Symposium Organizing Committee

Stephen Hart, Chair
Bruce B. Clarke
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Thomas Gianfagna
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James White

Proceedings of the Tenth Anniversary Rutgers Turfgrass Symposium

Albrecht Koppenhöfer and Barbara Fitzgerald, Editors

Director’s Opening Remarks:

Welcome to the Tenth Annual Rutgers Turfgrass Symposium. The Symposium Planning Committee, comprised of Steve Hart, Barbara Fitzgerald, Tom Gianfagna, Albrecht Koppenhöfer, and Jim White, has worked hard to make this year’s program a success. They have spent many hours arranging the oral portion of the program as well as the poster session and tonight’s social. Without their diligence and attention to detail, this year’s Symposium would not have been possible. I am sure that I speak for the entire Center Faculty when I congratulate them for a job well done.

The topics presented at this Symposium represent a broad range of basic and applied research conducted at Rutgers and at other institutions. I would like to thank the participants, particularly Dr. C. Reed Funk our keynote speaker, who have agreed to present their research at this year’s meeting. Their expertise and strong commitment to the advancement of turfgrass science is most appreciated.

This is also the tenth anniversary of the Rutgers Center for Turfgrass Science. Since its inception in 1991, Center faculty have worked hard to develop excellent research, undergraduate and graduate teaching, continuing professional education, and outreach programs at Cook College. To support these efforts, the Turfgrass Industry has donated more than 1.5 million dollars during the past 10 years in the form of research grants, student scholarships, equipment, gifts, and buildings. Last year alone, the Turfgrass Industry raised over $750,000 to construct the new Ralph Geiger Turfgrass Education Building at Hort Farm II, provided more than $70,000 in student scholarships and research grants, and raised more than $50,000 for turfgrass research via the Fifth Annual Rutgers Research Golf Classic. We are indeed fortunate to have such committed and generous partners.

In 2000, we were fortunate to attract Dr. Bingru Huang, a new turfgrass physiologist, to the Turfgrass Center. Dr. Huang has expressed an interest in initiating several collaborative research projects with members of the Center to develop turfgrasses with improved performance and stress tolerance. Her efforts will help ensure that the Rutgers Turfgrass Program will continue to serve the turfgrass industry in New Jersey with distinction.

I look forward to the continued expansion of the turfgrass program at Cook College and the exciting opportunities that lie ahead. I hope that you will enjoy the 2001 Turfgrass Symposium and will take advantage of the many benefits that it provides. Your active and enthusiastic participation will help make this year’s Symposium a resounding success.

Sincerely,

Bruce B. Clarke, Director
Center for Turfgrass Science

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TENTH ANNIVERSARY RUTGERS TURFGRASS SYMPOSIUM

Cook College, Rutgers University
January 11-12, 2001
Foran Hall – Room 138

Thursday, January 11, 2001

7:00 – 7:30 PM	Registration
7:30 – 7:40 PM	Welcome and Introduction: **Dr. Bruce Clarke, Director – Center for Turfgrass Science**
7:40 – 8:30 PM	Keynote Address: **Dr. C. Reed Funk** (Department of Plant Science, Rutgers University) *Seventy Years of Turfgrass Improvement at NJAES*
8:30 – 10:00 PM	Wine and Cheese Reception

Friday, January 12, 2001

8:30 – 9:00 AM	**Registration, Coffee and Donuts**
9:00 – 10:00 AM	**SESSION 1: TURFGRASS IMPROVEMENT** (Moderator: Dr. Faith Belanger)
9:00 – 9:20	**Dr. Barbara Zilinskas** (Department of Plant Science, Rutgers University) *Agrobacterium-mediated Transformation of Turfgrasses*
9:20 – 9:40	**Mr. Geng-Yun Zhang** (Department of Plant Science, Rutgers University) *Transformation of Triploid Bermudagrass (Cynodon dactylon x C. transvaalensis, cv. TifEagle) with BADH Gene for Drought Tolerance*
9:40 – 10:00	**Dr. William Meyer** (Department of Plant Science, Rutgers University) *Progress in Breeding for Disease Resistance in Open-Pollinated Cool-Season Turfgrasses*
10:00 – 10:30 AM	**Discussion and Coffee Break**
10:30 – 11:30 AM	**SESSION 2: TURF PHYSIOLOGY** (Moderator: Dr. Chee-kok Chin)
10:30 – 10:50	**Dr. Thomas Gianfagna** (Department of Plant Science, Rutgers University) *The Possible Roles of Alkaloids and Other Natural Products in Insect Resistance and Environmental Stress Tolerance of Turfgrasses*

10:50 – 11:10 **Dr. Bingru Huang** (Department of Plant Science, Rutgers University)
Dealing with Summer Bentgrass Decline: Why and How

11:10 – 11:30 **Dr. James White** (Department of Plant Pathology, Rutgers University)
Studies on the Physiology of Neotyphodium Endophytes

11:30 – 12:00 PM **Discussion and Poster Session**

12:00 – 1:30 PM **Lunch and Poster Session**

1:30 – 2:30 PM **SESSION 3: PEST ECOLOGY AND MANAGEMENT**
(Moderator: Dr. Randy Gaugler)

1:30 – 1:50 **Dr. Rick Brandenburg** (Department of Entomology, North Carolina State University) *The Ecology and Biology of Soil Insect Pests: The Secrets to Success*

1:50 – 2:10 **Dr. Albrecht Koppenhöfer** (Department of Entomology, Rutgers University) *Integrated and Biological White Grub Management*

2:10 – 2:30 **Dr. Donald Kobayashi** (Department of Plant Pathology, Rutgers University) *Bacterial Wilt of Turfgrass*

2:30 – 3:00 PM **Discussion and Coffee Break**

3:00 – 4:00 PM **SESSION 4: TURF MANAGEMENT**
(Moderator: Dr. Richard Hurley)

3:00 – 3:20 **Dr. James Murphy** (Department of Plant Science, Rutgers University)
Creeping Bentgrass Response to Root Zone Mixes in Two Different Environments

3:20 – 3:40 **Dr. Steve Hart** (Department of Plant Science, Rutgers University)
Annual Bluegrass Control and Seedhead Suppression with Ethofumesate

3:40 – 4:00 **Dr. Stephanie Hamel** (Department of Plant Science, Rutgers University)
Early Establishment Turfgrass Response to Phosphorus Amendment of Soils

4:00 – 4:30 PM **Discussion/Closing Remarks**

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Plenary Presentations

Seventy Years of Turfgrass Improvement at the New Jersey Agricultural Experiment Station

C. Reed Funk and William A. Meyer, *Department of Plant Science, Rutgers University*

The genetic improvement of turfgrass was initiated at Rutgers University by H.B. Sprague prior to the second world war. Dr. H.B. Sprague, the world-renowned agronomist at Rutgers, included turfgrass science as one of many areas of accomplishment and activity. He recruited Glenn Burton as a Ph.D. student to assist during the mid 1930's. Dr. Sprague believed that velvet bentgrass offered great potential for turfgrass improvement. It required little or no added fertilizer to produce a fine, dense, very attractive turf in shade or full sun, and at high or low mowing. He developed ‘Raritan’ velvet bentgrass released in 1940. Turfgrass enthusiasts including leading golf course superintendents also cooperated with research personnel of the United States Golf Association and the United States Department of Agriculture at the Arlington Turf Gardens in northern Virginia. This resulted in the development of many vegetatively propagated creeping bentgrasses, ‘Merion’ Kentucky bluegrass, and ‘Meyer’ Zoysiagrass. These productive programs were interrupted by the building of the Pentagon on the Arlington research facility and loss of key personnel to military service or critical jobs in support of the war effort.

Turfgrass extension, teaching, and research was re-established at Rutgers following World War II under the able and energetic leadership of Dr. Ralph Engel and later strengthened by the addition of Dr. Richard Skogley. Dr. Henry Indyk became Extension Specialist in Turfgrass when Dr. Skogley left to lead the Turfgrass Program at the University of Rhode Island. Each was convinced that significant opportunities existed in the development of improved turfgrasses. They and their turfgrass advisory committee recognized that more turfgrass including home lawns, golf courses, sports fields, parks, institutional grounds, and road berms, existed within 100 miles of Rutgers than perhaps any other agricultural research institution in the world. They were aware that our major cool-season turfgrass species were introduced from higher latitude, maritime climates of the British Isles and northwest Europe. These grasses were not well adapted to the hot, humid summers, relatively cold winters, diseases, and insect pests of the mid-Atlantic and transition zones of the USA. This presented a real challenge to turfgrass managers but a great opportunity for genetic improvement. The administration of what is now Cook College agreed and the position was offered in December of 1961 to Reed Funk, a new Ph.D with experience in breeding for salt tolerance at Utah State, alfalfa at Iowa State, and corn at Rutgers. It should be recognized that most turfgrass scientists at that time had received their graduate education in fields other than turfgrass. The startup funding and first year’s budget was $400.00 and part-time use of a university car for germplasm collection. Fortunately, Dr. Ralph Engel provided additional support in turf maintenance. Drs. Engel, Indyk, and Felix Juska at the USDA, agronomists at the United States Golf Association - Green Section, and seed growers in Oregon, Washington and Idaho provided much needed and very useful advice and suggestions.

The turfgrass germplasm collection program started in 1962 has continued to present with thousands of hours spent by turfgrass professionals examining tens of thousands of hectares of old turfs and heavily grazed pastures for elite turfgrass germplasm. Many single plants of Kentucky bluegrass, creeping bentgrass, dryland bentgrass, strong creeping red fescue, Zoysiagrass, bermudagrass, and one clone of centipedegrass had persisted and spread to produce patches of turf as much as 25 meters in diameter. Single plants of perennial ryegrass, Colonial bentgrass, velvet bentgrass, hard fescue, blue fescue, and Chewings fescue occasionally ranged from 1 meter to 4 meters in diameter. These rare plants came from the billions of seeds planted over past decades and contained genes for adaptation to their various environments. A unique, highly apomictic plant of Kentucky bluegrass has the possibility of being released as a new cultivar with most of its seeds producing plants genetically identical to the mother plant. Elite selections of creeping bentgrass, Zoysiagrass, or bermudagrass can be propagated vegetatively to produce a new cultivar. However, plants of sexual, cross-pollinated species including perennial ryegrass, tall fescue, fine fescues, rough bluegrass and seed propagated bentgrasses, zoysiagrasses, and bermudagrasses must be intercrossed with many other elite plants of their species to produce a useful cultivar. Normally, they must also be subjected to many years of population improvement to make them superior to turfgrasses already on the market.

Starting in 1962, a number of attractive plants of perennial ryegrass were found in old turfs near the sheep meadow in Central Park in New York City. Other interesting plants were found in Warinaco Park, Elizabeth, NJ; Paterson Park and Riverside Park in Baltimore, MD; the Colonia and Atlantic City golf courses; and the campus lawn of the University of Maryland, College Park, MD. Evaluation of selected plants in mowed clonal tests, spaced-plant nurseries, and disease screening tests and subsequently as single-plant progenies in closely mowed turf trials showed that the plants thriving in Central Park, New York City had considerable promise. A synthetic of the 16 best performing plants was sent to other locations for testing. It was soon apparent that ‘Manhattan’ had outstanding qualities compared to perennial ryegrasses in commercial use at that time and should be released. This required a decision by the New Jersey Agricultural Experiment Station as to the most appropriate method of making high quality seed of new turfgrass cultivars available to the public. After considerable discussion with leaders in the turfgrass industry, plant breeders at Rutgers and other universities, administrators, officials at the New Jersey Department of Agriculture, and seed certification personnel in New Jersey, Oregon, and Washington, we drafted a proposed release policy. A public meeting of interested parties was held on the turf trials at Rutgers followed by indoor discussion. A number of useful comments and suggestions were made and incorporated, followed by a general agreement of the need for and advantages of restricted release. This would make it feasible for one or more commercial seed companies or groups of seed growers to invest their time, resources and efforts in high quality seed increase by financing grower contracts with the most qualified farmers for seed production, maintaining seed inventories, promotion, and distribution throughout New Jersey, the USA, Canada, and, if appropriate, overseas. Rutgers would concentrate on research involving more effective breeding and evaluation techniques, germplasm collection and enhancement, and cultivar development.

With additional support from the United States Golf Association - Golf Course Superintendents Association of America Research Fund and a slowly increasing royalty stream, turfgrass breeding was gradually expanded. The New Jersey Agricultural Experiment Station also provided a technician in 1967. After Bill Siebels left, William K. Dickson accepted this position in September, 1968. Ronald F. Bara was promoted to this position in October, 1986 when Bill Dickson became Farm Supervisor at Horticultural Farm II. Ron Bara had served as a soft money technician. Other soft money technicians who have made many contributions to the turfgrass breeding program include Dirk Smith, Melissa Mohr, Chrissy Kubik, Jennifer Johnson-Cicalese, Janice Bara, Suichang Sun, and Joseph Clark. Capable, productive graduate students included Sang Joo Han, G.W. Pepin, Michael Dale, Kevin McVeigh, Bangalore Phaneendranath, William K. Dickson, Greg Mazur, David Kopec, Richard Hurley, Jennifer Johnson-Cicalese, Suichang Sun, Melodee Kemp (now Melodee Fraser), Jane Breen, Nancy Shih-Ying Lee, Stacy Bonos, Thomas Molnar, Gengyun (George) Zhang, Eric Watkins, and Yuanhong Han. Graduate students assisting Dr. Ralph Engel on his creeping bentgrass program included Phil Catron, Richard Rathjens, and Charles Kupat. Post-docs included Karen Plumley, David Huff, Cuong

Lam, Qin Yue, Haibo Liu, Richard Wang, Beth Baikan, David Thompson, Shyamali Hiranthi Samaranayake, Ponaka Reddy, Mike Lee, John Lindstrom, David Zaurov, Mohamed K. Ahmad, and Dhanonjoy Saha. Secretaries included Dorothy Rule, Aida Bianca, and Barbara Smith. Significant contributions were made by many members of the Rutgers faculty. They included Ralph Engel, Henry Indyk, Richard Skogley, Thomas Gianfagna, Qin Yue, Michael Richardson, James Murphy, Richard White, Joseph Heckman, Stephen Hart, Gojko Jelenkovic, Barbara Zilinskas, Faith Belanger, Marshall Bergen, Richard Buckley, Tseh An Chen, Bruce Clarke, James White, Richard Ilnicki, John Meade, Robert Duell, Philip Halisky, Joseph Peterson, Sami Ahmad, Herb Streu, Albrecht Koppenhöfer, Randy Gaugler, Cecil Still, John Sacalis, David Huff, and Chee-kok Chin.

We were all delighted to have Dr. William A. Meyer take over direction of turfgrass breeding in April 1996. He gave the program new energy, leadership, enthusiasm, and abilities. He has brought it to a new level of productivity and stature.

Much of the labor supporting the Turfgrass Breeding Program was provided by people operating the farms, greenhouses, and laboratories. These included Edward Visinski, Lester Matthews, Raymond Schaaf, William Dickson, Joseph Clarke, Conrad Bussey, Charles Dreyling, Michael Reynolds, Alan Habiak, Jim Schumacher, Dennis Haines, Glenn Tappen, Joseph Florentine, Bill Messeroll, John Messeroll, and John Lepucki. There have been numerous hourly student employees who have made special contributions in developing and often publishing their own research projects and performing other critical research. These include Bruce Johnson, William Boyd, Wayne Leydsman, Cara Johnson, David Funk, Carol Jean Petersen, Christine Constantelos, Bonnie Adams, Robert R. Peterson, Richard Schmit, Jennifer Johnson-Cicalese, Ronald Bara, Joseph Clark, Betsy Clark, Mary Beth Ruh, David Park, Allan Wolford, Dwayne Wolford, Wayne Park, Randy Wolford, Thomas Molnar, Thomas Hardy, Michelle Da Costa, Jennifer Carson, Greg Mazur, David Kopec, Jeffrey Adams, Bob Glennon, M.P. Asokan, Marie Williams, M.K. Ahmad, Janice Budny Bara, Nicholas Bachar, Roger Lee, Lora Betts, Kathi Hoffman Knight, Ghorban Niroomand, Eugene Szerszen, Anita Szerszen, Charles C. Kupatt, Jr., David Dougan, Bruce Attavian, Srinivasa Govindarajan, Jeffrey Seidenstein, Marie Williams, Pedro Perdomo, Dominick Stanzione, Ivan Payne, Gwyneth Mansue, Carrie Mansue, Kenneth Yourstone, James O'Connor and many others. They have gone on to productive careers in science, teaching, business, service, and other professions.

The effects of fungal endophytes in enhancing turfgrass performance and resistance to many harmful insects became apparent on the Rutgers University turfgrass field trials following research by Drs. Charles Bacon in Georgia and Ron Prestidge and associates in New Zealand. Scientists at Rutgers led and/or participated in studies that found that endophytic fungi are associated with many instances of enhanced turfgrass performance of perennial ryegrasses, tall fescues, Chewings fescues, hard fescues, blue fescues, and strong creeping red fescues. They showed an association between the presence of endophytic fungi and enhanced resistance to sod webworms, chinch bugs, and billbugs; improved summer performance and fall recovery; and resistance to crabgrass invasion in tall fescue and perennial ryegrass. They found that endophytic fungi were associated with resistance to chinch bugs and the dollarspot disease in many species of fine fescues. They subsequently developed many useful perennial ryegrasses and fescues with endophyte-enhanced performance.

In order to continue Rutgers leadership in endophyte research, Drs. Faith Belanger, James White, Michael Richardson, Thomas Gianfagna, Qin Yue, Cecil Still, and John Sacalis were hired or encouraged to do basic studies on endophyte biology and turfgrass-endophyte interactions. Assisted by a number of very capable graduate students and post-doctoral research scientists, these faculty members have made and continue to make many outstanding discoveries and contributions. Rutgers has the best and most productive program in the world on endophyte research in relation to turfgrass improvement.

Rutgers scientists working with endophytes since 1982 include: Laurel Hendrickson Lewis, Emilia Timpo, Philip Halisky, Robert Tate, Dhanonjoy Saha, Joseph Peterson, Robert Duell, Bruce Clarke, Darcy Furier, Jennifer Johnson-Cicalese, Suichang Sun, Richard White, David Huff, James Murphy, Margaret Secks, Sitheswary Logendra, Paula Newton, Lora Betts, Faith Belanger, Cuong K. Lam, Sami Ahmad, Sukhir K. Grewal, Haibo Liu, James White, Ponaka V. Reddy, Srinivara Govindarajan, Marshall Bergen, George Balady, Melinda Moy, Ray Sullivan, Bruce Clarke, Lane Treadway, Karen Plumley, Melissa Mohr, Michelle Da Costa, Thomas Molnar, Gengyun Zhang, David Zaurov, Richard Hurley, Jane Breen, Joseph Heckman, Tseh An Chen, John Sacalis, Cecil Still, Thomas Gianfagna, Qin Yue, William A. Meyer, Dirk Smith, Ronald Bara, Stacy Bonos, Greg Mazur, Eric Watkins, John Linstrom, Herb Streu, William K. Dickson, Beth Baikan, Mike Li, Louis Vasvary, and Reed Funk.

Bentgrasses

Many golf courses and other fine turf areas developed during the late 1800's and the first few decades of the 1900's were seeded with fine fescues and South German mixed bentgrass. The latter was harvested from roadsides and non-tilled farmlands in central Europe and included varying percentages of Colonial, creeping, dryland, and velvet bentgrasses. Recent collections from that region show that these bentgrasses were poorly adapted to New Jersey and other regions with hot, humid summers. It is apparent that only a few of the best plants survived to produce large patches of turf. The most attractive of the creeping bentgrasses were selected, evaluated and became the vegetatively propagated cultivars and much of the foundation of current breeding programs. Dr. Ralph Engel with the assistance of Alexander Radko of the USGA Green Section collected many promising creeping bentgrasses and established a large replicated test at Rutgers in October, 1962. By this time, ‘Penncross’, a three clone synthetic developed at Penn State, was becoming widely accepted reducing the need for vegetatively propagated bentgrasses. Professor Engel continued his lifelong interest in fine turf and his collection and evaluation program with financial support from Golf Course Superintendents Associations in New Jersey, Long Island, and the New York City metropolitan area. Many superintendents and USGA Green Section agronomists assisted in these germplasm collections and their financial support helped provide assistantships for Phil Catron, Richard Rathjens, and Charles Kupat. The cultivars ‘Cobra’ (Engel et al., 1994) and ‘Viper’ were developed from this program in cooperation with International Seeds, Inc. (now Cebeco International Seeds). As Dr. Engel was nearing retirement, Drs. Richard Hurley and Reed Funk initiated a new bentgrass improvement program directed primarily for cultivars useful on putting greens. They selected over 1,000 creeping bentgrass plants from dozens of old golf courses in New Jersey, New York, Pennsylvania, California, and Arizona between 1981 and 1985. After clonal evaluation in New Jersey and Oregon, 203 plants were selected to produce ‘Southshore’ (Hurley et al., 1990) released in 1992. ‘Lofts L-93' was also developed from this program after extensive testing and population improvement.

The opportunity to substantially increase the bentgrass breeding program at Rutgers was one of the primary incentives used to attract Dr. William A. Meyer to New Jersey. He is assisted by Dr. Karen Plumley, Dr. James Murphy, Pieter den Haan, Stacy Bonos, Ronald Bara, William Dickson, and Dirk Smith. Bridget Meyer, Anita Szersen, and Gengyun Zhang have also assisted in germplasm collection. They are making excellent progress in the genetic improvement of velvet, creeping, and Colonial bentgrass. Dr. Meyer and his team is also working with and assisting Drs. Faith Belanger, Barbara Zilinskas, and Tseh An Chen in their development of transgenic bentgrasses with herbicide resistance, stress tolerance, and disease resistance. The future is indeed bright for bentgrass breeding.

Turf-type Perennial Ryegrasses

'Manhattan' (Funk et al., 1969) released in 1967 proved to be a landmark cultivar which significantly enhanced the usefulness of perennial ryegrass for turf. Its success caused a number of plant breeding institutions throughout the world to redirect their programs to the development of improved turf-type ryegrasses. Manhattan and other germplasm sources developed at Rutgers have been used in many breeding programs in North America and Europe. Manhattan and the Kentucky bluegrass hybridization program gave considerable international recognition to the Rutgers program. It also convinced our administrators that the program was worthy of the support of a full-time technician and a graduate assistantship. 'Manhattan II' (Funk et al., 1984) was developed jointly with Pure-Seed Testing, and the Manhattan Ryegrass Growers Association. It was released in 1983 to replace Manhattan in the USA. However, the excellent wear tolerance and winter performance of the original Manhattan has encouraged mangers of European soccer fields to continue its widespread use.

Continuing germplasm collection and population improvement programs at Rutgers and elsewhere have resulted in a continued stream of better performing cultivars widely used in North America, Europe, Japan, eastern Asia, and Australia. Seed production of turf-type ryegrasses in the USA exceeded 200 million pounds in the year 2000. With each new National Turfgrass Evaluation Program (NTEP) trial, the best performing cultivars of the previous test usually end up mostly on the second page of the new test only 4 or 5 years later. This documents the effectiveness of the continued population improvement programs. They involve many cycles of phenotypic and genotypic selection and population backcrossing. Each cycle of improvement builds on the achievements of all previous cycles in these cross-pollinated species.

The occurrence of gray leafspot, a new disease on many ryegrass turfs, presents another challenge to turfgrass breeders. Fortunately, genes for resistance have been found in new germplasm collections made in eastern Europe by Dr. Meyer and his associates. These resistant plants have been crossed and backcrossed with the best plants from Rutgers and already combine good turf performance with genetic resistance to gray leafspot and other diseases.

Tall Fescue

Tall fescue is native to Europe and parts of Africa. It is best adapted to the hot, dry summer climates surrounding much of the Mediterranean Sea. The selection of 'Kentucky 31' and its release in the early 1940's initiated its widespread use throughout the warm, humid transition zone of the USA and the Mediterranean climates of California and Oregon. Natural selection of the best-adapted plants occurred over many decades on seed from Europe planted on a hillside pasture in Kentucky. Only plants able to survive the environmental stresses, diseases, and insect pests of this hot, humid location were able to produce multiple generations of seedlings. This concentrated the genetic factors for better adaptation to this new environment. Plants selected from this pasture were used as the parental germplasm of Kentucky 31. It rapidly became widely used for reducing soil erosion, providing forage, and as a deep-rooted, heat tolerant turfgrass.

Many turfgrass scientists recognized the useful qualities of tall fescue but also the need to overcome its limitations as a high quality turfgrass. An extensive germplasm collection effort covering many thousands of hectares of old turfs throughout the USA located a few attractive tall fescue plants that had persisted and spread to produce attractive turfs from 1 to over 5 meters in diameter. Their appearance and the history of the turfs indicated that they likely originated from seed sources brought from Europe many decades earlier. After evaluation in mowed clonal trials and spaced-plant nurseries, the best performing plants were intercrossed and single-plant progenies were seeded in turf trials mowed at 2 cm. Plots of Kentucky 31 and other cultivars were unable to persist under these conditions of frequent close mowing and were soon replaced by weeds. The best appearing plants were then selected from the best surviving progenies to initiate another cycle of selection. Additional germplasm was added as it became available from the continuing collection effort. A few promising plants selected from trispecies hybrids of perennial ryegrass, meadow fescue, and tall fescue developed at the U.S. Regional Pasture Research Laboratory, University Park, PA were included.

‘Rebel’ tall fescue (Funk et al., 1981) was released in 1980 following eighteen years of plant selection and population improvement. Rebel is considered a landmark cultivar being the first of a new class of turf-type tall fescues with finer leaves, greater density, a slower rate of vertical growth, better shade tolerance, a brighter darker-green color, improved wear resistance, and greater persistence under close mowing. Rebel and subsequent turf-type tall fescue cultivars and enhanced germplasms developed at Rutgers have contributed to most improved turf-type tall fescues.

Data from NTEP tests show continuing improvements in overall turf performance in tall fescue cultivars. Many new tall fescues are consistently outperforming cultivars available only 4 or 5 years earlier. A substantial percentage of these best performing new cultivars come directly from the Rutgers turfgrass breeding program and from companies working jointly with Rutgers (Table 1).

Fine Fescues

Fine fescues include strong creeping red, Chewings, hard, blue, and slender creeping fescues. As a group, they have fine, bristle-like leaves and the ability to produce a dense, fine-textured turf tolerant of medium-low soil fertility, moderately acid soils, moderate shade, tree root competition, and cold winters. They do not tolerate high nitrogen fertility, flooding, or poor drainage especially during warm to hot weather. Continuing genetic improvements make each of these species more useful to homeowners and turfgrass professionals.

Professor Robert W. Duell and his students including Richard Schmidt and Tony Palazzo showed great interest in fine fescues and participated in the development of ‘Banner’ Chewings fescue (Duell et al., 1976) released in 1985 and ‘Fortress’ strong creeping red fescue. Forty-five plants selected from old turfs in New Jersey, Maryland, Pennsylvania, and New York were used as the parents of Banner after extensive clonal evaluation and progeny testing. Continued collection and population improvement is continuing to improve Chewings, hard, blue, and strong creeping red fescues. Cultivars developed by or with the participation of Rutgers continue to perform very well in NTEP tests (Table 1). Screening of large seedling populations under short-daylength, cool-temperature winter greenhouse conditions has been effective in selecting plants with greater disease resistance, higher tiller number, a slower rate of vertical leaf elongation, and a richer, brighter dark-green color. Similar results have been obtained in screening large seedling populations of tall fescue and perennial ryegrass.

Rough Bluegrass

Rough bluegrass (*Poa trivialis* L.) is adapted to cool, moist, shaded environments but rapidly becomes dormant in summer when subjected to heat and drought. Improved turf-type cultivars are often very useful for the winter overseeding of dormant warm-season turfgrasses in the southern USA and similar regions. However, this species is frequently a weed in many cool-season turfs in temperate climates. Drs. Henry Indyk and Ralph Engel collected a number of attractive plants from old turfs of New Jersey and surrounding states. William K. Dickson, a technician on the turfgrass breeding team, was eager to see if he could make a high quality turfgrass cultivar from these and other collections. Intercrosses of the best performing selections were subjected to cycles of phenotypic recurrent selection and produced the cultivar ‘Sabre’ (Dickson et al., 1980) released in 1977. Sabre quickly became accepted in the winter overseeding market and eventually encouraged other turfgrass breeders to develop turf-type rough bluegrasses. Richard Hurley, studying for his Ph.D. degree at Rutgers, chose to work with rough bluegrass for his thesis project. A new, expanded germplasm collection and population improvement program resulted in the development of ‘Laser’ (Hurley et al., 1990) and subsequently ‘Winterplay’ and ‘Laser II’.

Kentucky Bluegrass

Kentucky bluegrass (*Poa pratensis* L.) is a major lawn-type turfgrass for much of the northern two thirds of the USA and southern Canada. The land growing Kentucky bluegrass lawns has a higher real estate value than the land growing any of our major crop plants such as corn or soybeans! Its high and variable chromosome number ($2n = 28$ to 153), its complex embryology, and its apomictic method of reproduction presents great challenges and opportunities to plant breeders. Apomixis is a method of asexual reproduction in which nearly all seeds of a highly apomictic plant produce plants genetically identical to their maternal parent. Sperm nuclei from the pollen merely fertilize the polar nuclei to produce the endosperm. Apomixis is a nearly ideal method of producing a hybrid cultivar. It can retain maximum hybrid vigor through future cycles of seed increase and eliminates the disadvantages of vegetative propagation. The development and use of apomictic reproduction in major crops such as wheat, rice, soybeans, cotton, tree crops, and alfalfa would substantially increase world production of food, forage, and fiber.

Kentucky bluegrass has great genetic diversity and is naturalized throughout virtually all temperate regions of the world. The species includes germplasm with virtually every characteristic wanted in an ideal lawngrass. However, turfgrass breeders have yet to develop a rapid, efficient breeding method to recombine all of these characteristics into one interbreeding population or apomictic cultivar.

Currently, the Rutgers turfgrass breeding group is expanding its Kentucky bluegrass improvement program. Capable, energetic young scientists will produce both better cultivars and more effective breeding and evaluation techniques.

Table 1. Top Performing Cultivars in Recent National Turfgrass Evaluation Tests

National Tall Fescue - 1992 - Final Report 1993-95 - 92 entries

1.* Jaguar 3**
3. Houndog V
4. Genesis
5. Pride
8. Coyote
9. Finelawn Petite
10. Pixie

National Tall Fescue - 1996 - Progress Report 1999 - 129 entries

1. Rembrandt
2. Millennium
4. Plantation
5. Masterpiece
7. Coyote
9. Shenandoah II
10. Jaguar 3

National Perennial Ryegrass - 1994 - Final Report 1995-98 - 96 entries

1. Palmer III
2. Brightstar II
3. Secretariat
4. Calypso II
5. Premier II
7. Monterey

National Kentucky Bluegrass - 1995 - Progress Report 1999

Medium-High Input - 103 entries

1. Midnight
5. Princeton P-105

Low input - 21 entries

2. Eagleton
4. Caliber
10. Dragon

National Bentgrass - 1993 - Final Report - 1994-97

Putting Green - 28 entries

1. L-93
8. Southshore

Fairway -Tee - 21 entries

4. Southshore

National Bentgrass - 1998 - Progress Report - 1999

Putting Green - 29 entries

7. L-93

Fairway - Tee

1. L-93

National Fineleaf Fescue test - 1998 - Progress Report 1999 - 79 entries

Strong Creeping Red Fescues - 22 entries

1. Jasper II
2. SRX-52961
3. ABT-CR-2
4. ABT-CR-3
5. PST- EFL
6. ISI FRR-7
7. ISI FRR-5
8. PST-4FR
9. Florentine
10. Pathfinder

Chewings Fescues - 24 entries

1. Longfellow II
2. Ambassador
3. ABT-CHW-3
4. ABT-CHW-2
5. Intrigue
6. Treasure
8. Pick FRC A-93
9. Shadow II
10. Pick FRC 4-92

Hard Fescues - 24 entries

1. 4001
2. ABT-HF1
3. Oxford
4. SRX 3961
6. Nordic
7. ABT-HF2
9. ISI FL-12
10. ISI Fl-11

* Numbers refer to rank in turf quality averaged over all locations.
**All varieties listed were developed with participation of the Rutgers Turfgrass breeding program.

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Agrobacterium-mediated Transformation of Turfgrasses

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Traditionally, turfgrass improvement has depended on conventional breeding programs. Developments in biotechnology are now permitting those involved in turfgrass improvement to use genetic materials from many sources, rather than from those species which are sexually compatible. Genetic transformation of turfgrasses has been achieved in several laboratories using direct gene transfer, including protoplast transformation and particle bombardment. Our laboratory has developed an alternative method that relies on *Agrobacterium tumefaciens* to mediate gene transfer. Commonly used in transformation of numerous dicotyledonous crops, this bacterium has more recently been demonstrated to be capable of mediating gene transfer to monocots as well, provided several modifications are made to improve transformation efficiency. We have developed protocols to achieve highly efficient transformation of creeping bentgrass. *Agrobacterium*-mediated transformation offers several advantages over direct gene transfer including stable integration of the transgene without rearrangement of host or transgene DNA; preferential integration of the transgene into transcriptionally active regions of the genome; ability to transfer large segments of DNA; and integration of low numbers of gene copies into the plant genome.

Our laboratory has since been attempting to define tissue culture and transformation parameters for *Agrobacterium*-mediated gene transfer to other turfgrass species. To date, we have worked with velvet bentgrass, tall fescue and Kentucky bluegrass with various degrees of success. Major challenges include the ability to produce embryogenic callus that maintains regenerabilty through the transformation and selection process. We have experimented with many genotypes, and as expected, the ease of initiating and propagating callus from mature seeds, followed by successfully transformation and regeneration, varies greatly with the cultivar and species. Most promising to date are velvet bentgrass SR7200 and tall fescue cultivars 1471 and Rebel Jr.

Transformation of Triploid Bermudagrass (*Cynodon dactylon* x *C. transvaalensis*, cv. TifEagle) with BADH Gene for Drought Tolerance

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Many high quality bermudagrass cultivars used on golf courses and sport fields are vegetatively propagated sterile triploids, which are clonal cultivars and originally came from F_1 hybrid progeny of *Cynodon dactylon* (2n=4x=36) x *C. transvaalensis* (2n=2x=18). The clonal characteristic of triploid bermudagrasses would allow them to be used as good targets for biotechnical improvement, because any good transformant could potentially result in a new cultivar. In addition, their sterile property makes less environmental impact. We have used particle bombardment to transform BADH gene into stolon node-derived calli from the bermudagrass variety, TifEagle. Cotransformation method was used to transform Hyg resistance gene and BADH gene into the callus, which were driven by rice actin promoter and maize ubiquitin promoter, respectively. After screening and regeneration on 200mg/L Hyg added medium, 58 Hyg resistant transgenic plants, which came from 82 different Hyg resistant callus lines, were obtained. PCR assay identified 26 transgenic lines contained BADH gene. Northern blot indicated the normal transcription of BADH gene in some transgenic lines. Drought tolerant test in the green house showed that drought tolerance of 5 transgenic lines was significantly better than the control.

Progress in Breeding for Disease Resistance in Open-Pollinated Cool-Season Turfgrasses

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The Rutgers turfgrass breeding project has plant improvement programs in the following open-pollinated turfgrass species: perennial ryegrass (*Lolium perenne*), tall fescue (*Festuca arundinacea*), Chewings fescue (*F. rubra* spp. *commutata*), strong creeping red fescue (*F. rubra* spp. *rubra*), hard fescue (*F. brevipilia*), blue fescue (*F. glauca*), creeping bentgrass (*Agrostis stolonifera*), Colonial bentgrass (*A. tenuis*) and velvet bentgrass (*A. canina* spp. *canina*), tufted hairgrass *(Deschampsia caespitosa*) and Junegrass (*Koeleria cristata*). This paper will discuss some of the most significant progress during the past four years.

In perennial ryegrass an epidemic of gray leaf spot (*Pyricularia grisea*) occurred in the fall of 2000 on the new seeding of perennial ryegrasses at Adelphia, NJ. Most of the older commercial cultivars were seriously damaged. Some new germplasm sources were found to show very good to excellent resistance. These new sources are being increased for harvest in the summer of 2001.

In the 1999 National Turfgrass Evaluation Trial (NTEP) at Hort Farm II, North Brunswick, NJ, some of the new perennial ryegrass cultivars recently released from the breeding program at Rutgers showed good resistance to crown rust (*Puccinia coronata*) compared to older varieties which were highly susceptible. Similar improvements were found on some of these new cultivars for resistance to dollar spot (*Sclerotinia homoeocarpa*). Most of the newly released cultivars are showing improved resistance to leaf spot (*Dreschlera siccans*) and brown patch (*Rhizoctonia solani*). Further improvements in perennial ryegrass are needed for resistance to brown patch and red thread (*Laetisaria fuciformis*).

Much progress has been made in tall fescue for resistance to leaf spot (*D. dictyoides*) and gray leaf spot. The new tall fescue seeding at Adelphia, NJ, this fall was located next to the perennial ryegrass trial that was devastated by gray leaf spot. >Kentucky 31' and >Torpedo= were significantly damaged by gray leaf spot. Many of the improved commercial cultivars and new experimentals showed very good resistance to gray leaf spot. There were some commercial and experimental tall fescues that had improved resistance to leaf spot in this trial that was trafficked during establishment with a roller.

Brown patch is the most serious disease of tall fescue in most of the use areas. There has been gradual slow progress made in the improvement of resistance to brown patch in tall fescue. This past summer some of the new experimental semi-dwarf cultivars with improved density showed improved resistance to brown patch compared to commercial cultivars. As the density increases in these new cultivars, there must be a concurrent increase in the brown patch resistance.

The improvements in level of leaf spot (*D. dictyoides*) resistance in Chewings, strong creeping and hard fescues has gradually improved with each cycle of selection. Results from progeny evaluations this fall indicate that further improvements are possible. Resistance to dollar spot in these three fine fescue species has been enhanced by the presence of the *Epichloe* endophyte. Some of the new Chewings, hard, and strong creeping red fescues in the 1998 NTEP showed improved resistance to dollar spot.

In Ph. D. thesis studies done by Stacy Bonos, she found a very small percentage (2%) of 500 creeping bentgrasses collected from old turf areas with improved resistance to dollar spot. These new sources of resistance are now being incorporated into the creeping bentgrass breeding program at Rutgers.

Many collections of velvet and Colonial bentgrass from old putting greens and fairways have shown improved resistance to dollar spot. Many of the velvet bentgrass collections from the Northeastern US have shown improved resistance to brown patch. In a large screening project for resistance to brown patch in colonial bentgrasses, only 25 single lines out of 9,500 showed improved resistance to brown patch. These new sources of resistance to brown patch in Colonial bentgrass are being increased for harvest in the summer of 2001. Brown patch is presently the most serious disease in closely mown Colonial bentgrass in New Jersey.

The above are some highlights of the progress being made to date to improve the disease resistance in these open-pollinated cool-season turfgrasses. There are still many opportunities to make further improvements in all of the turfgrass species.

The Possible Roles of Alkaloids and Other Natural Products in Insect Resistance and Environmental Stress Tolerance of Turfgrasses

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Endophyte-infected turfgrasses often exhibit superior resistance to insects and disease and may be more tolerant of environmental stress. Turfgrasses that contain endophytes may require fewer pesticide treatments, and usually maintain their appearance longer during periods of drought and heat stress. Insect resistance of endophyte-infected (E+) grasses has been correlated with the production of alkaloids. Peramine, ergovaline, and lolitrem B reduce insect feeding and survival, and these compounds are not produced by endophyte-free (E–) grasses.

We analyzed the alkaloid content of ryegrasses collected in Poland, focusing on six selections, each representing a different taxonomic group, as determined by Jim White's lab using DNA sequencing data. We are interested in determining if there may be useful endophytes in these selections, and if the different taxonomic groups also have different alkaloid profiles. All of the selections from each taxonomic group produce significant levels of peramine. There were, however, notable differences in lolitrem B and ergovaline levels. One of the most interesting of the ryegrass selections is 9576. It is a low lolitrem B producer, has undetectable levels (less than 5 ng/g) of ergovaline, but moderate levels of peramine. This should be a good candidate for producing ryegrass genotypes that are safe for grazing animals, but are still insect resistant. Lolitrem B and ergovaline are harmful to mammals and may be responsible in part for the various toxic syndromes affecting grazing animals that feed on E+ grasses. Peramine, however, is reported to have little affect on mammals.

There are other lines of defense against insects that may also be enhanced in E+ grasses. Some insects locate a suitable host by identifying and following the volatile organic compounds (VOCs) that are emitted by plants. VOCs, however, may also play a role in the repulsion of insects or in the attraction of insect predators. We have characterized the VOC profiles from tall fescue. The major volatile compounds from intact leaves are nonanal and 3-hexen-1-ol acetate at 25°C. Cut leaves at 25°C, however, produce predominantly 3-hexen-1-ol acetate and very little nonanal. At 34°C the production of 3-hexen-1-ol acetate is completely inhibited, and nonanal is the predominant VOC. There are also temperature dependent shifts in the monoterpene profiles. 3-hexen-1-ol acetate has been reported to attract Colorado potato beetles and cabbage rootfly in some plants. In other plants it attracts insect predators.

We have analyzed the VOCs from two selections of tufted hairgrass (*Deschampsia caespitosa*), one billbug susceptible and the other billbug resistant. The major VOC from the billbug resistant plant is 3-hexen-1-ol acetate. The susceptible type also produces this compound but only at 1% of the levels found in the resistant plant. Does this compound repel or inhibit billbug feeding?

Several acyclic monoterpenes were identified from both types, but the levels were significantly higher in the susceptible types. Linalool, also produced in much higher amounts in the susceptible type, is a hydroxylated monoterpene that is produced by plants in response to insect damage, and serves as an attractant to predators of plant pests. The susceptible type seems to have activated its defense mechanisms producing linalool and higher levels of monoterpenes. Unfortunately, there were apparently no insect predators around because in the field there was significant billbug injury to this plant.

Vitamin E is an important anti-oxidant and may play a role in environmental stress tolerance. We measured the vitamin E content of five fine fescue selections for which we have endophyte-free and endophyte-infected clones. Vitamin E content varied with both genotype and the presence of endophyte. Selections 23 and 33 had the highest vitamin E content and both of these plants are Chewings fescues. The three strong creeping red fescues (SCR) all had less than one-half the vitamin E levels of the Chewings types. Endophyte-infected plants generally had higher levels of vitamin E than endophyte-free plants, but there was a significant interaction with variety. The Chewings 33 and SCR 28 varieties produced significantly more vitamin E in the presence of the endophyte, but the other varieties showed no effect of endophyte on vitamin E content.

Dealing with Summer Bentgrass Decline: Why and How

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Creeping bentgrass (*Agrostis palustris*), a cool-season grass, grows vigorously in cool weather during spring and fall. During summer months, new root production slows, root dieback occurs, and shoot growth declines, leading to thin turf canopy. This problem has been called summer bentgrass decline (SBD). SBD is a common problem of creeping bentgrass greens in the transition zone states. Many factors could contribute to SBD, including abiotic factors such as high temperature, high relative humidity, excessive soil moisture, poor air movement and soil aeration and biotic factors as disease infection.

Over the years, there has been much confusion about whether SBD is a disease problem. Recent research has found that high soil temperature is the most critical factor controlling bentgrass decline. Exposing roots of creeping bentgrass to high soil temperature while maintaining shoots at the optimum air temperature reduced shoot and root growth; in contrast, lowering soil temperature from a supraoptimal level to an optimal level while exposing shoots to high air temperature increased turf and root growth to the level similar as plants grown at optimal air and soil temperatures.

Under cool conditions, bentgrass plants are able to maintain a balanced photosynthesis and respiration and thus adequate carbohydrate storage. However, under high temperature conditions, photosynthesis rate declines while respiration rate increases. Carbohydrate depletion may occur during prolonged hot summer, which could eventually lead to death of shoots and roots. SBD could also involve changes in other physiological factors associated with high temperature stress. Under high temperature conditions, root growth stops before shoot growth is affected. The death of roots initiates the decline of shoot growth, which might result from high temperature-labile processes in the roots. Roots are the primary sites of cytokinin synthesis and supply shoots with cytokinins, which are sensitive to high soil temperatures. Our studies found that cytokinin level in both leaves and roots of creeping bentgrass decreased at high soil temperature, but increased when cytokinin was applied to the root zone. These results suggest that the inhibition of cytokinin biosynthesis in roots could contribute to decline in shoot and root growth and cytokinin application to the root-zone could help suppress SBD.

An integrated management program that can reduce soil temperature, encourage root activity, promote carbohydrate accumulation, and control diseases will help prevent or control bentgrass decline during summer.

Studies on the Physiology of *Neotyphodium* Endophytes

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Neotyphodium endophytes and teleomorphs in the genus *Epichloë* are classified in the family Clavicipitaceae (Ascomycetes) along with *Balansia*, *Claviceps*, *Cordyceps*, and *Hyperdermium.* One evolutionary lineage of this family of fungi has evolved as biotrophic symbionts of grasses. The graminicolous Clavicipitaceae comprise a monophyletic group of fungi that are epibionts and endophytes. Several species of the genera *Balansia, Claviceps,* and *Epichloë* have evolved endophytism. Many of these endophytes have proven to have potential in the improvement of the hardiness of turf grasses. Because of the apparent natural importance of endophytes in grasses, we have helped to develop the Turf Center's research program targeted at evaluation of the beneficial features of endophytes and their utilization in improvement of plant performance.

Recently we have shown that many of the asymptomatic *Neotyphodium* endophytes egress from plants to form a superficial network of mycelium (epiphyllous nets) on surfaces of the leaf blades. This is significant because: 1) epiphyllous nets provide an opportunity for endophytes to spread from plant to plant via conidia produced epiphyllously, 2) the epiphyllous stage may provide the mechanism whereby parasexual hybridization occurs between *Neotyphodium* endophytes, and 3) epiphyllous nets increase resistance of grass leaves to leaf infecting fungi through niche exclusion. We have begun to screen grasses to identify endophytes that possess epiphyllous stages in perennial ryegrass. We hope to utilize these endophytes to improve resistance of perennial ryegrass to fungal pathogens.

Over the last several years we have developed a study of the secreted proteins of endophytes under the strategy that these proteins may interact with plants and impact on plant tissues or physiology. As a result of this effort we identified a protein produced by endophytes that acts as a phytochelator, causing the precipitation of molybdate from solution. We are continuing to characterize this phytochelator because of its potential role in making endophyte-infected grasses more tolerant to heavy metal contaminated soils.

We are also working toward developing novel non-toxic endophytes for turf grasses. We are taking two approaches to achieve this goal: 1) selection of natural non-producers of toxins; 2) and genetic improvement of endophytes by disruption of genes in the toxin pathways. Toward this goal we are currently evaluating the presence of the DMAT (dimethylallyltryptophane) synthase gene in various endophytes. This gene plays a key role in production of the toxic ergot alkaloids. We are also exploring additional genes that may be targeted to detoxify strains of endophytes.

The Ecology and Biology of Soil Insect Pests: The Secrets of Success

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The demands of society and regulatory agencies to develop environmentally and economically sound pest management programs often challenge our knowledge of pest biology and ecology. Several of the newer insecticide chemistries also require more specific timing of application relative to insect pest development and this makes a working knowledge of pest biology even more critical. Current research on the Oriental beetle grub, a new pest in the Southeast, utilizes a pheromone developed at Cornell University. This trapping program has documented a widespread abundance of this pest as well as a slightly different timing of its life cycle as compared to its close relative and established pest, the Japanese beetle. Additional research on the tunneling behavior of mole crickets has determined that the behavior of insects in the soil also plays a significant role in management success. Tawny mole crickets create “Y” shaped tunnels that appear to be advantageous to feeding behavior as well as providing means of escape from predators. Research also indicates mole crickets have the ability to detect and avoid a variety of control agents. This apparent repellency allows mole crickets to avoid exposure to insecticides and biological pesticides and reduces effectiveness. Mole crickets also prefer to oviposit in sites with specific soil characteristics thus enabling us to target areas with early season management strategies.

Integrated and Biological White Grub Management

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A complex of white grub species are the major turfgrass insect pest in the northeastern United States. While the Japanese beetle, *Popillia japonica*, has until recently been regarded as the key species, recent studies have shown that other white grub species are becoming more important in turfgrass. The Oriental beetle, *Exomala orientalis*, has become the most important white grub species in New Jersey and some neighboring areas. Other important species include the European chafer, *Rhizotrogus majalis*, and the Asiatic garden beetle, *Maladera castanea*.

Entomopathogenic nematodes offer an environmentally safe alternative to chemical insecticides in the management of white grubs. Nematode efficacy in the field, however, has been variable. Some of this variability may be caused by the variability in nematode susceptibility among white grub species and the three larval stages, and differences in pathogenicity to different white grub species among nematode species. We have conducted laboratory and greenhouse experiments to determine these interactions. In laboratory experiments 1^{st} and 2^{nd} instars of the Oriental beetle were more susceptible to the nematode *Heterorhabditis bacteriophora* than 3^{rd} instars. In the Japanese beetle there was only a trend for susceptibility to decrease with advancing larval development. A greenhouse experiment confirmed our observation for the Oriental beetle. White grub species had a strong effect on efficacy of several nematode species in laboratory and greenhouse experiments. Generally, the Japanese beetle was the most susceptible white grub species. A general separation of the remaining species was not possible because the ranking of nematode species differed among white grub species. For example, *Steinernema* spec. (isolated from Japanese and Oriental beetle larvae in NJ) was highly pathogenic to Japanese beetle, Oriental beetle, European chafer, and Asiatic garden beetle, but its performance in Northern masked chafer larvae was mediocre.

We have continued research on the synergism between nematodes and neonicotinoid insecticides. In previous studies we had found a synergistic interaction between the neonicotinoid imidacloprid and *H. bacteriophora* and *S. glaseri* in 5 white grub species including the Oriental beetle. In recent experiments with the Oriental beetle, we have expanded our observations on synergism to the entomopathogenic nematodes *H. megidis* and *H. marelatus* in greenhouse studies and also confirmed the synergism for *H. bacteriophora* under field conditions. Our studies also showed that a new neonicotinoid, thiamethoxam, was a weaker nematode synergist than imidacloprid. Finally, we have conducted a field experiment to test whether it is possible to initiate epizootics of natural nematode populations in natural white grub populations with applications of imidacloprid against 3^{rd} instar white grubs. While we observed a decrease in white grub populations and increase in nematode-infected white grubs 3 weeks after imidacloprid application, we were not able to show an increase in nematode populations in soil samples at 3 and 5 weeks after treatment. Whether this lack of response in the nematode populations was due to extremely dry soil conditions during a critical period of the experiment can only be speculated at this time.

Bacterial Wilt of Turfgrass

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Bacterial wilt is a disease affecting annual bluegrass and is caused by *Xanthomonas campestris* pv. *poae*. Although the disease was first described nearly 20 years ago, little has been described about the causal agent in terms of mechanisms of pathogenesis, its life cycle, or its host range. Recently, unconfirmed outbreaks of bacterial wilt have been reported in the northeastern United States. These outbreaks are potentially more problematic since they are reported to affect bentgrass, which is a turfgrass species that does not normally serve as host to the disease. To better understand the pathogen and the disease it causes, we have initiated a project to define pathogenicity factors in *X. campestris* pv. *poae*. Characterization of these factors in *X. campestris* pv. *poae* are expected to bring insight into the disease, help to evaluate specificities of pathogen host range, and provide methods to design specific probes for diagnostics and studies on the ecological behavior of the bacterium.

Creeping Bentgrass Response to Root Zone Mixes in Two Different Environments

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The suitability of root zone mixtures for turfgrass growth is commonly evaluated by laboratory testing of soil physical properties, and is frequently based on United States Golf Association sponsored research initiated in the 1950's. Initial soil physical properties are measured in the laboratory and used as a critical estimate of future performance in the field. Limited information is available; however, regarding changes in soil physical properties of root zone mixtures as turf matures on recently constructed golf putting greens.

The objectives addressed in this report include,

1. Determination of initial laboratory soil physical properties (K_{sat}, porosity, bulk density) of root zone mixtures differing in amendment source,
2. Determination of soil physical properties of root zone mixtures collected from field plots of the same materials,
3. Quantification of the changes in field soil physical properties from the initial laboratory results, and
4. Assessment of the impact of field soil physical properties on turf performance.

Physical property changes occurred in root zone mixtures within two growing seasons after turf establishment in the field. K_{sat} and air-filled porosity of the mixtures decreased, whereas, capillary porosity increased. The presence of roots in root zone samples was likely responsible for the shift in pore size distribution; however, other, not yet, identified factors may also contribute.

Plots having an average seasonal turf quality rating of 7 and higher (9=best) were associated with a laboratory measurement of root zone capillary porosity of 25% or greater. Capillary porosity of root zone samples collected from these same field plots 1999 was 27% and higher. Thus, higher turf quality has been observed on root zone mixtures that possess higher water holding capacity.

Saturated hydraulic conductivity (K_{sat}) of field samples has decreased for all root zone treatments compared to the initial K_{sat} value measured in the laboratory; however, amendment root zone treatments had K_{sat} values greater than 30 cm/hour (12 inches/hour). It should be noted that air encapsulation in root zone samples was minimized before the measurement of K_{sat} in these tests. Thus, the K_{sat} values reported appear rather high compared to those values reported by commercial laboratories. See 1998 summary of research reported in Atlanta for more information on this issue.

Microenvironment influenced rooting response within two growing seasons; less root mass was observed in the enclosed (lower) microenvironment. Lower root mass in the enclosed microenvironment was associated with higher bulk density and lower total porosity in the root zone. Changes in soil physical properties will continue to be monitored. It is expected that changes in soil physical properties will continue. These changes may be important for long term performance of bentgrass grown as putting green turf.

Annual Bluegrass Control and Seedhead Suppression with Ethofumesate

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Field Experiments were conducted in 2000 at the Rutgers University Experimental Horticultural Farm II in New Brunswick, NJ and the Riverton Golf Country Club in Riverton, NJ to evaluate spring and summer applications of ethofumesate for control of annual bluegrass and seedhead suppression in golf course fairways. At Horticultural Farm II the creeping bentgrass (*Agrostis palustris* 'Southshore') fairway was infested with approximately 40-50% annual bluegrass while the fairway at Riverton was an unknown variety of perennial ryegrass (*Lolium perenne)* infested with approximately 50-60% annual bluegrass. Ethofumesate applications were initiated on March 30 and April 2 at Riverton and Horticultural Farm II, respectively, and applied 8 times at approximately 3-4 week intervals throughout the spring and summer. The ethofumesate treatments consisted of two applications at 0.75 lb ai/A followed by six applications at 0.5, 0.38 or 0 lb/A, or 8 applications applied at 0.5 or 0.38 lb/A. One application of 0.5 lb/A paclobutrazol, applied in early May, was also evaluated for control of annual bluegrass. In the seedhead suppression experiment, single and sequential applications of ethofumesate were applied at 1.5, 1.0 or 0.75 lb/A, while single and sequential applications of ethephon were applied at 0.75 lb/A. A single application of mefluidide at 0.12 lb/A was included as a standard comparison. All ethofumesate applications were applied with 4.8 kg/h of urea, using a CO_2 backpack sprayer delivering 80 GPA.

In the seed head suppression study, a single application of ethofumesate provided 69-75% seed head suppression 7 WAT. Increasing the rate of ethofumesate did not significantly increase seed head suppression. However, applying a sequential application of ethofumesate increased seedhead suppression by 10-20%. Single and sequential applications of ethephon provided 76 and 86% seed head suppression, respectively. Mefluidide provided 96% seed head suppression at 4 WAT but seed head suppression fell to 73% at 7 WAT.

In the annual bluegrass control study at Riverton, annual bluegrass populations in check plots declined 25% by June, stabilized in the summer, and increased back to spring levels in late September. Two applications of ethofumesate at 0.75, 0.5, and 0.38 lb/A provided 45-55, 42, and 16% reductions in annual bluegrass populations by June. Summer applications of ethofumesate did not further reduce annual bluegrass populations. A single application of paclobutrazol reduced annual bluegrass populations by 52% by June. By late September annual bluegrass populations increased in all treatments, but the extent of this increase was less in the ethofumesate treatments than in the untreated check and the pacobutrazol treatment.

At Horticultural Farm II, annual bluegrass populations in the check plots remained stable throughout the spring and summer. Two applications of ethofumesate at 0.75, 0.5, and 0.38 lb/A provided 18-22, 18, and 9% reductions in annual bluegrass populations by June. Summer applications of ethofumesate did not further reduce annual bluegrass populations. Turf quality of bentgrass in the ethofumesate treatments remained equal to the untreated check, regardless of ethofumesate rate or number of applications. A single application of paclobutrazol reduced annual bluegrass populations 25% by June. In late September annual bluegrass populations increased in all treatments and equaled levels observed in early spring.

Early Establishment Turfgrass Response to Phosphorus Amendment of Soils

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Turfgrass establishment in response to P fertilization was studied in the greenhouse, on 24 New Jersey soils. The soil test P levels had a wide range: 6 mg kg^{-1} to 1238 mg kg^{-1} Mehlich-3 P, and the relationship to relative growth of three species of turfgrass was examined using Cate-Nelson analysis. This method determines soil test critical levels, above which a crop response is not expected. Height responses were used to calculate relative growth (height of unfertilized control turf divided by height of P fertilized turf, and multiplying by 100 to convert to percentage). Mehlich-1 (M1), Mehlich-3 (M3), and Bray soil test extractants were used to determine critical levels of soil test P on three cool season grasses: Kentucky bluegrass var. Midnight (*Poa pratensis* L.) (KB), tall fescue var. Coronado (*Festuca arundinacea* Schreb) (TF), and perennial rye var. BFP Elite (*Lolium perenne* L.) (PR). To obtain 90% relative growth, the turfgrasses required the soil test P levels listed in Table 1. The examination of the critical Mehlich-3 P to Al ratio, also expressed in Table 1, appears to be another suitable predictor of P needed for turfgrass establishment.

Of the three species, KB was the most sensitive to low soil test P levels and exhibited the greatest responses to P fertilization. Our results indicate that these three species have different soil test critical levels and therefore different requirements for P fertilization. To ensure rapid establishment of KB, TF, or PR, they should receive P fertilizer when planted on soils that test below their respective soil test P critical levels. On soils that test above the critical level, turfgrass may be established without the application of P fertilizer.

Using soil testing to direct P fertilization onto soils that would benefit from additional P avoids the expense and overuse of P fertilizer as well as minimizes the environmental risks associated with P runoff.

Table 1. Soil test Phosphorus critical levels for establishment of three species of turfgrass based on the Mehlich-1, Bray-1, Mehlich-3 and Mehlich-3, Phosphorus/ Aluminum soil test methods.

Turfgrass Species	Soil test P critical level			
	Mehlich-1	Bray-1	Mehlich-3	Mehlich-3, P/Al
	----------------	mg/kg	----------------	ratio
Kentucky bluegrass	280	360	400	0.84
Tall fescue	100	120	160	0.26
Perennial ryegrass	35	105	105	0.16

Poster Presentations

Genetic Variation of Dollar Spot Resistance in Creeping Bentgrass Genotypes

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The dollar spot disease incited by *Sclerotinia homoeocarpa* F.T. Bennet. is a common and destructive disease of both cool-season and warm-season grasses throughout the world. It is especially troublesome on closely mowed creeping bentgrasses used for golf greens and fairways. More than 70% of fungicides used on golf courses each year are used to control dollar spot, brown patch and anthracnose diseases. Furthermore, the intense and frequent use of fungicides to control dollar spot has contributed to the wide spread selection of resistant strains of *S. homoeocarpa* to the Demethylation Inhibiting and Benzomidazole classification of fungicides. Genetic resistance to dollar spot disease would be a promising alternative to chemical, cultural and bio-control methods. Differences in dollar spot resistance among existing creeping bentgrass cultivars have been documented. The variation in disease resistance is the basis for breeding disease resistant varieties. The objective of this study was to evaluate the response of 500 genotypes of creeping bentgrass to the fungus *S. homoeocarpa*, in two different environments for a period of two years.

In the spring of 1998, 500 genotypes of creeping bentgrass, collected from old golf courses in New Jersey, New York, Illinois and Arizona, were arranged in a randomized complete block design with 6 replications in each of two locations located at the Turfgrass Research Facility, in North Brunswick, NJ. Both sites were maintained under fairway conditions. Site 1 (Upper) was maintained at 17/32 in., while Site 2 (Lower) was maintained at 22/32 in. Five isolates of *S. homoeocarpa* were used to inoculate the field studies. Isolates were grown on sterilized 'Classic' Kentucky bluegrass seed. The inoculum was mixed evenly with equal proportions of each isolate, forced through a sieve and applied with a drop spreader at a rate of 1.75 g m^{-2} on 24 June 1998. Once symptoms began to develop, dollar spot resistance was evaluated weekly using a 1 to 9 scale, with 9 representing no disease and 1 representing completely brown turf. Ten resistant and ten susceptible genotypes were evaluated for lesion development throughout the growing season, as well as anatomical features such as stomate and trichome number.

This study indicated that dollar spot resistance within this population of creeping bentgrass was quite low, in fact, only 12 genotypes out of 500 (2% of the population) maintained adequate resistance to dollar spot over the 2 years and 2 locations of the study. Significant differences in percent green turf cover and lesion diameter size were observed between the ten resistant and susceptible genotypes in both locations. Differences in dollar spot resistance between years and locations indicated that disease severity is affected by environmental conditions. The population distribution of genotype response to dollar spot indicated that dollar spot might be inherited quantitatively.

Field Test Results of Transgenic Creeping Bentgrass Containing Potential Disease Resistance Genes

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Creeping bentgrass (*Agrostis palustris* Huds) is a high value specialty grass used primarily on golf course putting greens and fairways in temperate climates around the world. Creeping bentgrass is one of the most disease susceptible grasses maintained for turf purposes (Vargas, 1994). It is susceptible to a wide range of destructive fungal diseases including dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett). The prevalence of turfgrass pathogens and the extreme density of putting green and fairway turf currently necessitates the extensive use of fungicides for disease control. On golf courses, management of dollar spot requires more money than management of any other turfgrass disease (Vargas, 1994).

Genetic engineering of plants resulting in improved disease resistance has been reported for a number of genes. We are investigating the potential for genetic engineering to improve the disease resistance of creeping bentgrass. We have produced a number of transgenic bentgrass lines expressing potential disease resistance genes. A field test of these plants was established in the fall of 1999. In the summer of 2000 the field was inoculated with the dollar spot fungus and rated for disease. Some of the transgenic lines had a delay of 2 to 6 weeks in development of dollar spot symptoms relative to the control plants. These results are encouraging regarding the potential of biotechnology to improve dollar spot resistance of creeping bentgrass.

Temporal Changes in Soil Physical Properties of Root Zone Mixtures Varying in Sand Size Distribution

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Amended sand is routinely used for the construction of root zones for golf putting greens. Putting green root zone mixtures were constructed in two locations at Horticultural Research Farm II in North Brunswick, NJ, to examine the effect of sand size distribution and micro-environmental conditions on the performance of creeping bentgrass. Five sand size distributions, conforming to and finer than USGA recommendations for particle size distribution, were amended with sphagnum moss peat at a 9:1 (v/v) ratio. Initial physical property data of the sand/peat mixtures were collected in the laboratory prior to construction. Root samples and non-destructive core samples for soil physical property testing were removed from the constructed root zones 16 months after establishment to 'L-93' creeping bentgrass. Turfgrass quality ratings were taken throughout the growing season prior to sample collection.

Micro-environmental location significantly affected rooting in the surface 7.62 cm. Less root mass was observed in the "enclosed" micro-environment than in the "open" microenvironment. Lower root mass in the "enclosed" micro-environment resulted in greater bulk density and lower total porosity for root zone mixtures in the "enclosed" micro-environmental location. Saturated hydraulic conductivity (K_{sat}) and air-filled porosity of field-collected samples decreased from the initial values determined in the laboratory. Capillary porosity values of field collected samples increased from the initial values determined in the laboratory. These data indicate that a shift in pore size distribution, from larger sized pores to finer sized pores, occurs within 16 months after establishment to creeping bentgrass. Root zone mixtures with finer sand particle size distributions had the highest average seasonal quality ratings. The root zone mixtures with the highest quality ratings had sand size distributions that were finer than USGA recommendation for sand particle size distribution.

Changes in soil physical properties will continue to be monitored. It is expected that changes in field soil physical properties will continue. These changes may be important for long-term performance of creeping bentgrass grown as putting green turf.

Cultivar and Traffic Effects on Population Dynamics of *Agrostis* spp. and *Poa annua* Mixtures

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Over the past decade, there has been a concerted effort by turfgrass breeders to develop improved cultivars of creeping (*Agrostis stolonifera*) and velvet (*A. canina*) bentgrasses that are denser, finer, more aggressive, more stress tolerant, and more competitive than older industry standards. The objective of this study was to identify bentgrass cultivars that exhibit an improved genetic competitive ability against annual bluegrass (*Poa annua var. reptans*) invasion and maintain good performance under the influence of traffic.

Field studies were initiated on sandy loam and sand root zones managed as putting green and fairway turf under traffic stress to evaluate the performance of bentgrass and the invasion of annual bluegrass. Studies used a two-factor (traffic stress and bentgrass cultivar) split-plot design. Main plots were the traffic treatments including no traffic, wear, compaction, and the combination of wear and compaction. Subplot treatments were creeping bentgrass and velvet bentgrass cultivars. The sandy loam putting green and fairway were seeded September 1998 and traffic treatments were implemented August 1999. The sand putting green was seeded May 1999 and traffic treatments were initiated October 1999. Both putting greens were mowed to 3.2-mm or lower and the fairway was mowed at 10.3-mm. Annual bluegrass and bentgrass populations were assessed in spring, summer and fall using line-intersecting grid counts.

As expected, traffic reduced quality and increased annual bluegrass invasion. During 2000, wear treatment lowered turf quality more than the compaction treatment on the greens and the fairway. The combination of wear and compaction reduced quality ratings more than wear alone on the sandy loam putting green and fairway. Velvet bentgrass cultivars and denser cultivars of creeping bentgrass (Penn A-4, Penn G-1, Penn G-2) performed better and had less annual bluegrass invasion than other cultivars. 'Penncross' quality ratings were lowest under all traffic treatments and had the highest annual bluegrass population. Annual bluegrass invasion was highest under the traffic treatment of wear and compaction, and wear lowered the bentgrass population more than compaction in sandy loam putting green and fairway. Evaluation of turf performance and assessment of annual bluegrass encroachment will continue through 2001.

Evaluation of Chemical and Biological Fungicides for the Control of Bentgrass Dead Spot in Bentgrass

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Bentgrass dead spot, incited by the fungus *Ophiosphaerella agrostis,* is a new disease of creeping bentgrass greens and tees that was first identified in Maryland, Pennsylvania, Ohio, and Virginia during the summer of 1998. It is favored by hot, dry weather and to date has only been observed on turf less than six years old.

Symptoms of bentgrass dead spot first appear as reddish brown spots 0.5 to 1 inch in diameter. Spots quickly fade to a tan color and are often confused with dollar spot, copper spot, cutworm damage or golf ball marks. When the disease is active, spots may have a bronzed outer margin, rarely coalesce, and are usually distributed randomly over the turf surface. Bentgrass dead spot has been most prevalent on high sand content sites. Little is known about the chemicals that suppress this disease and fungicides are not currently labeled for its control.

To identify fungicide classes that most effectively control bentgrass dead spot, fungicides were evaluated at the Charleston Springs Golf Course in Millstone, New Jersey on a green naturally infested with *O. agrostis*. Fungicides representing ten different chemical classes were applied on a preventive basis at various rates and intervals from 10 July to 11 September, 2000. Chemicals were applied in water equivalent to 2 gal/1000 sq ft with a CO_2 powered sprayer. Data were collected for disease severity from 28 July to 13 September.

In general, fungicides within the benzimidazole (Clearys 3336 50W at 4.0 and 8.0 oz/1000 sq ft), dithiocarbamate (Fore Rainshield 80W at 8.0 oz/1000 sq ft), nitrile (Daconil Ultrex 82.5SDG at 3.2 and 5.0 oz/1000 sq ft), phenylpyrrole (Medallion 50WG at 0.5 oz/1000 sq ft) and the phosphonate (Chipco Aliette Signature 80WG at 4.0 oz/1000 sq ft) chemical classes provided the most effective control of bentgrass dead spot (78-97% control), compared to untreated turf. Of the sterol-inhibiting fungicides, only propiconazole (Banner MAXX 1.3MC at 1.0 and 2.0 fl oz/1000 sq ft) adequately controlled the disease (95% control), whereas myclobutanil (Eagle 40W at 0.6 oz/1000 sq ft) and triadimefon (Bayleton 50W at 2.0 oz/1000 sq ft) proved ineffective at the rates tested.

Similarly, two experimental strobilurin fungicides (BAS 500 and 505) consistently suppressed the disease (96-97% control), while the strobilurins trifloxystrobin (Compass 50WG at 0.15 oz/1000 sq ft) and azoxystrobin (Heritage 50WG at 0.2 oz/1000 sq ft) provided poor to fair control (3 and 72% control, respectively). Carboximide (ProStar 70WG at 2.2 oz/1000 sq ft) and phenylamide (Subdue MAXX 2MC at 1.0 fl oz/1000 sq ft) fungicides and a strain of *Bacillus subtilis* (Companion I at 4.0 and 8.0 oz/1000 sq ft) did not significantly control bentgrass dead spot, compared to untreated turf. Research is currently underway to evaluate turfgrass recovery after the disease is controlled and damaged areas are reseeded.

Management of Dollar Spot using Improved Bentgrass Cultivars and Selected Cultural and Chemical Regimes

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Several improved bentgrass cultivars have been developed recently for use on golf course greens and fairways. Many of these cultivars have been reported to have excellent disease resistance. Although it has been suggested that these cultivars may help reduce fungicide usage, to date, little research has been conducted to support these claims. To address this issue, the current study was designed to evaluate the disease response of several commercially available bentgrass cultivars maintained under different nitrogen fertility, mowing height, and fungicide regimes.

Eight bentgrass cultivars (Crenshaw, Southshore, Penncross, L-93, SR 1020, SR 7200, Penn A-4 and Penn G-2) were evaluated under field conditions in 1999 and 2000. All cultivars were maintained at two cutting heights: 0.14 in. (greens height) and 0.375 in. (fairway height), and two nitrogen levels: 2 lbs N / 1000 sq ft and 5 lbs N / 1000 sq ft. Cultivar treatments were subdivided into six fungicide application schedules (untreated, 7, 14, 28, or 56 day intervals, and an economic threshold of 0.3% disease) using the contact fungicide chlorothalonil (Daconil Ultrex 82.5SDG). Data were collected for turf quality, color, density, and dollar spot (*Sclerotinia homoeocarpa*) severity. Other foliar diseases, including brown patch (*Rhizoctonia solani*) and copper spot (*Gloeocercospora sorghi*), were also evaluated.

For most cultivars, dollar spot was most severe on turf receiving the low rate of nitrogen and the lower height of cut. Cultivars Penn G2, SR 7200 and L-93 were least susceptible to dollar spot under most nitrogen and cutting height treatments. Brown patch was most severe on turf maintained at greens height and high nitrogen, while a high incidence of copper spot was only seen on SR 7200. The total number of fungicide applications in 2000 was reduced 75-88% for cultivars Penn G-2, L-93, and SR 7200, compared to Crenshaw, the most susceptible cultivar to dollar spot. From this research, it is apparent that many of the new bentgrass cultivars can be used to reduce fungicide inputs while maintaining acceptable turf quality.

Impact of Water Volume, Nozzle Type, and Clipping Removal on the Efficacy of Trifloxystrobin and Other Selected Fungicides for the Control of Brown Patch in Cool-Season Turfgrass

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The efficacy of selected fungicides was assessed for the control of brown patch (*Rhizoctonia solani*) during the 1999 and 2000 growing seasons using different application methodologies and cultural practices. In the first study, trifloxystrobin (Compass 50WG) was evaluated at 0.15 oz/1000 sq ft on a bentgrass fairway (3/8 in.) in a factorial design using 0.5, 1.0, 2.0, 4.0, and 8.0 gal H_2O/1000 sq ft and three nozzle types: flat fan, rain drop, and turbo flood jet. Azoxystrobin (Heritage 50WG at 0.20 oz/1000 sq ft) and chlorothalonil (Daconil WeatherStik 6F at 3.0 fl oz/1000 sq ft) were also evaluated at the same water volumes using a flat fan nozzle only. In the second study, trifloxystrobin was applied to tall fescue (2 in.) at a rate of 0.10 and 0.25 oz/1000 sq ft and clippings were either returned or removed. For each year of the study, disease control was independent of nozzle type. The 0.5 gal water volume consistently resulted in the worst disease control. Water volumes above 0.5 gal provided similar levels of brown patch control. When flat fan nozzles were used, azoxystrobin was more effective than chlorothalonil or trifloxystrobin in suppressing brown patch. Returning treated clippings improved disease control up to 49% (one week post-treatment).