattan' perennial ryegrass and 'Rebel' tall fescue, are considered landmark cultivars and have served as a foundation for many of the new turf-type cultivars used throughout the world today. His tremendous intellect and keen sense of observation led to many significant discoveries including the development of the first successful method of breeding Kentucky bluegrass by means of intraspecific hybridization, and the discovery that endophytic fungi can impart increased tolerance to major insect pests and enhanced performance for turfgrasses growing under environmental stress. Reed's diverse germplasm collection and improvement programs have revolutionized the turfgrass sod and seed industries throughout the world.

Dr. Philip Halisky joined the turfgrass team in the mid-1960s as a research professor in turfgrass pathology specializing in *Helminthosporium* diseases of cool-season turf. Halisky conducted research and taught in the two-year Professional Golf Turf Management School for over 20 years and was an expert on smut diseases of grasses. By 1980, Rutgers was recognized as a world-leader in turf research and extension. By then, the program had outgrown its research farm on the corner of Dudley Rd. and College Farm Rd., so the entire operation was moved to Horticulture Farm 2 in North Brunswick in 1981. Dr. Bruce Clarke was hired in 1981 to replace Dr. Spence H. Davis, the extension specialist in turf and ornamental pathology. Clarke worked with Dr. Richard H. White, turfgrass physiologist at Rutgers from 1987 to 1992, and the rest of the turfgrass faculty to develop a strategic plan in 1987 that set the stage for hiring ten new faculty over the next two decades including: Dr. James Murphy, extension specialist in turfgrass management (1991), Dr. James White, research professor in endophyte systematics (1995), Dr. Michael Richardson, turfgrass physiologist (1995-1997), Dr. William Meyer, turfgrass breeder (1996), Dr. Faith Belanger, endophyte-grass associations (1998), Dr. Albrecht Koppenhöfer, turfgrass entomologist (1998), Dr. Steven Hart, turfgrass weed scientist (1999-2014), Dr. Bingru Huang, turfgrass stress physiologist (2000), Dr. Stacy Bonos, turfgrass breeder (2001), Dr. Ning Zhang, a research professor working with plant-associated fungi (2009), and Dr. Josh Honig, working in turfgrass molecular genetics (2015). Clarke became the Director of the Rutgers Center for Turfgrass Science in 1993, a position that he still holds.

The Rutgers Center for Turfgrass Science was established in 1991 and currently has 22 faculty, eight adjunct faculty, and more than 50 graduate students, post-doctoral associates, and staff. The core mission of the Turfgrass Center is to generate and disseminate new knowledge and to provide training and education in the turfgrass sciences by fostering internationally recognized, multidisciplinary research, undergraduate, graduate, and continuing professional education and service programs in support of the turfgrass industry. The central theme for turfgrass research in the Center encompasses germplasm enhancement (coordinated by Drs. William Meyer and Stacy Bonos) and turfgrass management (overseen by Dr. James Murphy). Current studies include developing grasses with better stress tolerance and pest resistance, host-endophyte associations; sustainable turf management, chemical and biological control of insects, weeds and diseases to reduce pesticide inputs; management of the annual bluegrass weevil, developing best management practices for foliar and root diseases, and turfgrass response to traffic, soil and low input management.

The breeding team led by Dr. William Meyer and Dr. Stacy Bonos has continued to expand the world famous turfgrass breeding program established by Reed Funk. Since 1996, extensive collection trips to Western and Eastern Europe have generated over 10,000 new germplasm sources for the Rutgers Turfgrass Program (personal communications, W. Meyer) . This has resulted in the largest collection of cool-season turfgrasses in the world. Continuing the germplasm collection and population improvement programs at Rutgers will help ensure a continuous stream of cultivars with improved pest and stress tolerance and exceptional turfgrass quality in the future.

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POSTER PRESENTATIONS

Exploration of the BI-1 Gene as a Quantitative Biomarker for Drought Tolerance Improvement in Turfgrasses

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Decline in turf quality due to drought stress is a major problem in turfgrass management. However, reliable markers that correlate with the quantitative trait of drought tolerance in turfgrass remain elusive for breeding programs. To overcome this bottleneck, discovery of a reliable molecular marker that correlates well with the drought tolerance trait could have a major impact on current efforts to breed improved varieties of creeping bentgrass (*Agrostis stolonifera* L.). Additionally, genetic modification through transformation with genes that can confer heightened stress tolerance may be a useful approach to further improve drought tolerance of creeping bentgrass in the future. The key objective of our project is to test the hypothesis that Bax Inhibitor-1 (BI-1) gene expression levels could be used as a genotyping marker for breeding more drought-tolerant grass species, especially for cool-season turfgrass varieties. In addition, we also would like to test the ability of transgenic expression of AtBI-1 (*Arabidopsis thaliana* BI-1) as a direct means of improving drought tolerance in elite turfgrass varieties in the future. To set the stage for these endeavors, we will present our recent work in characterizing BI-1 gene structure and expression in the model grass *Brachypodium distachyon* (L.) P. Beauv., as well as efforts to overexpress AtBI-1 in this grass species.

Classification of Tall Fescue (*Festuca arundinacea* Schreb.) Cultivars and Collections Using Chloroplast Microsatellite (cpSSR) Markers

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Tall fescue (*Festuca arundinacea* Schreb.) is a major grass species that has been used extensively as a turfgrass. Turf cultivars of tall fescue are highly suitable for home lawns and sports fields due to their superior drought and heat tolerance and fine texture. Tall fescue occurs in three morphotypes: 1) the continental morphotype that occurs from Northern Europe to the Northern Coast of the Mediterranean Sea; 2) a rhizomatous type that occurs on the Iberian Peninsula; and, 3) the Mediterranean type that occurs predominantly in North Africa. The objective of the current study was to determine the genetic relatedness and evolutionary history of tall fescue and some closely related species using chloroplast microsatellite (cpSSR) markers. Chloroplast SSR markers have been utilized in other grasses including *Zea* species, *Agrostis* species*, and Oryza sativa* L. Chloroplast SSR marker PCR primers were developed from the published chloroplast genome of tall fescue. Total genomic DNA was extracted from 104 cultivars and 66 collections of tall fescue along with one cultivar of perennial ryegrass (*Lolium perenne* L.), two accessions of annual ryegrass (*Lolium multiflorum* Lam.), three accessions of tetraploid tall fescue (*Festuca arundinacea* L. var. *glaucescens* Boiss), and two accessions of meadow fescue (*Festuca pratensis* (Huds.) P. Beauv.). Each population was comprised of 16 individuals, and each individual was genotyped using 18 cpSSR markers. Amplicon size was determined by capillary electrophoresis (Applied Biosystems 3500 XL Genetic Analyzer). A total of 85 alleles were identified in the current data set, with 3-8 alleles per locus. A total of 145 haplotypes were identified across all samples, with 109 being private haplotypes (those that only occur in 1 population). The number of haplotypes per population ranged from 1 to 9. Analysis of Molecular Variance (AMOVA) indicated that 58% of the total genetic variation was partitioned among populations, while 42% was partitioned within populations. Of 15,931 inter-population pairwise comparisons, 2873 were not significant ($P \geq 0.05$). The cpSSR dendrogram separated the turf and forage tall fescues, as well as each of the species in the current study; however, there was not clear resolution based on breeding history for the turf-type cultivars compared to previous analyses using nuclear microsatellite (nuSSR) markers. Based on this information, cpSSR markers are not capable of distinguishing different cultivars, but could be useful in determining species and tall fescue morphotype.

Classification of Tall Fescue (*Festuca arundinacea* Schreb.) Using Nuclear Microsatellite (nuSSR) Markers

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Tall fescue (*Festuca arundinacea* Schreb.) is an allohexaploid (2n=6x=42) grass (family Poaceae) that has applications for turf and forage. The native range of hexaploid tall fescue is from northern Europe though North Africa. It occurs in three morphotypes: 1) the continental morphotype, which is most predominant and the type from which most turfgrass cultivars were developed, occurring in northern Europe through Turkey; 2) the Mediterranean morphotype that occurs predominantly in North Africa; and, 3) a rhizomatous morphotype that occurs on the Iberian Peninsula. Reproductive barriers exist between the Mediterranean morphotype and the other morphotypes. The genomic constitution of the continental type is $G_1G_1G_2G_2PP$, with the G_1 and G_2 genomes coming from tetraploid tall fescue (*Festuca arudinacea* var. *glaucescens* Boiss) and the P genome coming from meadow fescue (*Festuca pratensis* (Huds.) P. Beauv.). Since the 1930s and the release of 'Kentucky 31', tall fescue has been widely used as a forage; and since 1981 with the release of 'Rebel', tall fescue has been extensively bred for turf use. Breeding efforts have enhanced its drought and heat tolerance, as well as produced cultivars with fine leaf texture allowing this species to become popular for home lawns and sports fields. The objective of this study was to determine the genetic relatedness between cultivars and collections of tall fescue using nuclear SSR (nuSSR) markers. Samples of 104 tall fescue cultivars and 66 tall fescue collections (16 individual samples to represent each cultivar or collection) were collected from turf plots at Adelphia, NJ, and separated into individual tillers. Tillers were maintained in a greenhouse for later DNA extraction. Perennial ryegrass (*Lolium perenne* L.), annual ryegrass (*Lolium multiflorum* Lam.), tetraploid tall fescue, and meadow fescue were used as outgroups for phylogenetic analysis. These outgroups were grown from seeds distributed from USDA ARS-GRIN. Complete genomic DNA of all samples was extracted with either the Sigma GenElute Plant Genomic DNA Miniprep Kit or the Qiagen DNeasy 96 Plant Kit according to the manufacturer's instructions. 29 nuSSR markers generated a total of 414 polymorphic bands in the samples of the current study. PCR product size from each individual was assessed using capillary electrophoresis (Applied Biosystems 3500 XL Genetic Analyzer). Analysis of Molecular Variance (AMOVA) results indicated that 75% of the genetic diversity was found within populations and 25% was partitioned among populations. A neighbor-joining (NJ) tree was generated using the pairwise Φ_{PT} results from the AMOVA analysis. NJ results showed that turf-type tall fescue cultivars grouped together, as did the forage-types. The collections tended to group by location of origin, and were genetically distinct from each other. 'Rhambler' and 'Sixpoint' were the only two cultivars not distinguishable by the current set of nuSSR markers. Collections showed greater within population diversity than the cultivars, indicating that these collections could be a good source of new and diverse germplasm. Results indicate that this set of SSR markers can be used in the future to fingerprint new cultivars and collections as they are generated or acquired.

Differential Gene Expression of Salt-Stressed Perennial Ryegrass

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The development of turfgrass cultivars that can tolerate salinity while maintaining safe, acceptable quality would result in a community and industry more accepting of voluntary utilization of alternative water sources. Salinity tolerance could involve a number of processes including the regulation or expression of compatible solutes/osmolytes, polyamines, reactive oxygen species, antioxidant defense mechanisms, ion transport and compartmentalization of injurious ions (Mudgal et al., 2010). Unfortunately, current breeding efforts to develop salt tolerant turfgrasses have been slow and the mechanism for salinity tolerance is not fully understood. The goal of this project was to study gene expression of salinity tolerant and susceptible perennial ryegrass (*Lolium perenne* L.) clones by sequencing the transcriptome of salt-stressed and non-stressed leaves.

Two genotypes, S1 – salt tolerant and BS5 – salt sensitive, were selected based on a previous salinity tolerance screening. These genotypes were vegetatively propagated into three replicates and grown under control and salinity stress conditions in a greenhouse using a greenhouse salinity screening technique (Koch and Bonos, 2011). At the onset of salt stress symptoms, leaf tissue samples were cut and immediately flash frozen in liquid nitrogen. RNA was extracted using RNeasy Plant Mini Kit and sequencing libraries were constructed using TruSeq RNA Sample Preparation Kit v2 by Illumina Inc. according to the manufacturer's instructions. Library samples were then run on a MiSeq (Illumina Inc.) benchtop sequencer. The raw reads from all samples were quality-trimmed to retain only high quality reads; To filter out possible fungal (*Epichloe festucae* Leuchtm., Schardl & M.R. Siegel) and *Lolium perenne* organelle (Chloroplast and Mitochondrion) reads, we aligned the trimmed reads to the *Epichloe festucae* genome sequence and to the *Lolium perenne* organelle sequences. The two genotype (S1 and BS5) transcriptomes were assembled separately and then were merged using reciprocal BLAST and CD-HIT (Li and Godzik, 2006). The reads from all samples were separately mapped to the reference transcriptome (50,073 contigs) and the number of reads mapped per contig were counted and used as input to DESeq2, an R/Bioconductor package (Anders and Huber, 2010) which infers differential expression (DE) based on the negative binomial distribution. For this analysis we used a cutoff of 5% to control for false detection rate (FDR, false positives), and considered only genes that had a log2-fold change $\geq\pm2$ and FDR <0.05 to be differentially expressed.

Two thousand two hundred and ninety-six genes were differentially expressed (DE) as a result of salt stress in the S1 genotype (tolerant), while the same comparison in the BS5 genotype resulted in 940 DE genes. The majority of the genes that were strongly upregulated in the salt tolerant genotype S1, were in the dehydrin (or LEA [Late Embryogenesis Abundant]) family of genes including drought acclimating dehydrin WZY2, Dehydrin DHN3, and LEA proteins. LEA proteins are believed to participate in protecting cellular components from dehydration in response to drought, salt or cold tolerance (Vaseva et al., 2011). The dehydrins and LEA proteins were strongly upregulated only in the salt tolerant genotype indicating that the tolerant genotype, through the production of these proteins, may be able to reduce dehydration induced damage or chelate ions, to alleviate the damaging effect of increased ion concentrations (Danyluk et al., 1998). These genes have been found to be produced earlier in tolerant genotypes than susceptible genotypes (Vaseva et al., 2011) (which is what we identified in the research). This suggests that salt tolerant perennial ryegrasses may have a better ability to prevent damage to proteins at the early onset of stress.

In the salt susceptible genotype BS5, several heat shock proteins, beta glucosidase, and cinnamoyl CoA reductase among others were preferentially upregulated. These genes have been associated with stress response in other crops. There were no LEA or dehydrin proteins produced in the susceptible genotype indicating that these genes could potentially be used as markers to screen germplasm for salinity tolerance in perennial ryegrass. We are hopeful that this project will bring us closer to identifying mechanisms involved with salinity tolerance and potentially identify sequence variation that can be used in the future for genomic selection in perennial ryegrass.

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Performance of Fine Fescues Under Abrasive Wear in Different Seasons

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Fine fescues (*Festuca spp.*) are low maintenance grasses with better shade and drought tolerance compared to other cool-season grasses. The wear tolerance of fine fescue is not well understood and the response of fine fescues to wear may vary based on the season. The objective of this study was to evaluate the performance of six fine fescue species under abrasive wear in spring, summer, and autumn, respectively.

This trial used a split-plot design with four replications. Seasonal wear was arranged as four completely random strips within each replication, and ten fine fescue entries were arranged as sub-plots within each wear strip. The four levels of seasonal wear included an untreated control and wear applied in spring (April to June), summer (July to August) or autumn (September to November). The ten fine fescue entries arranged as the subplot factor consisted of 'Aurora Gold' and 'Beacon' hard fescue (*Festuca brevipila* R. Tracey), 'Culumbra II' and 'Radar' Chewings fescue (*Festuca rubra* L. subsp. *fallax* (Tuill.) Nyman), 'Marvel' and 'Garnet' strong creeping red fescue (*Festuca rubra* L. subsp. *rubra*), 'Shoreline' and 'Seabreeze GT' slender creeping red fescue (*Festuca rubra* L. var. subsp. *litoralis* Vasey ex Beal), 'Quatro' sheep fescue (*Festuca ovina* L.) and 'Blueray' blue fescue x hard fescue (*Festuca glauca* Vill. x *Festuca brevipila* R. Tracey). Fine fescue entries were seeded September 2012 on a loam soil in North Brunswick, NJ. The trial was mowed at 6.4 cm and irrigated to avoid drought stress. Pesticides were applied preventatively to control diseases and insects.

Wear treatments were initiated in autumn 2013, and concluded after autumn in 2015. During each season of wear, eight passes (one pass per week; eight passes per year) of the Rutgers Wear Simulator were applied to the corresponding main plot during an 8 week period. Turf quality (1-9; 9 being best turf quality) was visually evaluated monthly from April to November. Uniformity of turf cover (1-9; 9 being most uniform visual appearance), fullness of turf canopy (FTC; 0-100%; 100% being fullest canopy), and leaf bruising (1-9; 9 being no bruising) were visually rated after the final treatment for each wear period (season). Additionally, green cover was measured using digital image analysis at the end of each wear period. Analysis of variance was performed on data using a 2 (control vs wear) x 10 (entries) split-plot design. Fullness of turf canopy and leaf bruising data will be presented in this poster.

As expected, wear had detrimental effects on FTC compared to the untreated controls after all six periods of wear (three seasons over two years). Beacon and Blueray had the greatest FTC after all six wear periods, and Quatro was among the entries with the greatest FTC after 5 of the 6 wear periods. Seabreeze GT had the least FTC after each of 6 wear periods.

The FTC response of fine fescues to wear depended on the entry (interaction) after the spring wear period in year 1 and summer wear period of year two. Beacon and Quatro exhibited excellent tolerance to wear and maintained a FTC that was not different from the untreated control; whereas wear reduced the FTC of other entries. After the four wear periods when entry did not interact with wear, Beacon and Blueray consistently had the greatest FTC.

Leaf bruising caused by wear appeared to be more severe in autumn and summer than spring. Beacon and Blueray were less susceptible to leaf bruising while Radar and Culumbra II were more susceptible to leaf bruising, especially in autumn. The leaf bruising response of some fine fescue entries appeared to vary with seasons; Quatro exhibited the least bruising in autumn but was more susceptible to bruising in summer.

This study will be continued in 2016 and additional statistical analyses will be evaluated for comparing the performance of fine fescues subjected to wear during autumn, spring or summer to better understand the seasonal effect of wear on fine fescue performance.

The Use of Microbes to Enhance Growth and Stress Tolerance in Turfgrasses

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Non-pathogenic microbes play an important role on host plants. These organisms may provide nutrients for hosts, change development and physiology of hosts, and increase host tolerance to abiotic and biotic stresses. In this study, we examined several species of turfgrasses for presence of seed-transmitted bacteria, and evaluated the effects of bacteria on seedling germination, development, and seedling resistance to hypersaline conditions. Sixteen bacterial strains were isolated and two of these, *Bacillus amyloliquefaciens* (ex Fukumoto 1943) Priest et al. 1987 emend. Wang et al. 2008 strain SF2 and *Bacillus pumilus* Meyer and Gottheil 1901 strain SF3 increased seed germination rates and root hair growth under water and hypersaline conditions. Additionally, some of the bacteria inhibited the growth of *Sclerotinia homoeocarpa* F.T. Bennett (Dollar spot disease) and *Rhizoctonia solani* Kuhn (Brown patch disease) on PDA media. We will conduct greenhouse and field tests to evaluate their effects on host resistance to pathogens.

Gene Editing of Creeping Bentgrass to Improve Stress Tolerance and Disease Resistance

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Creeping bentgrass (*Agrostis stolonifera* L.) is one of the most widely used cool-season grass species on golf courses. However, there is not one cultivar of creeping bentgrass that is considered completely resistant to dollar spot disease caused by *Sclerotinia homoeocarpa* F.T. Bennet. Creeping bentgrass is also susceptible to heat and drought stress during summer months. In this project, we use the new CRISPR/Cas (clustered regularly interspaced short palindromic repeats) -associated endonuclease gene editing technology to knock-out disease susceptibility and stress-related genes in creeping bentgrass to improve disease resistance and stress tolerance. Using bioinformatics tools, we have identified EST (expressed sequence tag) sequences for the following three genes that are related to disease and stress susceptibility in creeping bentgrass: *CPK12-like* (*CPKL*), *BONZAI1-like* (*BONL*) and *DREB1C-like* (*DREBL*). We have subsequently cloned the partial cDNAs of these three genes from 'Crenshaw' creeping bentgrass. The CRISPR vectors containing the sgRNA (single guide RNA) sequences to target these genes have been constructed. We have also developed the tissue culture system for Crenshaw creeping bentgrass transformation and are in the process of transforming callus tissues with the CRISPR vectors.

Chemical and Biological Analysis of New Tall Fescue Germplasm for Turf and Pasture Use

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The focus of our work in 2015 was to compare and evaluate microscopy with immunochemistry for the identification of endophytes. This was prompted by concerns over the accuracy of the widely used Agrinostics Immunochemical test kit for endophyte detection. Tall fescue (*Festuca arundinacea* Schreb.) selections can contain the endophyte *Epichloë coenophiala* (Morgan-Jones & W. Gams) C.W. Bacon & Schardl, 2015. We screened 1440 individual tillers from 30 selections of tall fescue, each with 24 plants/selection, for endophyte. Many of the selections (19) contained a mix of endophyte positive and negative plants. We conducted a blind test using plants from the mixed groups for the presence of the endophyte by microscopy. In each and every case, the results from microscopy were identical to the immunochemical test kit results. Nevertheless, both methods have limitations. The test kit is known to cross react with the closely related pathogen *Claviceps purpurea* (Fries) Tulasne and perhaps other species in the Claviceptaceae, whereas microscopy can fail to identify low titer samples containing endophytes, and it may be difficult to distinguish the *Epichloë* hyphae from other similar fungi present in seeds or tillers. Immunochemical screening is the most efficient method when large numbers of tillers or seeds need to be examined.

Evaluation of Hard Fescue (*Festuca brevipila* Tracy) for Summer Patch (*Magnaporthiopsis poae* J. Luo & N. Zhang) Resistance

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Communities and local governments around the country are currently focused on reducing environmental impacts and costs of maintaining recreational and homeowner landscapes. Breeding programs are actively trying to develop turfgrass cultivars with improved performance under low maintenance conditions (which includes reduced pesticides, mowing, fertility and irrigation). Hard fescue (*Festuca brevipila* Tracy) has been identified as a potential candidate species for low maintenance turf areas, due to its excellent drought tolerance, and lower mowing and fertility requirement compared to traditional cool-season grass species such as perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis* L.). However, one of the major weaknesses of this species is its susceptibility to *Magnaporthiopsis poae* J. Luo & N. Zhang, the causal organism of summer patch disease. Summer patch can cause severe damage to a turfgrass stand to the point that complete renovation is required. Summer Patch can be controlled with fungicides; however, pesticide use in low maintenance situations is undesirable.

Sixty-six entries of hard fescue were established in a mowed turf trial in a randomized complete block design at the Rutgers Horticultural Research Farm #2 in North Brunswick, NJ in the fall of 2012. Thirty-five hard fescue selections were established in a mowed spaced-plant trial in a randomized complete block design at the Plant Biology and Pathology Research and Extension Farm in Freehold, NJ in the summer of 2012. The mowed spaced-plant trial was inoculated with oats infected with *Magnaporthioposis poae* under each plant, while the turf trial at North Brunswick was not inoculated. Turf plots and mowed-spaced plants were visually evaluated in the summer months of 2013 and 2014 for summer patch disease severity. Resistance was measured on a visual scale from 1-9 (9= No Symptoms). Significant and consistent differences in summer patch resistance were observed over the two years within each of the trials. Selections that performed well included A10-198, A10-207, and A10-219 with ratings of 6.28, 6.30, and 6.59. Traditional cultivars such as Beacon, and Aurora Gold had the least summer patch resistance with ratings of 3.59 and 3.95. Further research is being conducted to determine the narrow sense heritability of summer patch resistance within the hard fescue species. This information will provide insight into the level of resistance that can be obtained through traditional breeding strategies.

Topdressing with Finer Sands on Velvet Bentgrass Putting Green Turf

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Sand topdressing is commonly applied to golf course putting greens to smooth the surface, dilute thatch, and protect plants from biotic and abiotic stresses. Sands recommended for topdressing primarily contain medium (0.25- to 0.50-mm) and coarse (0.50- to 1.0-mm) particles and are referred to as medium-coarse or coarse-medium sands (first mentioned size class represents the predominant size fraction in the sand). Often coarse particles are too large to easily infiltrate the dense canopies of modern putting green turf and remain on the surface for days after topdressing applications. Interference with mowing and play caused by these remnant particles could be reduced by using topdressing materials with little or no coarse sand. However, removing coarse particles from sand results in finer-texture and more uniform grade, which are thought to increase the potential for negative changes in the physical properties of the developing mat layer.

Recent research has shown that topdressing with sand that contained no coarse particles (i.e., medium-fine sand) dramatically reduced incorporation time and the amount of sand removed by mowing compared to topdressing with medium-coarse sand. Moreover, plots topdressed with either medium-fine or medium-coarse sand had reduced the volumetric water content (VWC) of the surface mat layer and increased water infiltration compared with non-topdressed plots, while the VWC and infiltration of plots topdressed with either medium-fine or medium-coarse sand were similar. Because of this improved turf performance on plots topdressed with medium-fine sand, further evaluation of topdressing with finer-textured sand (removal of both coarse and medium particles) would be useful.

A field trial was initiated in 2014 to assess the effects of eliminating coarse and medium particles from topdressing sand on the resulting performance of putting green turf. The trial was arranged as a randomized complete block design with 5 treatments and 8 blocks. Locally available medium-coarse, medium-fine, fine-medium, and fine sands were applied every 14-d at a rate of 0.3 L m^{-2} from 8 June to 10 Nov. 2014 and 22 May to 6 Nov. 2015. A non-topdressed control was also included. Plots were evaluated for turfgrass quality, turfgrass color, algae infestation, surface penetration using a depth-measuring micrometer, ball roll distance (BRD; Stimpmeter), sand incorporation, sand pick-up in mower clippings, and VWC of the surface 0- to 38-mm. The trial was conducted in North Brunswick, NJ on a 'Greenwich' velvet bentgrass (*Agrostis canina* L.) turf maintained at 2.8-mm. The turf had a 50- to 60-mm deep mat layer overlying a Nixon sandy loam (fine-loamy, mixed, semiactive, mesic Typic Hapludults). Rolling with a 1.2-tonne roller was performed 6-d wk^{-1} to apply compaction associated stresses similar to those that result from golf course traffic. Nitrogen was applied at 4.9 kg ha^{-1} every 14-d and soil pH, P and K were managed based on soil tests. Pests were controlled as needed and irrigation was applied predominantly as hand-watering to maintain moderately-dry conditions.

Topdressing improved turf quality compared with the control on 15 of 16 evaluation dates during 2014 and 12 of 12 evaluation dates during 2015. Turf quality rarely differed among sand sizes during 2014; however, fine and fine-medium sands began to produce better turf quality compared to medium-coarse sand by late-2015. Topdressing with all sands produced darker green turf color on 9 of 16 evaluation dates during 2014 and 3 of 12 dates during 2015. Interestingly, topdressing produced a lighter green turf color on 9 of 12 evaluation dates compared with the control during 2015. Darker green turf color and better turf quality caused by topdressing were most evident when summer stress damaged non-topdressed plots during August and September 2015. Low to moderate outbreaks of algae occurred after periods of extended surface wetness during 2014 and all sands reduced algae compared with the control on 6 of 8 evaluation dates. Topdressing did not affect the low level of algae development that occurred during 2015.

All sands increased resistance to surface penetration compared with the control on all 5 and 6 measurement dates in 2014 and 2015, respectively. Few and small differences in surface penetration were found among sand sizes during both years. Ball roll distance did not differ among sand types during 2014, but the combined effect of all sands (orthogonal contrast) increased BRD compared to the non-topdressed control on 1 of 4 measurement dates during 2014. In 2015, BRD was measured on only one date (21 August; 7-d after a topdressing application); medium-fine, fine-medium, and fine sands increased BRD by 0.4-m compared with the control. Medium-fine, fine-medium, and fine sands typically required only 1 day to incorporate into the turf canopy to an acceptable level; whereas, medium-coarse sand required at least 4 days. Initial analysis of sand pick-up in mower clippings indicated that topdressing with medium-fine, fine-medium, and fine sands resulted in at least 75% less sand removed by mowing the day after topdressing compared to topdressing with coarse-medium sand.

The pooled effect of topdressing reduced the VWC of the surface 0- to 38-mm compared to the control on 2 of 9 and 37 of 37 measurement dates during 2014 and 2015, respectively. Differences in VWC among sand sizes were not evident until mid-November 2014 when fine sand increased VWC compared to the other sands. Differences in VWC among sands were more pronounced during 2015, and the fine sand treatment frequently increased VWC compared to coarser sands. Additionally, the VWC of fine sand plots was not different from the non-topdressed control on 5 of 37 dates.

In summary, removing coarse particles from topdressing (i.e., using medium-fine, fine-medium, and fine sands) dramatically reduced the time required for sand to incorporate; reduced the amount of sand removed by mowing; increased BRD; and improved turf quality compared to topdressing with medium-coarse sand. However, reducing the amount of both coarse and medium particles in topdressing eventually resulted in a wetter surface compared to the coarser topdressing sand plots. This research will be continued to examine the longer-term effects of topdressing particle size on the performance of putting green turf.

Breeding Switchgrass for Cultivation on Reclaimed Mine Lands

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In 2007, the Energy Independence and Security Act mandated that by 2022 transportation fuel sold in the United States must consist of at least 36 billion gallons of fuel from renewable sources. This regulation also requires that a large percentage of the 36 billion gallons be generated from advanced biofuels (i.e. cellulosic ethanol) instead of ethanol derived from corn (*Zea mays* L.). Switchgrass (*Panicum virgatum* L.) is a perennial, warm-season bunchgrass that has been identified by the United States Department of Agriculture as the model biofuel feedstock species. The species is native to most of North America and consists of both upland (UL) and lowland (LL) ecotypes. These ecotypes differ at the genotype and phenotype level, which allows switchgrass to be cultivated in a wide variety of climates and growing conditions.

A major attribute of switchgrass is the ability of the species to produce high levels of biomass yield on marginal lands not suitable for agronomic crop production. To date, a majority of switchgrass research has been conducted on prime farmland, making it difficult to estimate the performance of cultivars on marginal land. Performance of UL and LL ecotypes has been shown to vary widely across different growing conditions with significant cultivar x environment interactions reported for traits such as biomass yield. Therefore, the primary objective of this study was to determine whether selecting plants for traits in prime soils would reflect similar performance when grown in a reclaimed mine land soil. The information gained from this study will be used to select switchgrass lines that can be developed for cellulosic ethanol production on marginal land.

Seventy-five maternal switchgrass lines from Rutgers University and 75 lines from the Cornell switchgrass breeding program were planted in 2013 at one location with prime soil (either Freehold, NJ or Ithaca, NY) and one reclaimed mine land with marginal soil (Philipsburg, PA). Measurements included visually assessing plants for vigor (rating scale of 1 – 10, 1 = very poor growth) and harvesting plants at the end of the growing season for estimation of biomass yield. Vigor scores were used to select a subset of plants from each breeding population for biomass yield determination.

A total of 37 Rutgers lines were selected for harvest; 22 lines were selected for performing well in NJ and PA. The remaining lines consisted of 6 lines that were vigorous in PA, 5 lines that were vigorous in NJ, and 4 lines that performed poorly at both locations. A total of 36 lines were selected and harvested from the Cornell population. Lines harvested included 14 that performed well at both locations, along with 8 lines that were not vigorous at either location, 7 lines that were vigorous in NY, and 7 lines that were vigorous in PA. Significant differences in yield were detected between the prime and marginal sites and among the switchgrass lines evaluated for both the Rutgers and Cornell populations. Biomass yield for the Rutgers lines ranged from 0.33

– 0.86 kg $plant^{-1}$ in NJ and 0.05 – 0.23 kg $plant^{-1}$ in PA and ranged from 0.338-0.796 Kg $plant^{-1}$ in NY and 0.071-0.207 kg $plant^{-1}$ in PA for the Cornell lines. Performance between the ecotypes was similar at each location for both breeding populations. A significant correlation between biomass yield and vigor was detected for both the Rutgers and Cornell lines, but only within each location.

Overall, plant performance of the switchgrass lines (as measured by vigor and yield) was significantly lower at the marginal site in PA compared to the two prime locations in NJ and NY. Based on the correlation analysis, vigor can be used to identify and select new switchgrass germplasm for yield; however, the selection process must be conducted on marginal soils, since not all genotypes that performed well on prime farmland also performed well on marginal soil. Data from the 2015 season has been collected and will be analyzed to confirm the results from 2014.

Sustainable Management of the Annual Bluegrass Weevil

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The annual bluegrass weevil (ABW), *Listronotus maculicollis* Dietz, is a major pest of short-mown turf areas on golf courses (fairways, tees, approaches, collars, greens) in the Mid-Atlantic and Northeast regions of the United States and in the southern parts of Quebec and Ontario in eastern Canada. A combination of high turfgrass quality expectations and a dearth of effective management alternatives often lead to overuse of synthetic insecticides for ABW management. This in turn has led and continues to lead to development of resistance to pyrethroid and other insecticide classes. There is a need to develop a better understanding of the extent and scope of insecticide resistance as a base for optimizing the use and longevity of existing insecticides for ABW management. But there is also a dearth of effective and feasible monitoring techniques and alternative control options for ABW. The overall goal of this project is to optimize existing ABW monitoring methods, develop alternative management strategies, and integrate them in order to achieve significant ABW suppression with reduced chemical input.

Insecticide resistance

At present, the spread of insecticide resistance and cross resistance patterns are mostly unknown. The limited amount of field data available for apparently insecticide-resistant ABW does not even provide a clear picture as to how the efficacy of various insecticide mode-of-actions is affected by resistance. In order to develop better recommendations on (1) how to detect and monitor resistance development, (2) how to prevent insecticide resistance, and (3) how to manage resistant populations it is essential to better understand the degree and scope of resistance (different ABW lifecycle stages, different insecticide modes of action) and mechanisms involved.

Topical bioassays were conducted to determine resistance levels and cross resistance patterns to the major insecticide modes of actions in adult ABW and included the active ingredients bifenthrin (pyrethroid), λ-cyhalothrin (pyrethroid), chlorpyrifos (organophosphate), clothianidin (neonicotinoid), spinosad (spinosyn), indoxacarb (oxadiazine), and chlorantraniliprole (anthranilic diamide). Nine different populations were collected from golf courses throughout southeastern Pennsylvania, New Jersey, southeastern New York, and southwestern Connecticut with different histories of insecticide use and ABW infestation. Six concentrations of the insecticide active ingredients (AI, technical grade) were applied topically (1 µl/adult) using microapplicators. Treated ABW were placed in Petri dishes lined with moist filter paper with food provided. Mortality was evaluated 72 h after treatment and the lethal dose killing 50% of tested individuals (LD_{50}) was determined. Resistance ratios were calculated (RR_{50} = LD_{50} of resistant / LD_{50} of susceptible population) and their significance determined.

The populations collected at Rutgers Horticultural Farm 2 (HF), North Brunswick, NJ and at Pine Brook GC (PB), Manalapan, NJ were determined to be pyrethroid-susceptible. The other populations had various levels of pyrethroids resistance/tolerance, with RR_{50} ranging from 14 to 343 for bifenthrin and 8 to 324 for λ-cyhalothrin. Pyrethroid resistant populations also demonstrated elevated tolerance to chlorpyrifos (RR_{50} 3.3-15.5), clothianidin (RR_{50} 2.9-9.7), and spinosad (RR_{50} 3.0-5.1). Topical assays with indoxacarb and chlorantraniliprole did not yield meaningful dose-response curves due to low mortality for the resistant populations. Different types of assays may need to be employed to study these compounds.

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 the presence of PBO (8-20 fold) and DEF (9-39 fold) which indicates involvement of oxidase and esterase systems as possible resistance mechanisms. DEM had a weak effect on bifenthrin toxicity for most populations. Synergists did not significantly affect chlorpyrifos toxicity in our study.

To determine and compare the level of adult and larval resistance to major insecticide modes of action, selected insecticides of different chemical classes (see above) were tested against susceptible and resistant ABW populations in greenhouse experiments. For adult assays, 10 adults were caged in *Poa annua* pots 2 h before treatments were applied using a Generation III Research sprayer. For larval assays, larval populations were created by caging adults (3 pairs) in containers with established *P. annua* for 1 week to lay eggs. 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 assay types including the topical laboratory test with regard to resistance level (RR_{50}) of the various populations to the different 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). Percent reduction provided by spinosad and indoxacarb differed only between the most resistant 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. Resistance ratios obtained from different assay types were proportionally similar. 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.

Biological/biorational control

Our prior research had demonstrated that entomopathogenic nematodes can provide acceptable control levels of moderate ABW densities but may be overwhelmed by very high densities. In greenhouse and field tests we found that combined application of nematodes and imidacloprid tended to improve nematode efficacy against ABW. Furthermore, split applications of nematodes also tended to improve efficacy with combinations of imidacloprid and split nematode applications providing up to 95% control. Where imidacloprid is already used for white grub control, its combination with split nematode application could be a highly effective option for ABW larval control. We also found that nematodes and their combinations with imidacloprid were similarly effective against pyrethroid-resistant ABW populations thereby offering a viable alternative for the management of insecticide-resistant ABW populations.

Grandevo (8 lbs/ac) (based on bacterium *Chromobacterium subtsugae* strain PRAA4-1 + fermentation products) gave 46% control of susceptible adults and 57% and 39% control of susceptible and resistant larvae, respectively. Venerate (8 fl. oz./acre) (based on heat-killed *Burkholderia* spp. strain A396 bacteria + fermentation products) provided 57% and 49% control of susceptible and resistant adults, respectively, and 33% and 22% control of susceptible and resistant larvae, respectively. Molt-X (22 fl. oz./ac) (based on botanical azadirachtin) 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.

BotaniGard ES (5.75 qt./ac), based on the entomopathogenic fungus *Beauveria bassiana* GHA strain, applied against third and fourth instars was ineffective, whether applied alone or in combination with Merit or Molt-X. BotaniGard was unreliable when applied when densities of overwintered adults peaked (0 - 42%) but interacted synergistically with the pyrethroid-based product Talstar (AI bifenthrin) against resistant adults (72 - 84%). Talstar alone was ineffective (0 - 34%) as was the organophosphate-based product Dursban (AI chlorpyrifos) (0%). 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.

ABW reproductive diapause and key factors affecting its termination

It is assumed that overwintering ABW adults undergo a reproductive diapause. Understanding the factors triggering diapause termination is critical to the timely management of ABW. In order to predict the onset of spring oviposition and the optimal time for insecticide applications it is important to know what environmental conditions are conducive for diapause termination. Our studies to date suggest an egg laying threshold of 8°C with oviposition still very low at 11-13°C, but significantly increasing at 15 and 16°C, peaking at 21-25°. Fewer eggs were laid at a 10:14 Light:Dark (L:D) regime than at 12:12 L:D and 14:10 L:D, but the effect of photoperiod was weaker than that of temperature. Factors affecting induction and termination of diapause still need to be studied.

We tested the response to food, and investigated the effect of temperature, food and cooling period on the development of reproductive organs in ABW. Adults collected from overwintering sites in late October/early November were kept in sterile moist sand at 6/4 °C (Day/night: L:D 10:14) for different lengths of time. Adults were then brought to room temperature (22 °C) and subsamples were dissected weekly for 4 weeks to measure the length of ovary and width of germaria in female adults, and widths of seminal vesicle and accessory glands and diameter of prostate gland in male adults weekly for 4 weeks. Food was essential to the organ development, and the weevil started to feed within 3 days after being transferred to room temperature. However, temperature played a more important role in triggering the termination of reproductive diapause, whereas a cooling period during diapause accelerated and synchronized the diapause termination process. Oviposition also significantly differed under various temperature and photoperiod regimes.

Anything But Barren: Fungal Diversity and Functions in the Pine Barrens

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Pine barrens is a unique ecosystem that has acidic and nutrient-poor soils, where switchgrass (*Panicum virgatum* L.) and other stress tolerant species are dominant understory plants. Our results indicate that grass (Poaceae) roots in the pine barrens ecosystem are one of the major reservoirs of novel fungi with about 47% being undescribed species. Importantly, we observed that *Acidomelania panicicola* (Leotiomycetes), a new genus and species we described from switchgrass in the New Jersey Pine Barrens significantly increases root hair growth of switchgrass and rice plants in acidic and low nutrient conditions. We also described another new genus *Pseudophialophora* (Magnaporthales, Sordariomycetes) that contains several pathogenic species. Naming and description of a number of other new fungal taxa are in progress. In addition, we compared the root fungal community between wild switchgrass from the New Jersey Pine Barrens and cultivated switchgrass in managed farms using both culture and metagenomics methods. A custom pipeline was developed to analyze the Illumina metagenomics data. Both methods suggest that Leotiomycetes are dominant fungi in the switchgrass roots from the nutrient-poor pine barrens soils, while Sordariomycetes are dominant in the roots growing in the rich farm soils. More plant-fungal interaction experiments are being conducted in various conditions in order to test our hypothesis that *Acidomelania* and other similar dark septate endophytes in Leotiomycetes play a role in increasing plant tolerance to abiotic stresses (e.g., low pH, low nutrients, drought) and contribute to improved establishment and persistence in acidic, poor soils. Results from this work will facilitate ecological and evolutionary studies on root-associated fungi.

False Green Kyllinga Control in Cool-Season Grasses

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False green kyllinga (*Kyllinga gracillima* Miq.*)* has become a troublesome weed of landscape and sports turfs in southern New Jersey. Herbicide options to control this weed in cool-season turfs are more limited compared to the options that have adequate safety on warm-season turfs. Greenhouse and field trials were conducted to assess the efficacy of herbicides on false green kyllinga at rates that have safety on cool-season turfs. The greenhouse trial evaluated five herbicides and five herbicide combinations for efficacy on two clones of false green kyllinga collected from two counties in NJ. The field study was initiated on 11 June 2015 on a soccer field in Ocean County, NJ having well established mats of false green kyllinga (87% cover in control plots on 29 Sep. 2015). Repeat applications of halosulfuron, mesotrione and triclopyr, and a single application of imazosulfuron provided 98% or greater control of false green kyllinga in the greenhouse trial. Repeat applications of sulfentrazone and single applications of combination herbicides containing sulfentrazone provided no more than 63% control of false green kyllinga in the greenhouse trial. Halosulfuron and imazosulfuron were the only herbicides that provided commercially acceptable control of false green kyllinga in the field trial. One application of imazosulfuron reduced cover of false green kyllinga to 4% cover by 29 September. Two applications of halosulfuron reduced false green kyllinga cover to 13% by 29 September; whereas, one application of halosulfuron reduced cover of false green kyllinga to 40%. Neither mesotrione, triclopyr nor the combination of these herbicides were effective at suppressing false green kyllinga in the field trial. Sulfentrazone applied at the greatest label rate for cool-season turf and in three of the four herbicide combinations produced some suppression of false green kyllinga (47 to 55% cover on 29 September). Results indicate that imazosulfuron has promise for the control false green kyllinga in cool-season turf; further work is needed to evaluate the consistency of control.

Securing and Expanding the U.S. Hazelnut Industry Through Breeding for Resistance to Eastern Filbert Blight

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The Rutgers Center for Turfgass Science has been supporting the nut tree breeding project at Rutgers University started by Dr. C. Reed Funk since 1996. Recently, we have focused much of our attention on hazelnuts (*Corylus* sp.), as these species are showing great promise for New Jersey and the "Fruit Belt" region of the eastern US. We present here an overview of our collaborative research project with partners at Oregon State University (OSU).

Hazelnuts are a low-input, high-value crop whose demand exceeds current supply. The US is a significant leader in hazelnut breeding and research, yet US production amounts to <5% of the world's crop and most US consumption is from imported nuts. Eastern filbert blight (EFB), caused by the fungus *Anisogramma anomala* (Peck) E. Müller, is devastating to the European hazelnut (*Corylus avellana* L.), on which commercial production depends. Breeding for resistance is complicated by the 2-year life cycle of the pathogen, which includes a 16-month latent period. The European hazelnut ranks fifth in world tree nut production. The world's crop averages 870,000 metric tons/year. At the current grower price of $1.70 per pound (dry, in-shell), the annual value of the crop is $3.26 billion (US dollars). Leading producers are Turkey (68%), Italy (12.6%), US (3.8%), Azerbaijan (3.4%), and the Republic of Georgia (2.8%), with less from Spain, France and Chile. Production areas are in moderate climates near large bodies of water. To meet increasing demand, there are new large-scale plantings in Oregon, Chile, Georgia, and China. European cultivars generally do not tolerate the climate of the Midwest or eastern US, even though wild *C. avellana* is found in a diversity of climates, including very cold regions. The northern limit of the distribution of *C. avellana* extends from 68°N in Norway to Helsinki to the Ural Mountains, exemplifying the adaptive potential of the species. *Corylus avellana* is a diploid (2n = 2x = 22) with a small genome (385 Mb). A linkage map was constructed for the cross OSU 252.146 x OSU 414.062. The genome and transcriptome of 'Jefferson' have been sequenced using Illumina NGS (next generation sequencing) technology and the data mined to develop new markers. A BAC library for 'Jefferson' was fingerprinted.

'Gasaway' source of EFB Resistance. Gasaway was the first *C. avellana* cultivar observed to express a very high level of resistance to EFB. The resistance is conferred by a dominant allele at a single locus (Mehlenbacher et al., 1991). The OSU hazelnut breeding program has combined 'Gasaway' resistance with other desirable traits, and new cultivars and pollenizers have been released and are widely planted. Some cultivars with Gasaway resistance develop EFB in NJ (Molnar et al., 2010; Capik and Molnar, 2012), suggesting the *R*-gene could be breaking down. However, our recent study of a large population of Gasaway-related seedlings segregating for EFB suggests otherwise. In a study of 23 progenies totaling 1,034 trees and segregating for EFB in NJ we found that the expected 1 resistant:1 susceptible segregation model did not hold true. However, when tolerant classes (Rating = 1 and 2; 0-5 scale, with 0 being completely resistant) were included as “resistant”, the proportion of “resistant” trees was 50.3%, fitting the expected model. This also held true for 7 progenies (285 trees) expected to segregate in a 3 resistant:1 susceptible. These results show that the Gasaway *R*-gene continues to provide a useful and predictable level of at least tolerance to EFB. Yet-to-be described modifying genes/factors appear to play a role in the final disease response, and resistant genotypes can be selected. In a broader context, these results also suggest that, despite the presence of EFB on cultivars containing the ‘Gasaway’ *R*-gene in New Jersey, the gene is not “breaking down”, but rather that some cultivars selected as resistant in Oregon may lack the necessary modifying genes for full protection in the eastern US (Molnar et al., 2015).

New Sources of Resistance Continue to be Discovered. From the screening of hundreds of the world’s cultivars, other clonal accessions, and thousands of seedlings from across Europe and the Caucasus, more than 100 accessions resistant to EFB are now at the disposal of breeders (Capik and Molnar, 2012; Capik et al., 2013; Muehlbauer et al., 2014; Sathuvalli et al., 2010, 2011a, 2011b, 2012). Resistant/tolerant *C. avellana* originate from Chile, Estonia, Georgia, Italy, Latvia, Lithuania, Moldova, Poland, Russia, Serbia, Spain, Turkey, and Ukraine. Evaluation of a new seed-based germplasm collection from the Republic of Georgia was completed. From 1,394 plants, from 47 seed lots, we identified 79 resistant individuals (Leadbetter et al. 2015a). These plants provide a wealth of new material for study and use in breeding.

Studying Inheritance of Resistance. Genetic control of new sources of resistance is investigated by subjecting seedlings from controlled crosses (resistant × susceptible) to the EFB fungus through greenhouse inoculations, inoculations under disease-covered structures, and direct field planting in areas of high disease pressure. Real-time PCR is also being utilized. Based on segregation patterns in the offspring we can assess the level of genetic control, and also identify candidates for mapping and use in breeding. At OSU, the following ten individuals showed the 1 resistant:1 susceptible ratio expected if controlled by a single locus with a dominant allele for resistance: seven from Russia (Moscow selections #2, #23, #26, #27, and #37 and Holmskij selections OSU 1187.101 and OSU 1166.119), one from Crimea (OSU 1185.126) and two from other species (*Corylus americana* Walter ‘Winkler’ and *Corylus heterophylla* Fisch. ex Trautv. ‘Ogyoo’). Similarly, a recent study at Rutgers of new sources of resistance from Russia and Crimea yielded similar segregation patterns (Leadbetter et al. 2015b). All of these progenies segregated in a clear bimodal distribution of resistant and highly susceptible trees with few intermediate (tolerant) trees. This indicates control by one (or a few) major genes. Those segregating in a 1 resistant:1 susceptible pattern are likely controlled at a single locus and merit attention for mapping.

Mapping Resistance Genes. EFB resistance from Gasaway is conferred by a dominant allele at a single locus on linkage group 6 (LG6). All recent releases from the OSU hazelnut breeding program carry ‘Gasaway’ resistance. Randomly amplified polymorphic DNA (RAPD) markers 152-800 and 268-580 linked to ‘Gasaway’ resistance continue to be used for marker-assisted selection. Of the ~100 resistant accessions identified, a few are cultivars imported as scions, but the majority are seedling selections from seed lots collected in many countries. In stepwise manner, we have used simple sequence repeat (SSR) markers to map new EFB resistance genes. To date, resistance from ten sources has been mapped. Resistance from Gasaway, the Spanish cultivar Culplà, Serbian cultivars Crvenje and Uebov, and selections OSU 495.072 (southern Russia) and OSU 408.040 (Univ. of Minnesota) maps to the same region on LG6. This is somewhat surprising given the wide geographic origin of these resistant accessions. Resistance from the Spanish cultivar Ratoli, *C. americana* ‘Rush’, and ‘Yoder #5’ (an American-European hybrid) maps to LG7. Resistance from Georgian OSU 759.010 maps to LG2.

Crosses with New Resistance Sources. At Rutgers and OSU, resistant accessions from several new sources have been crossed with susceptible selections and segregation observed in the resulting seedling populations. Additional resistant accessions used at OSU in crosses with susceptible selections in 2014 and 2015 include ‘Amarillo Tardio’ from Chile, selections from Cecil Farris (Michigan), 5 from Holmskij (Russia), 7 from Crimea, and 4 from Turkey. In 2015, crosses were made at Rutgers to study 4 new selections from Poland, with additional crosses with new Turkish, Latvian, Estonian, and Georgian accessions planned for 2016.

SSR-based Diversity Study of U.S. Hazelnut Collection. A large, comprehensive genetic diversity study of European hazelnut is now underway. Previous studies were small in size and fragmented, and used different germplasm and genetic markers. This makes understanding the available body of genetic resources challenging. The combined collections of OSU, USDA-ARS and Rutgers currently include about 700 accessions. At Rutgers, DNA was extracted from 110 EFB-resistant *C. avellana* accessions identified in germplasm screening efforts. At OSU, DNA was extracted from the remaining samples, and added to the DNA samples from Rutgers. Fifty-five simple sequence repeat (SSR) marker primer pairs with high PIC values, few null alleles, and no unexpected allele sizes, are currently being fingerprinted at OSU.

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Assessing the Species Composition of Tall Fescue and Kentucky Bluegrass Mixtures

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Tall fescue (*Festuca arundinacea* Schreb.) and Kentucky bluegrass (*Poa pratensis* L.) cultivars are often seeded as mixtures throughout the cool temperate and transition climatic zones of the United States. The objective of this study was to assess the effect of wear stress on the species composition and performance of mixtures of tall fescue and Kentucky bluegrass. Individual plots of Kentucky bluegrass and tall fescue were seeded at 45 and 436 kg ha^{-1}, respectively, in September 2010 on a loam soil in North Brunswick, NJ. Species mixtures were seeded at 218 and 23 kg ha^{-1} of tall fescue and Kentucky bluegrass, respectively. Wear was applied using the Rutgers Wear Simulator during autumn 2011, 2012, and 2013. Turfgrass quality (1 to 9 scale; 9=best turf quality) was visually rated once per month during the growing season of 2011 through 2014. The species composition of each plot was determined by identifying 24 randomly selected tillers in July 2012 and August 2013 and 2014. Data were analyzed using a 5 x 4 x 2 factorial of Kentucky bluegrass cultivars (no-Kentucky bluegrass, 'Midnight II', 'Blue Note', A05-361, and A05-361), tall fescue cultivars ('Falcon V', 'Mustang 4', 'Justice', and 'Greenkeeper') and wear (no-wear and wear) arranged in a strip plot design with three replications.

As expected, wear reduced turfgrass quality of Kentucky bluegrass and tall fescue. Among tall fescue cultivars, Falcon V, Mustang 4, and Justice exhibited the best turfgrass quality after wear in 2011; additionally, plots containing Kentucky bluegrass had better turfgrass quality compared to plots without Kentucky bluegrass. The turf quality response to wear in 2012 and 2013 depended on the specific combination of tall fescue and Kentucky bluegrass cultivars. Mixing Midnight II and Blue Note Kentucky bluegrass with Greenkeeper tall fescue improved turfgrass quality compared to Greenkeeper alone on both post-wear rating dates in 2012 and 2013. Conversely, mixing A05-361 and A05-344 Kentucky bluegrass with any of the tall fescue cultivars did not improve turfgrass quality compared to the respective tall fescue cultivars alone. Thus, the turf quality of lower quality tall fescue cultivars (Greenkeeper) subjected to traffic is more likely to be better when grown as a mixture with high quality Kentucky bluegrass cultivars (Midnight II or Blue Note).

Analysis of variance indicated that the Kentucky bluegrass factor explained 86, 82 and 82% of the total variation in species composition during 2012, 2013 and 2014, respectively; whereas, the tall fescue factor explained only 1, 2 and 2% during 2012, 2013, and 2014, respectively. The Kentucky bluegrass population was much greater in mixtures that contained Midnight II and Blue Note than A05-361 and A05-344 Kentucky bluegrass across all tall fescue cultivars in all three years. Species population was not affected by tall fescue cultivar in 2012 but Kentucky bluegrass population was greater in Greenkeeper tall fescue compared to other tall fescues in 2013 and 2014. Interestingly, wear during the previous autumn had no effect on species composition during the next summer in any year.

Data from this research suggest that the effect of mixing Kentucky bluegrass with tall fescue on turfgrass quality can be affected by the cultivar of either species. Additionally, the species composition of tall fescue and Kentucky bluegrass mixtures will be more strongly influenced by the Kentucky bluegrass cultivar than the tall fescue cultivar.

Characterization of an *Epichloë festucae* Leuchtm., Schardl, M.R. Siegel Antifungal Protein

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Strong creeping red fescue (*Festuca rubra* subsp. *rubra* L.) is an important low maintenance turfgrass species. Strong creeping red fescue plants are often naturally infected with the fungal endophyte *Epichloë festucae* Leuchtm., Schardl & M.R. Siegel. Endophyte infection confers insect and disease resistance to the host grass. Endophyte-mediated disease resistance is not a general feature of other grass/endophyte interactions and the basis of the disease resistance is currently unknown. An abundantly expressed transcript for a protein similar to a *Penicillium* antifungal protein was recovered from a SOLiD-SAGE transcriptome of *E. festucae*-infected *F. rubra*. Genes similar to the *E. festucae* antifungal protein are not found in most *Epichloë* spp. for which whole genome sequences are available. The uniqueness of the *E. festucae* antifungal gene and its transcript abundance makes it a candidate factor involved in the observed disease resistance of endophyte-infected *F. rubra*. We are currently characterizing the antifungal protein and have partially purified it from apoplastic proteins isolated from endophyte-infected plants. The partially purified protein exhibited antifungal activity against the dollar spot pathogen (*Sclerotinia homoeocarpa* F.T. Bennett) in plate assays. We have expressed the protein in yeast in order to obtain sufficient quantities of the protein for additional antifungal assays. The antifungal protein expressed in yeast also exhibited antifungal activity against the dollar spot pathogen. We are also attempting to knockout the antifungal protein gene in order to assess its effect on dollar spot disease resistance in endophyte-infected turf. Hygromycin-resistant transformants have been recovered and are currently being screened to identify a knockout transformant for further testing.

Evaluation of Nine Tenacity Selected Fine Fescues: Quantifying the Tolerance Levels and Determination of the Absorption and Translocation

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The fine fescues (*Festuca* spp.) are a group of cool-season turfgrasses that are adapted to cool, dry, shaded environments, infertile, acidic soils and drought conditions. These grasses also exhibit better performance under lower fertility levels than other cool-season turfgrasses. These qualities give fine fescues the reputation of being low maintenance grasses. Tenacity (mesotrione) is an HPPD inhibiting herbicide that has good pre- and post-emergent control of many problematic grassy weeds including *Poa annua*. Currently the Tenacity label does not recommend use in fine fescues at seeding. The Rutgers turfgrass breeding program has been working to develop Tenacity tolerant fine fescues where the herbicide can be utilized safely. The current research is an evaluation of three lines of hard fescue (*F. brevipila* Tracey), three lines of Chewings fescue *(F. rubra* L. subsp. *commutata* Gaudin*)* and three lines of strong creeping red fescue *(F. rubra* L. subsp. *rubra)* from Tenacity selected breeding material. These plants were selected based on their previous response from a field application of Tenacity. Plants were established from vegetative plugs and maintained in conetainers in a growth chamber with settings of 25/15 ℃ day/night temperature, 50% humidity, and 10/14 daylight/darkness photoperiod. Herbicide treatments were applied to plants at rates of 0, 17.5, 35, 70, 140, 280, 560, 1121, 2242, 4483, and 8966 grams a.i. ha^{-1} + 0.25% non ionic surfactant. Visual percent injury ratings (0-100 percent with 0 = no injury and 100 = plant death) were taken and means separated using fishers protected LSD. Absorption and translocation were measured in these lines using C^{14} labeled mesotrione applied as foliar and root applications. Hard fescues were the most tolerant species with the lowest foliar absorption. Strong creeping red fescue was the least tolerant species, and had the greatest root translocation of absorbed herbicide. Root uptake was comparable among species; however, variability among lines was observed. Foliar absorption and translocation of radioactivity do not appear to be associated with the differential tolerance levels to mesotrione of the individual lines within each species; however, the differential tolerance of the three fine fescue species was associated with the differences in the foliar and root absorptions we observed. Other factors likely contribute to mesotrione sensitivity, and further studies are needed to better understand the mechanism of increased tolerance.